PRIVATISATION AND TECHNOLOGICAL CHANGE: THE CASE OF THE BRITISH ELECTRICITY SUPPLY INDUSTRY

Mark Winskel

PhD

The University of Edinburgh

1998

Abstract

Since privatisation in 1991, there has been a transformation in electricity generation technology within the British electricity supply industry (ESI). In a sudden *dash-for-gas*, previously unused combined cycle gas turbine (CCGT) technology has been adopted for all new power stations in Britain. The dominant generation technologies before privatisation – coal-fired steam turbines and nuclear power – have been marginalised, and all proposals for new coal-fired and nuclear plant cancelled. Using a wide range of sources, including the evidence submitted to various parliamentary select committee inquiries, an analysis is made of the causes of recent changes in electricity generation technology in Britain. Particular generation technology projects are analysed in greater depth using personally-conducted interviews.

The research suggests that technological changes in the British ESI since privatisation can only be understood by reference to a range of technical, economic, regulatory, organisational, political and historical factors. The different technical forms of electricity generation reflect particular technical opportunities, economic criteria, institutional interests, and political priorities prevalent at different times in the industry's development. Before privatisation, the forms of generation technologies were largely a reflection of the vested interests of government and the corporate institutions of the ESI. During privatisation, the dominant influences on change were the government's dual policy goals of economic liberalisation, and securing the future of nuclear power. The post-privatisation changes reflect the radically different economic environment for the ESI, and also institutional rivalry in a semi-competitive market structure. CCGT technology, politically and institutionally excluded from the industry before privatisation, has gained ascendancy due to the interaction of a number of coinciding and largely unrelated dynamics. These include improved gas turbine technology, greater availability of natural gas, structural changes in the ESI, and the introduction of pollution abatement legislation.

Consideration is also given to the value, in analysing technological change in the British ESI, of a number of concepts and models from the technology studies and social shaping of technology literature. It is argued that since technological change is a complex and often unpredictable process involving a number of interacting dynamics, no single analytical model provides a fully satisfactory explanation. In the pre-privatised industry, Hughes' model of evolving sociotechnical systems offers the most insight. During and after privatisation, other concepts emphasising institutional interests and micro-social actor networks are of more value. Attention is also given to the notions of technological autonomy and determinism in the context of the British ESI. Although often associated with electricity generation technologies, especially nuclear power, autonomy and determinism are seen to neglect the dependency of technologies on their surrounding economic, institutional and political environments. Nevertheless, there is evidence of a distinctive dynamism of sociotechnical systems – generation technologies have been both cause and effect of the development of the ESI. CCGT technology, as well as reflecting the restructuring of the industry since privatisation, has enabled and promoted change.

Acknowledgements

Thesis writing is inevitably in large part an individual effort, requiring many solitary hours of reading, writing and thinking. Perhaps because of this, the support of others is all the more important, and I have been helped by many people in the course of my work.

Particular thanks must first go to my supervisors at Edinburgh University, Dr. Wendy Faulkner of the Science Studies Unit and Dr. James Hine of the Department of Business Studies. This work could not have been completed without their combined support and encouragement.

I have also been greatly helped by many other members of staff at Edinburgh University, most especially within the Research Centre for Social Sciences, under its founding Director, Professor Frank Bechofer, and present Director, Dr. Robin Williams. I would also like to add particular thanks to Dr. Alfonso Molina of the Department of Business Studies. Beyond Edinburgh, I was given assistance by the members of the Science Policy Research Unit's Energy Group at the University of Sussex, headed by Gordon MacKerron. In addition, I am also grateful to those industry insiders who offered me their insight and assistance. Financially, this research was funded by a SERC/ESRC Joint Panel Studentship.

As well as the assistance of University staff, the support of fellow research students has been invaluable. Amongst the many friends and colleagues here, I would particularly like to mention Jose Monserrat Neto, Ca Ngoc Tran, Minjeong Kang, and Xiaobai Shen, with all of whom I shared the pleasures and pains of research student life. Many other friends also supported me along the way.

Finally, special thanks to my girlfriend Sonia, whose faith in my abilities – and whose determination that I succeed – at times exceeded my own.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1: GENERAL INTRODUCTION

1.1 Themes and Perspectives

1.1.1 Technological Presuppositions

Technological change seems to be a powerful engine of change in modern society. For many people, new technology is something developed and implemented by others, bringing with it, in a deterministic fashion, certain inevitable personal and social consequences. It appears to be an essentially non-human force – the product of science or economics. As a result, technological artifacts are seen as politically 'neutral', or in the *Baconian* tradition, socially progressive.[1]

Technology as an external autonomous phenomenon impacting onto society is an oft-repeated theme in discussions of technological change. It has been particularly common in relation to electricity generation technologies, especially nuclear power. Electricity itself is invisible and intangible, and electricity generation technology is remote, large-scale, and removed from the everyday experience of most people; as Donald MacKenzie and Judy Wajcman pointed out, "we think about electricity only when the bill has to be paid, or the supply fails".[2] Similarly, Stewart Russell stated that "the challenge in studying energy/utility systems is that they are black-boxed by most people; for all but the closely involved, their output are taken for granted".[3]

Traditional accounts of technological development have been dominated by descriptions of the technical properties of artifacts, and accounts of how one technology succeeded another due principally to its superior technical performance. In such *internal* histories of technology, wider economic, political, and cultural concerns – if mentioned at all – are relegated to the margins. At the same time, the social sciences and humanities have generally tended to ignore technology as a proper subject of study, or concern themselves solely with the 'impacts' of technological change on society, and leave unexamined the

---

[1] Donald MacKenzie and Judy Wajcman (eds.), 'Introductory Essay', in *The Social Shaping of Technology*, Milton Keynes, Open University Press, 1985, pp2-25: 4
[2] ibid:2
[3] Stewart Russell, 'Heating Networks', *Social Studies of Science*, Vol.24, pp587-95, 1994:587

internal workings of the technological world, and those concerned with its development. By doing so, they have implicitly reinforced the widely-held perception of the *otherness* of technology

In practice, technology is *by definition* situated within a particular social setting, and technological artifacts are designed to meet particular economic or social needs; as Barry Barnes pointed out, "technology is necessarily connected into its social, political, and economic environment; if technical activity is not so connected, we do not call it technology".[4] In recent years, there has been a greatly increased effort within the social sciences – particularly within *technology studies* – to study technological change as a social process, and to examine technological artifacts as the products of a range of technical, economic, institutional, and political influences.

1.1.2 Generation Technology in the British Electricity Supply Industry

The privatisation of the British Electricity Supply Industry (ESI) between 1988 and 1991 was associated with dramatic and largely unexpected changes in electricity generation technology. The Government imposed substantial restructuring on the ESI ahead of flotation, involving the breaking-up of the monopoly generation and transmission company, the Central Electricity Generating Board (CEGB). At the same time as this reorganisation was being devised and implemented, the dominant technical forms of electricity generation under nationalisation were cast aside in favour of a previously unused technology. In a sudden 'dash-for-gas', all proposals for new coal-fired steam turbine and nuclear power plants were abandoned in favour of combined-cycle gas turbine (CCGT) power plant schemes. Within a short period of time, therefore, long-established and apparently highly stable organisational forms – and their technological affiliations – were broken-down and replaced.

Privatisation represented the most significant change to the British ESI since nationalisation in 1947-48. It was also the most radical reorganisation of any comparable ESI in recent years. The Watt Committee on Energy described the privatisation of the British ESI as "an act of faith, based on political belief in the virtues

---

[4] Barry Barnes, 'Review of Thomas Hughes' *Networks of Power*', *Social Studies of Science*, Vol.14, pp309-1, 1984:313

of competition and market forces".[5] The independent energy analyst Andrew Holmes suggested that in carrying through its proposals, the Government had passed through largely unchartered policymaking for electricity generation and supply:

> Two aspects of the British system have not been sufficiently appreciated: its radicalism and its uniqueness ... Nowhere, in the UK or outside it, has privatisation involved such a thorough change of ownership, structure, and method of operations, as that carried out on the British electricity supply industry. The system that has resulted has no real resemblence to any other electricity system in the world. There is no other system which has gone nearly so far in disaggregation, emphasis on competition, and the attempt to establish a free market ... The concept of open, commercial competition between rival power generators has not played a major part in the electricity planning of any major industrial economy.[6]

At the same time, although unique in certain respects, the structural, regulatory, and technological changes to the British ESI reflected worldwide trends towards liberalisation and privatisation in utility/network industries in the 1980s and 1990s. The British case, because it went much further in the scope of its reforms and the degree consequences, can therefore be considered to lie at the extreme 'radical' end of a spectrum of change. This is reflected in the changes in generation technology in the period during and after privatisation in the British ESI as compared to similar systems elsewhere over the same period. As Tables 1 and 2 show below, whilst there has been (and will continue to be) a growing use of gas-fired generation and CCGT technology in the 1990s and beyond, nowhere else is this trend as strong as in the case of the British dash-for-gas .

[5] House of Commons Energy Select Committee, *Consequences of Electricity Privatisation*, HC 113, 1991-92, Vol.II:36
[6] ibid:70

Table 1: Net Maximum Generation Capacity by Type of Generation Plant (GW)

		1990	1991	1992	1993	1994	1995
UK	ST	53.76	50.83	47.22	44.21	41.08	40.91
	SGT	3.55	3.61	3.18	2.73	2.56	2.56
	CCGT	--	--	1.34	5.61	8.75	9.37
US	ST	463.71	465.72	467.37	467.46	466.22	467.02
	SGT	47.24	48.81	51.16	52.44	56.07	58.31
	CCGT	20.2	23.76	27.46	31.92	38.26	39.94
Germany	ST	63.14	80.82	77.84	76.52	75.48	76.23
	SGT	5.08	5.95	6.05	6.07	6.84	6.86
	CCGT	--	--	--	--	--	--
France	ST	21.11	21.04	20.66	21.6	21.58	21.78
	SGT	1.21	1.18	1.45	1.47	1.47	1.61
	CCGT	--	--	--	--	--	--
Netherlands	ST	13.85	13.58	13.31	13.19	13.64	13.55
	SGT	1.1	1.18	1.19	1.3	1.35	1.32
	CCGT	1.71	1.76	1.82	1.79	1.89	2.26
Japan	ST	116.14	116.75	118.73	119.98	123.86	125.31
	SGT	2.37	2.67	3.68	4.37	4.61	4.77
	CCGT	3.66	4.72	5.04	6.26	5.83	7.57

Key: ST=Steam Turbine; SGT=Simple Gas Turbine; CCGT=Combined Cycle Gas Turbine

Source: International Energy Agency, *Electricity Information 1996*, Paris, OECD/IEA, July 1997; based on Table 18.

Table 1: Net Maximum Generation Capacity by Type of Generation Plant (GW)

		1990	1991	1992	1993	1994	1995
UK	ST	53.76	50.83	47.22	44.21	41.08	40.91
	SGT	3.55	3.61	3.18	2.73	2.56	2.56
	CCGT	--	--	1.34	5.61	8.75	9.37
US	ST	463.71	465.72	467.37	467.46	466.22	467.02
	SGT	47.24	48.81	51.16	52.44	56.07	58.31
	CCGT	20.2	23.76	27.46	31.92	38.26	39.94
Germany	ST	63.14	80.82	77.84	76.52	75.48	76.23
	SGT	5.08	5.95	6.05	6.07	6.84	6.86
	CCGT	--	--	--	--	--	--
France	ST	21.11	21.04	20.66	21.6	21.58	21.78
	SGT	1.21	1.18	1.45	1.47	1.47	1.61
	CCGT	--	--	--	--	--	--
Netherlands	ST	13.85	13.58	13.31	13.19	13.64	13.55
	SGT	1.1	1.18	1.19	1.3	1.35	1.32
	CCGT	1.71	1.76	1.82	1.79	1.89	2.26
Japan	ST	116.14	116.75	118.73	119.98	123.86	125.31
	SGT	2.37	2.67	3.68	4.37	4.61	4.77
	CCGT	3.66	4.72	5.04	6.26	5.83	7.57

Key: ST=Steam Turbine; SGT=Simple Gas Turbine; CCGT=Combined Cycle Gas Turbine

Source: International Energy Agency, *Electricity Information 1996*, Paris, OECD/IEA, July 1997; based on Table 18.

Table 2: Electricity Generation by Fuel Type (TWh)

		1973	1980	1995	2000	2005	2010	73-95*	95-05*
UK	Total	281.3	284.1	332.9	366.3	395.3	412.8	0.8	1.7
	Gas	2.74	2.12	58.31	133.9	138.0	203.6	14.9	9.0
US	Total	1695	2427	3558	3896	4199	4447	2.7	1.7
	Gas	364.9	370.5	528.8	727.4	981.9	1192	1.7	6.4
Germany	Total	374.3	466.3	532.5	550.9	566.0	583.6	1.6	0.6
	Gas	40.95	65.99	43.17	56.3	61.7	68.5	0.2	3.6
France	Total	182.5	256.9	489.3	552.1	584.9	612.0	4.6	1.8
	Gas	10.09	7.01	3.84	17.05	19.55	22.45	-4.3	17.7
Netherlands	Total	52.63	64.81	81.07	71.29	87.54	107.1	2.0	0.8
	Gas	41.85	25.81	42.03	46.39	63.99	77.68	--	4.3
Japan	Total	465.4	572.5	980.9	1030	1111	1198	3.4	1.3
	Gas	10.5	81.11	191.0	231.5	226.5	212.5	14.1	1.7

* Average Annual Percentage Change

Source: International Energy Agency, *Electricity Information 1996*, Paris, OECD/IEA, July 1997; based on Table 4.

The changes in generation technology in the British ESI at this time were clearly related in some way to the restructuring of the industry associated with privatisation. At the same time, they also reflected international changes in the technology and economics of generation. From different perspectives, therefore, this example of technological change could be seen to be, variously, as being *politically-driven*: an outcome of liberalisation and privatisation; *economically-driven*: a result of changes in the relative cost of generation plant and fuel supplies; or *technologically-driven*, in response to technical improvements in the performance of CCGT plant.

The broad aim of the research presented here is to analyse the causes of changes in electricity generation technology in the British ESI associated with privatisation, and to consider the extent to which they can be seen the result of technological, economic, and political factors. At the same time, the ESI case has been used to 'test' a range of concepts and theories found within that part of the social sciences – known as *technology studies* – which attempts to analyse the relations between technology and wider socio-economic processes. In employing this literature, I have been particularly concerned with how technology itself may be conceived as a distinctive influence on socio-economic change, and how technological dynamics relate to, and interact with, economic and political forces.

1.1.3 Thesis Outline

Following this introduction, Chapter 2 presents a selected review of the technology studies literature. Consideration is first given to notions of technological determinism and autonomy as applied to electricity generation technology, especially Langdon Winner's suggested autonomy of nuclear power. This is followed by a critique of autonomy and determinism offered by a 'social shaping of technology' perspective. The rest of the chapter reviews a range of social shaping concepts and models, including Thomas Hughes' model of technologies as evolving sociotechnical systems, social constructivism and actor-network theory, and finally, a range of institutional-level approaches. At the end of the chapter there is a statement of my own analytical perspective and research design.

Chapter 3 analyses the development of electricity generation technology within the British ESI before privatisation, up to the mid-1980s. Within this, particular attention is given to periods of significant changes in generation technology, and also to episodes of restructuring of the industry. A separate section reviews the development of gas turbine/CCGT technology, which took place largely outside of the confines of the British ESI. At the end of the chapter there is a summary of the various influences on changes in generation technology in Britain in the period before privatisation.

The next three chapters address the interaction of the major forms of generation technology in Britain with the ESI privatisation process. In each case, the relevant changes are considered in broadly chronological order. As will be described in the next chapter, the primary research resource drawn on here was official papers and the evidence submitted to various parliamentary select committee inquiries. Additional evidence has been sought from a wide range of published and unpublished material from within the industry and from independent analysts, and also a small number of personally-conducted interviews with industry insiders.

Chapter 4 analyses the interaction of the ESI privatisation process with nuclear power technology, and the fortunes of nuclear power technology in Britain in the post-privatised ESI. Because much of the debate on privatisation centred on nuclear power technology, this chapter also details more general aspects of privatisation, such as the formulation of the Government's proposals, and the passage of the privatisation Bill through parliament. A separate section focuses on the impact of privatisation on the fast reactor research programme – the dominant R&D project in the nationalised ESI.

Chapter 5 analyses the interaction of gas turbine/CCGT generation technology with the ESI privatisation process, and the dash-for-gas in the post-privatised ESI. The chapter includes sections on the international commercialisation of CCGT technology in the late-1980s, on the introduction of CCGT plant proposals in the British ESI during the privatisation process, and on parliamentary and industry analysis of the dash-for-gas. A small number of CCGT schemes are analysed in greater depth using personal interviews with those involved.

Chapter 6 considers the changes affecting coal-fired steam turbine technology – the dominant form of generation technology in the nationalised ESI – associated with the ESI privatisation process. Attention is first given to the anticipated impact of ESI restructuring on coal-fired generation, and then, to the declining fortunes of coal-fired generation in the post-privatisation period, including the *coal crisis*. A separate section analyses the changes affecting steam turbine research and development associated with ESI privatisation, and on the impact on the British plant manufacturing industry.

Chapter 7 returns to the technology studies literature presented in Chapter 2. Consideration is given here to the value of the different concepts and models in understanding the changes in generation technology associated with British ESI privatisation. At the same time, an analysis is undertaken of the extent to which the ESI case supports or undermines the concepts and models reviewed earlier. At the end of the chapter, a comment is made on the particular analytical insights offered by a technology studies perspective, and on the distinctive role of technology in wider socio-economic change.

CHAPTER 2:

APPROACHES TO THE ANALYSIS OF TECHNOLOGICAL CHANGE

2.1 Introduction

This chapter presents a review of concepts and models from social science analyses of technological change – the so-called *technology studies* literature. The review is necessarily selective – within what Robin Williams and David Edge referred to as the "broad church" of *social shaping* approaches, numerous analytical themes have emerged in recent years.[1] Rather than following Williams and Edge in attempting a comprehensive overview of these developments, my aim has been to identify and examine those theories and concepts which appear most useful for the present study – an analysis of recent changes in electricity generation technology in Britain associated with ESI privatisation. I have therefore concentrated particularly on those analysts who have studied energy or electricity technologies. At the same time, some attention is given to more general technology studies issues, such as technological autonomy and determinism, the role of technology as both cause and effect of socio-economic change, and the analytical 'separability' of the various technical, economic, and political influences involved in technological change.

For the social sciences, the study of technology and technological change present intractable conceptual and methodological problems. In their review of social science theories of technological change, Arie Rip and René Kemp described the *abstraction* involved in the disciplinary study of technology:

> Technology, clearly, does not fall into one neat category of the social sciences. It cuts across levels and categories so that no one social scientific discipline, oriented to its own methods and ideals of explanation, can capture the complexity ... social sciences abstracts those aspects of technology that fit their respective disciplinary moulds.[2]

[1] Robin Williams and David Edge, 'The Social Shaping of Technology', *Research Policy*, Vol.25, pp865-899, 1996:866

[2] Arie Rip and René Kemp, 'Towards a Theory of Socio-Technical Change', limited circulation monograph, School of Philosophy and Social Science, University of Twente and MERIT, University of Limburg, May 1996. Published in edited form as Chapter 4 of *Human Choice and Climate Change*, prepared by Batelle Pacific Northwest Labs., Washington DC.

The interdisciplinary concepts and methods of technology studies represent an attempt at a more realistic analysis of technological change. However, Edge argued that almost all approaches within technology studies lack a "satisfactory conceptualisation of the precise way new technologies emerge and evolve over time", and added that "even the most perceptive authors retreat to rather loose metaphors".[3] In practice – as a number of other analysts have pointed out – such is the complexity of technological change, and the variety of influences that are capable of shaping technical forms, any attempt at 'overall theory' is doomed to over-generalisation and simplification. Barry Barnes suggested that where theory becomes too "strict and formal" in this area, it is perhaps wiser not to follow.[4] Similarly, in a review of attempts to describe the links between technology and politics, John Street argued that the interrelations were so complex and changeable, that no satisfactory general theory was possible: "the very idea that we can generate a complete theory of political and technical change seems misconceived. There is too much to be accommodated".[5] Street went on to discuss the limitations of general claims concerning the relationship between technological and political dynamics; for example, he argued that the "political-choice model" – which views different technological designs as outcomes of different political priorities – ignored the way technological change can *reconstruct* politics:

> By concentrating on the external influences on technical change, it allows no room for the internal dynamics of technical innovation and development ... [it] overlooks the micropolitics of innovation, and fails to explain how the larger political interests are realised in the application of scientific knowledge ... [it] imbues the political structure with the capacity to control and anticipate change. In doing so, the model makes little allowance for the unintended consequences of technology ... or for the systemic character of technology which is expressed in the idea of technological momentum.[6]

Street argued that, in reality, "it makes more sense to talk of political interests *coping* with technology rather than controlling it".[7] He concluded that, in the face of this complexity, and the limitations of any attempt at general theory, "there is no single approach to the relationship between politics and technology. In analysing the connection we need to retain a *spirit of eclecticism*".[8] He added, however, that this was "not meant as an unqualified embrace of empiricism nor a renunciation of theory ... It is rather a rejection of a general theory, and a request for a broader range of hypotheses about how

---

3 David Edge, 'The Social Shaping of Technology', Edinburgh University PICT Working Paper No.1, 1988:2

4 Barry Barnes, 'Review of Thomas Hughes' Networks of Power', *Social Studies of Science*, Vol.14, pp309-314, 1984:311

5 John Street, *Politics and Technology*, Basingstoke, MacMillan, 1992:40

6 ibid:39-40

7 ibid:40, emphasis in original.

8 ibid:45, emphasis added.

technology and politics may combine".[9] The futility of attempts to construct a theory of technological change means that analytical concepts and models concerning technological change must address more modest – but nevertheless useful – purposes.[10]

My concern here has therefore been to review a range of more relevant theoretical concepts and models, and, in accordance with Street's "spirit of eclecticism", to identify their relative strengths and weaknesses, so as to develop an appropriate analytical framework for the British ESI case. Section 2.2 considers notions of technological autonomy and determinism. Section 2.3 reviews Thomas Hughes' sociotechnical systems model. Section 2.4 considers social constructivist and actor-network approaches. Section 2.5 reviews a number of approaches focused on the institutional level. Finally, Section 2.6 reflects on the concepts and themes discussed in the chapter in terms of their suitability for the British electricity supply industry case, and also offers a statement of my own research design and methodology.

2.2 Technological Autonomy and Determinism

2.2.1 Introduction: Autonomy and Determinism in Technology Studies

As David Edgerton pointed out, technological autonomy and technological determinism strictly relate to different social spheres: autonomy is a theory of *technology*, specifically an assertion of the auto-generative nature of technological change, whereas determinism is a theory of *society*, and suggests that in industrial societies, technological imperatives dictate the pace and direction of social change.[11] In practice, they often come together, and they are recurrent themes in studies of the role of technology in society. Merrit Roe Smith stated that "the belief in technology as the governing force in society dates back at least to the early stages of the Industrial Revolution".[12] Although he cautioned against simplistic technological determinism, Lewis Mumford, in his 1934 book *Technics and Civilization*, nevertheless postulated a close association between technical and social form.[13] In the post-war period, autonomous and determinist notions of technology were

9 ibid:45

10 Thomas J. Misa identified three purposes of theories of technological development: theories as a comparative frameworks, theories as a normative analyses, and theories aimed at informing technology policy. (Thomas J. Misa, 'Theories of Technological Change: Parameters and Purposes', *Science, Technology, and Human Values* ,Vol.17, No.1, pp3-12, Winter 1992:7-9)

11 David Edgerton, 'Tilting at Paper Tigers', *British Journal for the History of Science*, Vol.26, pp67-75, 1993:17

12 Merrit Roe Smith, 'Technological Determinism in American Culture', in Smith, Merrit Roe, and Marx, Leo, (eds.), *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp2-35:2

13 Lewis Mumford, *Technics and Civilization*, London, Routledge, 1934. Mumford identified three successive phases in the development of technological civilisation. Amongst other characteristics, he stated that "each phase has its own

perhaps most prominently articulated by Jacques Ellul. In his 1954 book *The Technological Society*[14], Ellul claimed:

> There is an automatic growth ... of everything which concerns technique[15] ... this is a self generating process ... technique engenders itself ... [it] is autonomous with respect to economics and politics ... neither economic nor political evolution conditions technical progress ... the converse is actually the case ... technique elicits and conditions social, political, and economic change ... technique's own internal necessities are determinative.[16]

Ellul also suggested that "the structures of the modern state and its organs of government are subordinate to the techniques dependent on the state".[17] Another prominent advocate of technological determinism in the 1960s was Herbert Marcuse. In his 1964 book, *One Dimensional Man,* Marcuse argued that technology had absorbed culture, politics, and the economy, and that "technological rationality" now grew according to its own internal laws.[18] In the same period, other analysts described a moderated form of technological determinism. In his 1967 book, The *New Industrial State,* John Kenneth Galbraith identified a series of "technological imperatives" which, he argued, had become the dominant influence on economic development in advanced industrial societies.[19] Galbraith also argued that modern technological systems required long term planning on the part of the "technostructure" – the various corporate bodies involved in decision-making processes. Galbraith argued that "the autonomy of the technostructure ... is a functional necessity of the industrial system".[20]

In 1967 the economic historian Robert Heilbroner argued that "the influence of the machine on social relations" could be described as a "soft determinism".[21] Whilst Heilbroner made clear that he recognised that technological change was a social activity sensitive to different economic and political conditions, he suggested that within a specific historical and social context – market-based capitalist societies – the growth of

---

means of utilising and generating energy", and he suggested that the last *neotechnic* phase was closely associated with the development of electrical power. (Extract from *Technics and Civilization* in Larry A. Hickman, (ed.), *Technology as a Human Affair,* New York, McGraw Hill, 1990, pp276-294)

14 Jacques Ellul, *The Technological Society,* New York, Vintage, 1964

15 Ellul used the term "technique" to cover "broad aspects of the technological order" – the social relations surrounding technology as well as the artifacts themselves. (Larry A. Hickman, (ed.), *Technology as a Human Affair,* New York, McGraw Hill, 1990:71)

16 Emphasis added. Extract from *The Technological Society* in Hickman, op cit:325, 333

17 Extract from *The Technological Society* in John Street, op cit:24

18 Extract from *One Dimensional Man* in Hickman, op cit:357-367 (*One Dimensional Man* was published in English by Sphere, London, in 1968)

19 John Kenneth Galbraith, *The New Industrial State* (2nd Edition), London, André Deutsch, 1972:13

20 ibid:400

21 Robert L. Heilbroner, 'Do Machines Make History?' in Merrit Roe Smith and Leo Marx (eds.), *Does Technology Drive History? The Dilemma of Technological Determinism,* Cambridge MA, MIT Press, 1994, pp53-65:61. (Originally published in *Technology and Culture,* Vol.8, pp335-345, July 1967)

technology, driven by the impetus of scientific research, had assumed an "'automatic' aspect".[22] He stated that "the technology of a society imposes a determinate pattern of social relations on that technology ... the prevailing level of technology imposes itself powerfully on the structural organization of the productive side of society".[23] In a recent review of his 1967 paper, Heilbroner restated his belief in a "soft" technological determinism.[24]

Notions of technological autonomy and determinism have had a particularly powerful presence in the analysis of energy supply technology. David Collingridge, for example, whilst stressing – like Mumford – that the adoption of technologies was a matter of social choice, analysed electricity generation technology from an implicitly autonomous and determinist position.[25] Collingridge discussed the "dilemma of control", and "unwanted social consequences" of large-scale technologies such as nuclear power. He stated that "the social consequences of a technology cannot be predicted early in the life of the technology. By the time undesirable consequences are discovered, however, the technology is often so much part of the whole social and economic fabric that its control is extremely difficult".[26] Collingridge concluded that special decision-making processes were required for inflexible, long lead-time, large scale technologies such as nuclear power.[27]

2.2.2 Langdon Winner's Autonomous Technology

Technological autonomy has been considered at greatest length in recent years by Langdon Winner. In his 1977 book, *Autonomous Technology*, Winner surveyed the history of thought concerning autonomy, or "conceptions and observations to the effect that technology is somehow out of control by human agency".[28] Winner himself argued that "far from being controlled by the desired and rational ends of human beings, technology in a real sense now governs its own course, speed, and destination".[29] However, whilst being sympathetic to autonomist notions, he dismissed technological

[22] Heilbroner, op cit:64
[23] ibid:59, 61
[24] Robert L. Heilbroner, 'Technological Determinism Revisited', in Merrit Roe Smith and Leo Marx (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp67-78: 77-78
[25] David Collingridge, *The Social Control of Technology*, London, Pinter, 1980; also *The Management of Scale: Big Organisations, Big Decisions, Big Mistakes*, London, Routledge, 1992
[26] Collingridge, *The Social Control of Technology*, op cit.
[27] ibid:103 For energy policy, he argued, this uncertainty implied an important role for R&D as an 'insurance cover' for maintaining diversity.
[28] Langdon Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, Cambridge MA, MIT Press, 1977:15; also *The Whale and the Reactor: A Search for Limits in an Age of High Technology*, Chicago, University of Chicago Press, 1986
[29] Winner, *Autonomous Technology*, op cit:16

determinism; indeed, he stated, "it is somnabulism (rather than determinism) that characterizes technological politics".[30]

In the course of his discussion of autonomy, Winner also traced the notion of *technocracy*, or "rule by scientific and elites".[31] He drew attention to a long history of social and political analysts, such as Bacon, Saint-Simon, and Veblen, who had favoured technocracy, and had in different ways suggested that "rule by technically trained experts is the only kind of government appropriate to a social system based on advanced science and technology".[32] At the same time, Winner also discussed analysts such as Galbraith, who – whilst identifying a tendency to technocratic rule – opposed such a development, and suggested means of reversing the trend.

In later parts of *Autonomous Technology*, Winner developed his own "theory of technological politics", the central theme of which was an assertion of the autonomy of technology:

> Once underway, the technological reconstruction of the world tends to continue. The elaboration of rational artifice on a large scale requires that virtually everything in reach be transformed to suit the special needs of the technological ensemble ... *More highly developed, rational-artificial structures tend to overwhelm and replace less well-adapted forms of life* ... technical systems, once built and operating, do not respond positively to human guidance ... [they] become severed from the ends originally set for them and, in effect, reprogram themselves and their environments to suit the special conditions of their own operation ... modern technology tends to remove its workings from effective direction by human agency. The results ... closely approximate a self-generating self-sustaining technical evolution.[33]

Winner also conceptualised the process of technological change in terms of the development of "systems" or "large sociotechnical aggregates".[34] He argued that conventional political and economic forces had little influence on the development of such systems; rather, politics and economics were themselves shaped by the system: "political reality becomes a set of institutions and practices shaped by the domination of technical requirements ... *the system controls or strongly influences the political*

---

[30] ibid:324. In a more recent paper, Winner argued that "in [autonomy's] more subtle versions, determinism is not the central issue at all, but rather the unintended consequences of technological change" (Langdon Winner, 'Social Constructivism: Opening the Black Box and Finding it Empty', *Science as Culture*, Vol.3, Pt.3, No.16, 1993, pp427-452:443)

[31] Winner, *Autonomous Technology*, op cit:135. The concept of technocracy in social thought was also considered by Frank Fischer in *Technocracy and the Politics of Expertise*, Newbury Park CA, Sage 1990

[32] Winner, *Autonomous Technology*, op cit:146

[33] ibid:208, 212, 214, 227, 236. Emphasis in original. Winner referred to the "adjustment of human ends to ... available means" as "reverse adaption". (ibid:229)

[34] ibid:242

processes that ostensibly regulate its output and operating conditions".[35] Winner contrasted the traditional 'pluralist' model – in which technical systems are seen as responsive, flexible, and at the command of political institutions – with his own very different perspective:

> In the technological perspective megatechnical systems are seen to have definite operational imperatives of their own, which must be met. Society stands at the disposal of the systems for the satisfaction of their requirements. The systems themselves are anything but responsive and flexible. Their conditions of size, complexity and mutual interdependence give them a rigidity and inertia difficult to overcome. Rather than respond to commands generated by political or social processes, such systems produce demands which society must fulfil or face unfortunate consequences ... Frequently, therefore, requirements of successful technological performance mean that control must be exercised over agencies that were formerly themselves in control.[36]

Economic influences, Winner argued, were similarly subservient. He stated that whilst the autonomy of technology does "not deny the presence of ... economic forces ... [it] suggests economic factors may not be the overwhelmingly decisive ones".[37] Following Galbraith, he stated that "the system controls markets relevant to its operations", and added that rather than conventional economic or political forces, it was technocratic planning that dominated the development of technologies.[38] The pace and direction of system development, Winner suggested, was determined largely by the system's own internal dynamics: "*the system seeks a 'mission' to match its technological capabilities ... [it] propagates or manipulates the needs it also serves*", and that it "*discovers or creates a crisis to justify its own further expansion*".[39] He went on to consider, as an example of these characteristics of system development, the 1970s *energy crisis* – an urgent topic at the time *Autonomous Technology* was written. He described the simultaneous "propagation of need" and "discovery of crisis" by electric power companies in the energy crisis as "double reverse adaptations".[40]

Winner then examined another key process of system development, that of centralisation. He argued that, as a consequence of "technical rationality, efficiency, and ... economies of scale", organisations become increasingly concentrated over time in areas of advanced technological performance, and added that "formerly independent systems tend to

---

[35] ibid:237, 243. Emphasis in original.
[36] ibid:251-2
[37] ibid:236
[38] ibid:242, 240
[39] ibid:244, 246, 248. Emphasis in original.
[40] ibid:250

coalesce to form large, more comprehensive networks".[41] As both Mumford and Ellul had also observed, he stated that this trend was exemplified by electricity generation and transmission.[42] He concluded that, whilst there may be some marginal exceptions, the general tendency in society was towards greater technocracy, in response to "*the technological imperative and reverse adaption as they appear to a whole society with the force of overwhelming necessity*".[43]

Elsewhere, Winner has elaborated his "theory of technological politics", which, he stated, was concerned to draw attention to the "momentum of large-scale technological systems", and to the "response of modern societies to technological imperatives".[44] He now distinguished between two levels of the politicisation of artifacts: firstly, technical arrangements as "forms of social order", such as in the choice of design of bridges, buildings, and transport systems, and secondly, "inherently political technologies", such as nuclear power, which were more deeply politicised, to the extent that their very existence was predicated on "particular kinds of political relationships".[45] He argued that the decision to develop inherently political technologies was critical, in that thereafter, the presence of the technology itself was enough to sustain supportive political structures, as it moved beyond political control and became autonomous:

> The things we call 'technologies' are ways of building order in our world ... because choices tend to become strongly fixed in material equipment, economic investment, and social habit, the original flexibility vanishes for all intents and purposes once the initial commitments are made. In that sense technological innovations are similar to legislative acts or political foundings that establish a framework for public order that will endure over many generations ... Once artifacts like nuclear power plants have been built and put into operation, the kinds of reasoning that justify the adaption of social life to technical requirements pop up as spontaneously as flowers in the spring ... the initial choice about whether or not to adopt something is decisive in regard to its consequences.[46]

Especially for inherently political technologies, Winner concluded, choices about technology were concurrently organisational and political choices:

---

41 ibid:252-3

42 ibid:253 Here, Winner quoted Ellul as stating that whilst "electrical networks may remain for some time independent of one another ... this situation cannot last long when ... independence gives rise to [extra] costs ... [and] practical difficulties in electrical technique. The interconnection of electrical networks is demanded by all technical men". (Extract from *The Technological Society*).

43 ibid:258. Emphasis in original.

44 Langdon Winner 'Do Artifacts Have Politics?', in Donald MacKenzie and Judy Wajcman (eds.), *The Social Shaping of Technology*, op cit, pp26-38:27 (Originally published in *Daedalus*, Vol.109, pp121-136, 1980)

45 ibid:27

46 ibid:30, 36

> If such systems are to work effectively ... certain requirements of internal social organisation have to be fulfilled; the material possibilities that modern technologies make available could not be exploited otherwise ... if you accept nuclear power plants, you also accept a techno-scientific-industrial-military elite. Without these people in charge, you could not have nuclear power.[47]

A number of other analysts have drawn attention to the organisational demands associated with nuclear power. Jane Roberts *et al.*, for example, suggested that "the technological characteristics of nuclear power determine the institutional structures necessary to sustain a programme of reactors. If the structure is not sufficiently centralised, powerful, and well organised, the programme will falter".[48]

2.2.3 Social Shaping Critique of Technological Autonomy and Determinism

Technological autonomy and determinism both suggest a pattern of technological development largely insensitive to social context. Autonomy implies that technological progress is essentially independent of surrounding economic and political structures, whilst determinism implies that a particular technology brings with it a number of social consequences irrespective of social circumstances. As Smith observed, the adherents of such notions invest great authority in technology itself:

> The writings of Mumford, Ellul and Winner have an ironic twist: in speaking out against the pervasive power of technological systems ... these critics have endowed modern technics with a degree of agency and influence that often goes beyond even what its most enthusiastic advocates claim. Thus, to the extent that they place technology at the forefront of social and cultural change ... [they] are technological determinists.[49]

Furthermore, because they are pitched at a high level of generality, technological autonomy and determinism tend to gloss over the detailed processes by which politics and technology interact. As Street pointed out, whilst autonomy seeks to identify general patterns in technological development, it does not discriminate between the different ways political systems organise their technological systems.[50] Because their concern is with the internal imperatives of the technological system, the proponents of autonomy

---

[47] ibid:31, 34

[48] Jane Roberts, *et al.*, *Privatising Electricity: The Politics of Power*, London, Bellhaven Press, 1991:44

[49] Merrit Roe Smith, 'Technological Determinism in American Culture', in Merrit Roe Smith and Leo Marx (eds.), *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp2-35:34. Smith went on to distinguish between Ellul's "avowedly determinist position", and the "more nuanced and carefully delineated stances of Mumford and Winner"(ibid).

[50] John Street, *Politics and Technology*, Basingstoke, MacMillan, 1992:40

and determinism tend to downplay any investigation of the way in which supporting economic and political structures actually shape the development of technology and technical form. Rip and Kemp pointed to the social dynamics laying behind what may initially appear to be technological autonomy and determinism:

> [Technological] dynamics can have a life of their own, not because technological dynamics are autonomous, but because the efforts of actors are geared towards the goal of achieving the next 'generation' ... [Similarly] it makes little sense to speak of the impact of technology on society ... the invention and adoption of [technology] ... itself shaped by social and economic factors, is part of overall transformations ... one cannot single out ... [a] particular bit of technology as the cause.[51]

In response to the limitations of autonomous and determinist notions, a body of research has developed in recent years concerned with the *social shaping* of technology.[52] As Edge stated, social shaping approaches hold that technological change is not simply governed by its own "internal logic", but is rather "the product of particular economic, cultural, political, and organisational influences".[53] Paul N. Edwards stated that from a social shaping perspective, technological change should be seen as a complex social process involving technological products and impacts:

> Technological change ... is a *social process*: technologies can and do have 'social impacts', but they are simultaneously social *products* that embody power relationships and social goals and structures. Social impacts and the social production of artifacts in practice occur in a tightly knit cycle.[54]

Edwards also described how technological artifacts, shaped by particular social influences, *embody* prevailing economic and political values in their make-up and operation, and thereby promote, stabilise, and give lasting expression to such values. He stated that technological artifacts are "not only inserted into an organisation or a culture, but frequently embody particular images of how the organisation or culture functions and what the roles of its members should be. Once introduced ... by embodying those images, [they] can help institutionalize and rigidify them".[55] Edwards added that whilst technologies "rarely 'cause' social change in the direct sense implied by the 'impact'

---

[51] Arie Rip and René Kemp, 'Towards a Theory of Socio-Technical Change', limited circulation monograph, School of Philosophy and Social Science, University of Twente and MERIT, University of Limburg, May 1996:25

[52] Donald MacKenzie and Judy Wajcman (eds.), *The Social Shaping of Technology*, Milton Keynes, Open University Press, 1985. Whilst the rest of this chapter concentrates on certain recent contributions to the social shaping of technology, as is widely acknowledged, these contributions draw on earlier work in this area. Notable here is David F. Noble, *America by Design: Science, Technology, and the Rise of Corporate Capitalism*, New York, Alfred A. Knopf, 1977

[53] David Edge, 'The Social Shaping of Technology', Edinburgh University, Research Centre for Social Sciences, PICT Working Paper No.1, 1988:1

[54] Paul N. Edwards, 'From "Impact" to Social Process: Computers in Society and Culture', in *Handbook of Science and Technology Studies*, edited by Sheila Jasanoff et al (eds), 1995:258. Emphasis in original.

[55] ibid:284

model, they often create pressures and possibilities to which social systems respond ... [they] affect society through an interactive process of social construction".[56] He concluded that "neither a 'social impacts' nor a 'social products' approach will produce an adequate picture of this interaction; only an image of technological change as a social process is likely to be robust enough to capture the flavor of how ... [technologies] work in society".[57]

In his 1983 book, *The Culture of Technology*, Arnold Pacey argued that uncovering the "cultural aspects of technology" required close examination of autonomous or determinist notions enrolled to support or oppose particular technological developments.[58] Pacey suggested that the use of terms such as 'technological imperative' may serve a political purpose, since it "reinforces the determinist impression of technical advance ... [it] is partly an expression of values".[59] He equated the use of such terms with a technocentric belief in technical progress, and in the interests of technologists to promote their work.[60] Pacey also criticised any view of technological progress as smoothly or linearly progressive, and argued that this was often based on a superficial understanding of events. As an example, he considered the evolution of steam engines and turbines. He argued that whilst the thermal efficiency of engines had greatly improved over time, this progress had not been linear or consistent; rather, improvements were "clustered together, leading to a step-wise pattern of advance rather than smoothly-continuous progress".[61] He emphasised that each step was characterised by "specific organizational arrangements as well as by new techniques", which he described as "movements in *technology-practice*".[62] He added that "there are crucial moments of recognition when a varied collection of different factors fit together and a new form of practice takes off".[63]

However, whilst rejecting autonomist or determinist notions, Pacey also criticised any view of technological change as being merely a reflection of prevailing political, economic, and organisational interests. He argued that both these positions was over-simplistic, as was indicated by the often unintended consequences of new technologies:

---

56 ibid:284 I have adapted Edwards' argument here from computers to technology in general.
57 ibid:284
58 Arnold Pacey, *The Culture of Technology*, Oxford, Basil Blackwell, 1983:6
59 ibid:79
60 ibid:157
61 ibid:29
62 ibid:29. Emphasis added.
63 ibid:29. Pacey identified one of these key episodes in the British electricity supply industry, as occurring during the *electric revolution* of the 1920s and '30s. At this time, he stated, broad views about electrification as a form of social progress combined with technical improvements in power station efficiency, and provided for rapid expansion of the ESI system.

> Technological determinism is untenable – but so is its complete opposite. Most inventions have been made with a specific social purpose in mind, but many also have an influence nobody expected or intended. The reality is perhaps easier to comprehend by thinking of technology-practice with its integral social components. Innovation may then be seen as the outcome of a cycle of mutual adjustments between social, cultural and technical factors. The cycle may begin with a technical idea, or a radical change in organisation, but either way, there will be interaction with the other factors as the innovation comes to fruition.[64]

Pacey also argued that bureaucracies tended to develop a characteristically *incremental* pattern of technological change, whereas radical innovations tended to emerge from small firms or individuals outside of bureaucracies.[65] In the British electricity supply industry, he identified the Central Electricity Generating Board (CEGB) with bureaucratic innovation; the CEGB, he stated, had been "very resistant to innovations marginal to its main interests ... In such branches of technology ... there has been a fairly systematic suppression of innovation".[66]

In recent years there has been a proliferation of research into technological change adopting – explicitly or implicitly – a social shaping perspective. Distinctive approaches have emerged, each emphasising different aspects of the complex process of technological change. Whilst a full discussion of these is beyond the scope of this review, some of the more important and relevant contributions to this area are now considered.

2.3 Thomas Hughes' Sociotechnical Systems Approach

2.3.1 Introduction: Technologies as Cultural Artifacts

In his 1983 book *Networks of Power*, Thomas Hughes undertook a wide-ranging analysis of the early development of electric power systems in the USA, Britain, and Germany.[67] Hughes adopted a view of technologies as *cultural artifacts* which reflected the societies which constructed them, and he suggested that by studying the differences between technologies built in different places and at different times, changing social conditions and values could be uncovered: "variations in the basic [technological] essentials often reveal variations in resources, traditions, political arrangements, and economic practices

---

64 ibid:25
65 ibid:138
66 ibid:139, 141
67 Thomas P. Hughes, *Networks of Power: Electrification in Western Society 1880-1930*, Baltimore, John Hopkins University Press, 1983

from one society to another and from one time to another".[68] Rather like Winner (2.2.2), Hughes recognised that technologies were politicised in their design and operation, and that they represent and embody certain political values:

> Technologies give rise to binding nuclei for a host of dependent political and economic interests. Interwoven with political and economic interests of particular kinds, technology is far from neutral. Like other political and economic forces, they can be labelled as conservative or liberal – or even radical ... a conservative technology will maintain the existing structures and trends, and ... liberal ones will bring changes in the direction of societal development.[69]

Hughes also stated that because they embody the economic and political forces that prevailed at the time of their inception, technologies may become a legacy to outdated values: "because technology is often manifested in material form ... its lasting effects are easily observed ... surviving technology brings to the present the character of the past, a past that imposed its characteristics on the technology when it was first invented, developed, and introduced into use".[70] Elsewhere, he stated that "durable physical artifacts project into the future the socially constructed characteristics acquired in the past when they were designed".[71]

2.3.2 System and Context

In the course of *Networks of Power*, Hughes developed a model of technological change in terms of the evolution of the *technological system*. Drawing on more general use of 'systems theory' in the social sciences, Hughes defined his technological system as a network of interconnected technical and social components operating under central control; the elements outside the control of the system he referred to as the 'environment'.[72] He went on to suggest that system development – and technological change – was an outcome of the interaction between *internal* and *contextual* dynamics:

---

68 ibid:2

69 ibid:319

70 ibid:285. This was similarly referred to, also in the context of the electricity supply systems, by Leslie Hannah. Hannah stated that "in the past the technical mistakes of one generation had been embodied in capital investment and thus bequeathed to the succeeding generation" (Leslie Hannah, *Electricity Before Nationalisation*, London, MacMillan/The Electricity Council, 1979:95).

71 Thomas P. Hughes, 'The Evolution of Large Technological Systems', in W. E. Bijker, T. P. Hughes, and T. Pinch, (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987, pp51-82:77

72 Hughes, *Networks of Power*, op cit:5-6 Although he stated that he was reluctant to offer anything more than a "loosely structured model" of system development, Hughes went on to suggest that the developing system passed through five stages, beginning with invention, followed by technology transfer, system growth, momentum, and ending with the "pre-eminence of financiers" (ibid:14-16).

> Power systems reflect and influence the context, but they also develop an internal dynamic ... the history of evolving power systems requires attention not only to the forces at work within a given context, but to the internal dynamics of a developing technological system as well.[73]

For Hughes, the twofold internal and contextual dynamism of the technological system provided explanation of the ambiguous relation between technology and wider society, in that technologies both *instigated* as well as *reflected* social change – as Hughes stated, that "electric power systems, like so much other technology, are both *causes and effects* of social change".[74] He went on to describe how internal and contextual dynamics together provided explanation of *similarities* and *differences* between electric power systems developed in different settings. The internal dynamic of electric power systems, he argued, operated on an international stage (the electricity supply industry developed at a time of international exchange of ideas, trade, and finance), and so provided an "international pool of technology", lending many similarities in the power systems developed in different places.[75] Contextual dynamics, by contrast, tended to reflect local economic and political interests, and as such, provided regional and national variations in the adoption of the international pool of technology. He concluded that "out of local conditions comes a technology ... with a distinctive style".[76]

In various parts of *Networks of Power*, Hughes gave further consideration to the distinctiveness of internal and contextual dynamics. He argued that the internal dynamism of technological systems arose not from any supposed autonomy of technology, but rather from the activities of those individuals and organisations most closely involved its development. As a result of their efforts, he added, expanding technological systems built up a powerful *momentum*:

> Technological systems ... [are] not simplistically autonomous, or free from the influence of nontechnical factors ... [they do] however, have an internal drive and an increasing momentum ... [The] ongoing solution of critical problems by inventors, engineers, and entrepreneurs ... [provide] this.[77]

Hughes also suggested that the internal dynamism of a particular system was associated with a *technical core*, which may, he added, carry with it unanticipated effects; whilst a technical core may be constructed and deployed for a particular purpose, once introduced,

[73] ibid:2
[74] ibid:2. Emphasis added.
[75] ibid:405
[76] ibid:404-5
[77] ibid:462

it may find novel uses, or bring with it unforeseen consequences. He described this in what he identified as the technical core of electric power systems – the steam turbine:

> The technical core of the regional power system involved the widespread use of steam turbines in power plants, which after 1900 resulted in the unprecedented and unexpected spread of power systems. Station engineers and managers originally introduced steam turbines to replace the monstrously large reciprocating engines used in heavily populated areas, where the price of real estate was high. Turbines, however, proved to be more efficient than reciprocating steam engines, and they also lowered installation, operating, and labour costs. The largely unforeseen consequence of the introduction of the turbine was the sharp acceleration of the quest for load sufficient to fulfill the economy-of-scale potential of a large, efficiently loaded turbine. The turbines were, in effect, supply in search of demand.[78]

However, although he suggested that it could cause the system to develop in unanticipated ways, Hughes dismissed any deterministic action on the part of the technical core. He stated that whilst "a superficial analysis might present the load-seeking turbine as an instance of technological determinism ... a closer study will show that the force of technology was circumscribed by a host of nontechnological factors which, together with the technology, shaped the events and trends that followed the introduction of the turbine".[79]

Elsewhere in *Networks of Power*, Hughes discussed the various contextual influences, or "external cultural factors" which, together with internal drives, shaped the development of technological systems. He listed these as "entrepreneurial drive and decisions, economic principles, legislative constraints or supports, institutional structures, historical contingencies, and geographic factors".[80] As with internal dynamics, Hughes emphasised that none of these were determinative of technological change: "the factors do not operate deterministically ... [they] only partially shape technology through the mediating influence of individuals and groups"; indeed, he stated, they were overlapping and mutually shaping: "the factors complexly and systematically interact with technology and with one another ... they and the relationships among them change as a power system grows".[81]

Hughes went on to consider the distinctive action of some of the contextual factors in the case of the rapidly developing electricity supply industries of the 1920s. He argued, for example, that *institutional or organisational structures*, including ownership, were in-

---

78 ibid:363-4
79 ibid:364
80 ibid:462
81 ibid:405

part responses to the technical core of the system: "managers and financiers organised and reorganised utilities to facilitate the steady expansion implicit in regional power technology".[82] Elsewhere, he added that "the management structure reflects the particular economic mix of power plants in the system, and the layout of the power plant mix is analogous to the management structure".[83] The *regulatory and legislative framework* of power systems, he stated, reflected political and organisational interests and rivalries:

> Legislation manifests the ideological, economic, and social character of a culture ... a hostile legislature, influenced for instance by competing interests, either private or governmental, sometimes withheld the powers needed by utilities ... Regulations were sometimes restrictive and frustrated investment and growth; often they appeared to be framed in a utility's own best interests – and indeed they sometimes were by pliable legislators.[84]

Amongst the various contextual factors shaping technological development, Hughes particularly emphasised the importance of certain *economic principles.* Unlike other contextual influences, he stated, these exerted a similarly powerful influence across all capitalist societies. Especially important here, he added, were capital interest rates.[85] He concluded that although no single influences on the electric power system could be said to have been determining, two forces were so powerful that they exerted what he referred to as a "soft determinism". These were firstly, economic principles, and secondly, the gathering internal dynamism or momentum of the system itself.[86]

2.3.3 System Building and System Displacement

In tracing the development of electric power systems, Hughes focused on the actions of certain key individuals, whom he referred to as *system builders.*[87] He was particularly concerned with the system builders' efforts to secure control of the system, and drive forward its development through the identification of any barriers to advance, and the targeting of effort and resources to overcome these critical problems, or "reverse-salients".[88] From this perspective, he interpreted the changing organisational structure of

---

82 ibid:406

83 Hughes, 'The Evolution of Large Technological Systems', op cit:52

84 Hughes, *Networks of Power,* op cit:407. Other analysts have also drawn attention to the importance of legislation in the development of electric power systems. For example, according to J. S. Forrest, legislation "played a controlling role in the development of electricity supply in [Britain]... The electricity system has been fashioned by the interplay of electricity demand, costs, technology, and legislation". (J. S. Forrest, *One Hundred Years of Public Electricity,* Egham, PE Consulting Group, 1975:10)

85 Hughes, *Networks of Power,* op cit:462-3

86 ibid:465

87 ibid:x

88 ibid:14

the industry, such as its horizontal and vertical integration, as reflecting the system builders' success in increasing their control over the industry.[89] At the end of *Networks of Power*, Hughes suggested that electric power systems – which were made up of a heterogeneous mix of technical, financial, and institutional elements – should be described as a *sociotechnical systems*.[90] He made clear that he understood the system to include everything under control of the system builders, and argued that as technologies developed under their guidance, they became surrounded by supportive institutional, legislative and financial arrangements that provided an in-built conservativeness, and made for incremental rather than radical changes in technology:

> Sociotechnical systems had high momentum, force, and direction because of their institutionally structured nature, heavy capital investments, supportive legislation, and the commitment of know-how and experience. This momentum was a conservative force, reacting against abrupt changes in the line of development ... rarely were radical inventions, technical or social, introduced.[91]

Hughes suggested in high momentum systems, system-builders' control of their environment led them to assume continued stability of contextual influences, and project into the future the continuity of their own control. He discussed this with reference to the growing electric power systems of the early-twentieth century:

> Engineers and managers engaged in prediction prefer the extrapolation of trends to the formulation of complex scenarios based on likely interactions of trends and contingencies suggested by historical precedents and analogies. Before World War I they undoubtedly anticipated that the trends of the past decade or so would extend into the future. Because of the momentum of the electric supply industry, this was a reasonable assumption. Moreover, the factors affecting the growth – the context in which it occurred – were, by implication, projected into the future. The combination of growing momentum and reinforcing context was expected to overwhelm contingent perturbations.[92]

In a later paper, Hughes gave further consideration to the expansion of the sociotechnical system under the system builders:

> A technological system usually has an environment consisting of intractable factors not under the control of the system managers ... Over time, technological systems manage increasingly to incorporate environment into the system, thereby eliminating sources of uncertainty, such as a once free market ... In a closed system ... managers ... [can]

---

89 ibid:407

90 ibid:465

91 ibid:465 Elsewhere, Hughes stated that "because radical innovations do not contribute to the growth of existing technological systems ... organizations rarely nurture a radical invention ... [they] do not become components in existing systems" ('The Evolution of Large Technological Systems', op cit:57-8).

92 Hughes, *Networks of Power*, op cit:285

resort to bureaucracy, routinization and deskilling to eliminate uncertainty ... Prediction by extrapolation ... then becomes less fanciful.[93]

At certain times in the history of electric power systems, however, Hughes recognised that wider events, such as war, were able to usurp the system momentum, and result in more radical changes in technological development:

> The perturbations and lasting changes brought by catastrophes such as war result from changes that are strong enough to disrupt the momentum of systems. ... The fact that the exigencies of war caused the accelerated development of certain technological characteristics ... shows again that the rate and direction of technological change can be shaped by nontechnological factors. In other words, technology is not necessarily a simple extrapolation of its past, or a working out of inherent technological implications.[94]

At the end of *Networks of Power*, Hughes concluded that despite their internal dynamism and momentum, sociotechnical systems never became autonomous, but were always sensitive to changing social conditions. At any given time, therefore, major changes in social circumstances were capable of bringing about radical changes in the system: "it is difficult to change the direction of large electric power systems ... such systems are not autonomous ... they are evolving cultural artifacts rather than isolated technologies".[95] Elsewhere, he reiterated that systems were never autonomous:

> Technological systems, even after prolonged growth and consolidation, do not become autonomous; they acquire momentum ... A high level of momentum often causes observers to assume that a technological system has become autonomous ... [but] appearances of autonomy have proved deceptive.[96]

In the same paper, Hughes conceded that the model of system development introduced in *Networks of Power* was designed to apply to expanding systems, such as the electric power systems of the late-nineteenth and early-twentieth centuries, and was less well-suited for studying patterns in declining systems.[97] In considering the postwar breakdown of continuity of electric power systems, Hughes showed some recognition of the limits of the systems approach under circumstances in which system growth falters or breaks down:

---

93 Thomas P. Hughes, 'The Evolution of Large Technological Systems', in W. E. Bijker, T. P. Hughes, and T. Pinch, (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987, pp51-82:52-3

94 Hughes, *Networks of Power*, op cit:285-6

95 ibid:465

96 Hughes, 'The Evolution of Large Technological Systems', op cit:76, 79

97 ibid:56

> Since World War II changes such as the supply of oil, the rise of environmental protection groups, and the decreasing effectiveness of efficiency-raising technical devices for generating equipment have all challenged the electrical utility managers' assumptions of momentum and trajectory. These instances, in which the momentum of systems was broken, remind historians and sociologists to use concepts and patterns of evolving systems as heuristic aids and system managers to employ them cautiously as predictive models. Momentum, however, remains a more useful concept than autonomy .... The metaphor encompasses both structural factors and contingent events.[98]

In a more recent book, Hughes considered further the possibility of system decline. He described the powerful vested interests that developed around mature systems, and which presented significant barriers to the overthrow of such systems:

> Large technological systems represent powerful vested interests ... numerous persons develop specialized skills and acquire specialized knowledge appropriate for the system of which they are a part. A major change in the characteristics of the system or its demise would de-skill these people. The machines, devices and processes in the system are the capital, but a special kind of hardware capital with characteristics that might be called 'system specific'. Changes in the system also make hardware capital obsolete. Faced with these eventualities, the people and the investors in technological systems construct a bulwark of organizational structures, ideological commitments, and political power to protect themselves and the system ... This is a major reason that mature systems suffocate nascent ones.[99]

Hughes then went on to speculate on the possible causes of the displacement of mature systems. He suggested that the vulnerability of such systems was associated with their embodiment of environmental conditions prevalent at the time at which they became established:

> In order to bring about a substantial change in the motion and direction of massive systems of production, such as electric light-and-power systems, a counterforce of comparable magnitude becomes imperative. Changes in circumstances comparable to those that cause the demise of organisms need to occur. To counter large technological systems, forces analogous to those that killed off dinosaurs are needed. Like the dinosaurs, some technological systems have embedded in them characteristics that were taken on in times past, characteristics suited for past environments but not for the present. Because these characteristics are often embedded in the hardware of a technological system, they are especially long-lived. These anachronistic characteristics persist despite incremental changes in the environment that favor different characteristics. Only an overpowering change in environmental circumstances can kill off the new dinosaurs.[100]

---

98 ibid:80

99 Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970*, New York, Viking Penguin, 1989:460-1

100 ibid:462

Hughes added that "the possibilities of change can be seen as a conflict between technological momentum and the social construction of technology".[101] In examining precedents for systems displacement, he identified sudden economic changes such as the 1973 oil embargo (which caused a radical change in car design), and technological catastrophes such as Three-Mile Island and Chernobyl (which interrupted the growth of nuclear power systems); he also suggested that "value changes", such as the rise of environmental movements, might break the momentum of large systems. He concluded that "the most likely cause of displacement of large, centrally controlled systems would seem to be a confluence of contingency, catastrophe, and conversion that would break the momentum and socially construct a new style of technology".[102]

Whilst he recognised the possibility of system displacement, Hughes maintained that the basic dynamics of system development described in *Networks of Power* remained valid:

> New systems, be they electronic and military or computer or industrial, tend to display the same patterns of growth and momentum. In the modern era, old systems do sometimes fade away, but even larger and more complex ones often displace them ... Economic principles like economies of scale, economies of scope, and diversity of load that ... other system builders applied primarily in the region and nation are being implemented by their system-building successors in an international arena.[103]

2.3.4 Criticisms of Hughes' Systems Approach

In recent years there has been considerable criticism within technology studies of the systems or contextual approach used by Hughes in *Networks of Power*. Edge described the general weakness associated with contextual approaches: "discussion of each type of influence tends to be relatively isolated from discussion of the others ... [for] example, those concerned with the impact of organisational factors on the process of technical change ... [tend] to ignore the importance of market structures and competitive pressures, and *vice versa*".[104]

Mikael Hård argued that whilst Hughes' sociotechnical systems model had a commonsense character, and analytical convenience – which, he suggested, explained much of its popularity with researchers – it perpetuated a view of technological change

[101] ibid:470. Social constructivism is discussed later in this chapter (2.4.1).
[102] ibid:470-1
[103] ibid:470-2. He explicitly referred here to the increasing concentration of multinational electrical plant manufacturers.
[104] David Edge, 'The Social Shaping of Technology', Edinburgh University PICT Working Paper No.1, 1988:2

"as a self-regulating and tension-managing process".[105] Hård suggested that Hughes' description of an interdependent, goal oriented system was inevitably *functionalist*: "to explain the relations between the capacities of electricity generators and of power lines in terms of direct interdependencies is straightforward, but to interpret social interaction in the same way can be nothing but functionalist".[106] Hård pointed out that "in Hughes' works, the only conscious people we find are the system builders"[107], and he suggested that the methodological focus on the system builder meant that the systems approach tended to focus on the resolution of problems in order to drive forward system development. He added that "even if various systems may clash and the builders of different systems may be in conflict, each well-functioning system is in itself harmonious".[108] As a result, he argued, systems theory was unable to deal adequately with conflict over technological alternatives, since any criticism of existing systems were seen as dysfunctions. Hård concluded that the limited perspective of systems approaches resulted in an analytical bias towards the exploration of conservative dynamics and away from more radical changes:

> The world of a sociotechnical system looks and feels like an iron cage. There is no place for critique and no way out ... By presenting a view of technology in terms of functionally arranged sociotechnical systems, we will support those who benefit from harmony and cooperation and discourage those who might benefit from conflict and opposition. We might be able to reveal both unexpected and unwanted aspects of technology, but we will remain unable to suggest an alternative vision.[109]

Similarly, Wolfgang Rudig stated that he found Hughes' notion of sociotechnical system development through the identification of certain key problems (what Hughes termed "reverse salients") rather determinist, and added that systems theory failed to give adequate attention to alternative possible technologies.[110]

W. Bernard Carlson argued that Hughes' emphasis on system-building was associated with a failure of the systems approach when applied to *consumer-led* as opposed to *producer-led* industries.[111] Carlson suggested that Thomas Edison and his managers – who were portrayed by Hughes and others as highly successful system builders – were

---

105 Mikael Hård, 'Beyond Harmony and Consensus: A Social Conflict Approach to Technology', *Science, Technology and Human Values*, Vol.18, No.4, Autumn 1993, pp408-432:412
106 ibid:412-3
107 ibid:413
108 ibid:413
109 ibid:413. As discussed above (2.3.3), Hughes himself conceded that established systems are normally conservative.
110 Wolfgang Rudig, 'Towards a 'New' Political Science of Technology', University of Strathclyde Papers on Government and Politics, No. 63, 1990:6
111 W. Bernard Carlson, 'Artifact and Frames of Meaning: Thomas A. Edison, his Managers, and the Cultural Construction of Motion Pictures', in W. E. Bijker and J. Law (eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp175-198

producer-oriented, and did not appreciate the demands of consumer culture. For Carlson, this explained why Edison was unable to repeat his success in electric power systems – a producer dominated industry – in his later efforts in motion pictures, an industry which quickly became consumer-dominated.

Three years after the publication of *Networks of Power*, Hughes himself stated that "there are problems with the contextual approach".[112] He now indicated that he was dissatisfied with the use of terms such as 'internal/external' and 'core/context', and the use of a series of contextual influences. He stated that contextual approaches had a tendency to "resort to labelling the context as 'social', or to stringing out a list of analytical categories, including the social, political, and economic. This, however, merely substituted one set of high-level abstractions for another, and left too much room for misunderstanding the social".[113] He added that "the hard analytical categories – such as technology, science, politics, economics and the social – should be used sparingly, if their use leads to difficulty in comprehending interconnection"[114], and he emphasised that sociotechnical systems should be seen rather as a *seamless web.*

Hughes went on to explain that his rethinking on these issues arose in-part from consideration of the work of the system builders themselves, such as Thomas Edison. According to Hughes, Edison was successful in pushing forward the development of the electric power system precisely because he ignored any supposed divisions between technological, economic, and political matters.[115] As a result, he suggested replacing 'hard' contextual factors with "overlapping soft categories".[116] He also stated that the problems accompanying contextual approaches were such that approaches adopting a more abstract terminology potentially offered a more promising way forward:

> The long-term use of analytical categories such as ... content and context ... internalist and externalist ... has conditioned historians to set up discrete entities rather than seamless webs, particles rather than waves. One way to transform our cognitive mode is to avoid these traditional categories with their time-worn connotations, and resort to neologisms and the abstractions of interaction.[117]

---

[112] Thomas P. Hughes, 'The Seamless Web: Technology, Science, Etcetera, Etcetera', Social *Studies of Science* , Vol.16, pp281-292, 1986:281

[113] ibid:283

[114] ibid:285

[115] Elsewhere, Hughes stated that Edison's inventive method "synthesised the technological, economic, and scientific", and added that Edison "could not conceive of technology as distinct from economics". (Thomas P. Hughes, 'Edison and Electric Light', in D. MacKenzie and J. Wajcman (eds.), *The Social Shaping of Technology*, Milton Keynes, Open University Press, 1985, pp39-52: 40, 45)

[116] Hughes, 'The Seamless Web', op cit:287

[117] ibid:291

As Hughes alluded to, a number of approaches using more abstract concepts have emerged within technology studies in recent years, most notably *social constructivism* and *actor-network theory*. Although a comprehensive review of these two strands of social shaping approaches is beyond the scope of this chapter, their theoretical origins and main themes are now briefly considered.

2.4 Social Constructivist and Actor Network Approaches

2.4.1 Social Constructivism

In a seminal paper first published in 1984, Trevor J. Pinch and Wiebe E. Bijker criticised established ways of analysing technological development, and developed instead an approach based on a view of "technological artefacts as social constructs".[118] Pinch and Bijker applied an analytical perspective developed from the sociology of scientific knowledge, in an attempt to provide what they described as a "symmetrical sociological explanation" of technological change, "which treats successful and failed artefacts in an equivalent way".[119] Within this, they introduced a methodological framework in which technological change was explained primarily in terms of the success or failure of different *relevant social groups* to impose their preferred technological design. The different meanings associated with competing designs by different groups were said by Pinch and Bijker to lend the technology *interpretative flexibility*.[120] Only after one social group had succeeded in making its interpretation dominant, they argued, could a stable technological form, or *closure*, be achieved. They added that "a variety of closure mechanisms play a part in bringing about ... the stabilization of an artefact".[121] Pinch and Bijker concluded with a call for further research based on this approach – what they referred to as the "integrated study of the social construction of facts and artefacts"[122] –

---

[118] Trevor J. Pinch and Wiebe E. Bijker, 'The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other', *Social Studies of Science*, Vol.14, pp 399-441, 1984:407

[119] ibid:407

[120] In a subsequent article, Bijker stated that "the interpretative flexibility of artifacts is synonymous with refuting technological determinism", and added that it was "the *raison d'être* of the social studies of technology, the justification for its existence". (Wiebe E. Bijker, 'Do Not Despair: There is Life after Constructivism', *Science, Technology, and Human Values* ,Vol.18, No.1 pp113-138, Winter 1993:118.)

[121] Pinch and Bijker, op cit:425 In particular, they contrasted "rhetorical closure" with "closure by redefinition of a problem" (ibid). Elsewhere, Bijker and John Law argued that stability of technical form required that the social relations around technology were themselves stable: "technology is stabilised if and only if the heterogeneous relations in which it is implicated, and of which it forms a part, are themselves stabilised" (Wiebe E. Bijker and John Law 'General Introduction', in W. E. Bijker and J. Law (eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp1-14:12).

[122] Pinch and Bijker, op cit:432

and indeed, their paper was the starting-point of a large body of research undertaken in recent years concerned with the social construction of technology.[123]

In a subsequent paper, Bijker and John Law reflected on the analytical origins of social constructivism.[124] They made clear that their starting point was a social shaping critique of technological autonomy and determinism; they stated that "technologies do not provide their own explanation ... there is no internal technical logic that drives innovation [and] technologically determinist explanations will not do".[125] Like Hughes, Bijker and Law also recognised the ambivalent role of technology in social change:

> Technology does not spring, *ab initio*, from some disinterested fount of innovation. Rather it is born of the social, the economic, and the technical relations that are already in place. A product of the existing structure of opportunities and constraints, it extends, shapes, reworks, or reproduces that structure in ways that are more or less unpredictable. And, in doing do, it distributes, or redistributes, opportunities and constraints equally or unequally, fairly or unfairly.[126]

In reviewing established ways of studying technological change, Bijker and Law suggested that the most rewarding research was often found from within the *social history of technology*, which, they stated, "at its best, locks away neither social relations nor the content of technology".[127] However, they added that there was a need to move away from the detailed case-by-case studies of the social history of technology, towards some degree of generalisation. Whilst they conceded that this would inevitably involve a trade-off – since theory necessarily involved some simplification, and an explicit or implicit statement of priorities – they argued that this was desirable, since it allowed for similarities and differences between individual case-studies to emerge, and a consideration to be made of the underlying pattern and dynamism of technological change.[128]

---

123 See, for example, W. E. Bijker, T. P. Hughes, and T. Pinch (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987; W. E. Bijker and J. Law (eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992; P. J. Vergragt, 'The Social Shaping of Industrial Innovations', *Social Studies of Science*, Vol.18, pp483-513, 1988

124 Wiebe E. Bijker and John Law 'General Introduction', in W. E. Bijker and J. Law (eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992

125 ibid:8. They added that "we should be similarly cautious of explanations that talk of technological trajectories or paradigms" (ibid).

126 ibid:11

127 ibid:5

128 ibid:7

Elsewhere, Bijker stated that a technological artifact was "gradually constructed or deconstructed in the social interactions of relevant social groups"[129], and added that "instability is more revealing about a systems characteristics than stability".[130] Following on from Hughes' metaphor of the seamless web of technological development, Bijker stated that in the analysis of technological change, "our theoretical concepts are required to be as heterogeneous as the actors' activities and as seamless as the web to which the concepts will be applied ... our conceptual framework should not compel us to make any a priori choices as to the social or technical or scientific character of the specific patterns it will make visible to us".[131]

In implicit recognition of the limitations of the early constructivist model to accommodate social structure (as discussed below, 2.4.3), Bijker now introduced a modified form of social constructivism, including concepts such as the *technological frame* and *sociotechnical ensembles*. He defined the technological frame in rather vague terms as a "heterogeneous cognitive and social domain", built up and maintained as part of the stabilisation of an artifact, which provides the goals, thoughts and tools for action, but which "will constrain the freedom of members of the relevant social group".[132] He also suggested that, in recognition of the fact that "the technical is socially constructed and the social is technically constructed", technical artifacts (and social institutions) should be replaced as the unit of analysis by *sociotechnical ensembles*.[133] He added that sociotechnical ensembles developed in different types of technological frames: in some cases there was no single dominant group or set of vested interests; in others, one group is dominant, whilst in a third type, two or more entrenched groups with divergent frames compete for dominance. In the last case, innovations that allow the amalgamation of the vested interests of the different groups will be sought.[134] Bijker concluded that "society is not determined by technology, nor is technology determined by society. Both emerge as two sides of the sociotechnical coin, during the construction processes of artifacts, facts, *and* relevant social groups".[135]

---

129 Wiebe E. Bijker, 'Do Not Despair: There is Life after Constructivism', *Science, Technology, and Human Values* ,Vol.18, No.1 pp113-138, Winter 1993:119

130 ibid:119

131 ibid:120-1

132 ibid:123

133 ibid:125

134 ibid:128. Similarly, Bijker and Law argued that when one dominant group is able to insist upon its definition of a problem, conventional innovations will tend to emerge (J. Law, and W. E. Bijker, 'Postscript: Technology, Stability, and Social Theory', in W. E. Bijker and J. Law (eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp291-312:302).

135 Bijker, 'Do Not Despair,' op cit:125 (Emphasis in original). More recently, Bijker has attempted to incorporate differentiated power within a constructivist view; see 'The Politics of Sociotechnical Change' in W. E. Bijker, *Of Bicycles, Bakelites and Bulbs: Toward a Theory of Sociotechnical Change*, Cambridge MA, MIT Press, 1995, pp269-290.

2.4.2 Actor-Network Theory

Alongside social constructivism, another rich theme within technology studies in recent years has been the *actor-network* approach developed by Michel Callon and others.[136] Callon first presented his theoretical ideas in a study of the evolution of an electric vehicle project in France during the 1970s.[137] Here, he criticised established sociological analysis of technological change, which, he argued, was unable to accommodate the ways in which society could be transformed by the efforts of entrepreneurs and technologists; he argued that in order to capture this, conventional sociological terminology had to be abandoned.[138] In their place, Callon presented a series of concepts with which to analyse processes of technological change, most notably the *actor-network* itself, which he stated, "is composed of a series of heterogeneous elements, animate and inanimate, that have been linked together for a certain period of time".[139] He added that the actor-network included all of the human and non-human entities essential for the existence of any given technology - scientists, consumers, manufacturing companies, and also electrons, catalysts, batteries etc. He argued that technological artifacts should be seen as the outcome of such networks:

> Technical objects must be seen as a result of the shaping of many associated and heterogeneous elements. They will be as durable as these associations, neither more nor less. Therefore we cannot describe technical objects without describing the actor-worlds that shape them in all their diversity and scope.[140]

Callon emphasised that the network was predicated on all the different elements within it, and that the loss of any one element would mean the dissolution of the network, and the technology that it supports. Describing the construction of the actor-world, he argued, was equivalent to describing the social construction of artifacts. He emphasised the importance, in the construction of the actor-world, of *translation*, or "the methods by which an actor enrols others".[141] It is through translation, Callon argued, that

---

[136] Other than the analysts considered here, the work of Bruno Latour has been particularly important in the development of actor-network theory. See, for example, B. Latour, *Science in Action: How to Follow Scientists and Engineers Through Society*, Milton Keynes, Open University Press, 1987; B. Latour, 'The Prince for Machines as well as for Machinations', in B. Elliott, (ed.), *Technology and Social Process*, Edinburgh, Edinburgh University Press, 1988, pp20-43

[137] Michel Callon, 'The Sociology of an Actor-Network: The Case of the Electric Vehicle' pp19-34 in M. Callon, J. Law and A. Rip (eds.), *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World*, Basingstoke, MacMillan, 1986

[138] ibid:31

[139] Michel Callon, 'Society in the Making: The Study of Technology as a Tool for Sociological Analysis' in W. E. Bijker, T. P. Hughes, and T. Pinch, (eds.),*The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987, pp83-103:93

[140] Callon, 'The Sociology of an Actor-Network', op cit:23

[141] Editor's introduction, in M. Callon, J. Law and A. Rip (eds.), op cit:xvii

technologies establish themselves in key positions or "obligatory points of passage", and the actor-network "accumulates materials that render it durable".[142]

Using the actor-network model, Callon explained the eventual failure of the French electric vehicle project as primarily a result of "resistance" of fuel cell catalysts – the failure of scientists to advance the performance of fuel cells meant that the anticipated market for the technology did not develop.[143] He argued that such an explanation would have been unobservable by conventional sociological analysis. He concluded that the fluidity of actor-networks "makes it possible to abandon the constricting framework of sociological analysis with its pre-established social categories and its rigid social/natural divide ... [it thereby] gains access to the same room to manoeuvre and the same freedom as engineers themselves employ".[144]

Callon also discussed the critical role of key individuals, referred to as "engineer-sociologists", in maintaining the actor-network, and suggested analysts should follow the activities of such individuals.[145] He went on to consider the difference between actor-network theory and Hughes' systems approach. Although he recognised that there were many similarities, such as those between engineer-sociologists and Hughes' system builders, Callon argued that there were also important differences, particularly concerning the boundaries between system and context in Hughes' approach: "the systems concept presupposes that a distinction can be made between the system itself and its environment ... [but] how do we define the limits of a system and explain concretely the influence of the environment?"[146] He argued that although Hughes managed to avoid this problem by a "pragmatic use of theory", it was circumvented entirely in actor-network theory. He concluded that "by abandoning the concept of system for that of actor-network ... we are taking Hughes' analysis ... a step further".[147]

Another analyst closely associated with actor-network theory, John Law, considered the relative merits of constructivist and systems approaches to the analysis of technological change.[148] Law argued that although these have much in common, in that they both emphasise the social shaping of technology, they specified a different relationship between technology and the rest of society:

---

142 Callon, 'The Sociology of an Actor-Network', op cit:26, 28

143 Callon, 'Society in the Making', op cit:90

144 ibid:100

145 ibid:98

146 ibid:100

147 ibid:101

148 John Law, 'Technology and Heterogeneous Engineering: The Case of Portuguese Expansion' in W. E. Bijker, T. P. Hughes, and T. Pinch, (eds.),*The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987 pp111-134

> Social constructivism works on the assumption that the social lies behind and directs the growth and stabilisation of artifacts ... that the detection of relatively stable directing social interests offers a satisfying explanation for the growth of technology. By contrast, the systems approach proceeds on the assumption that the social is not especially privileged ... that social interests are variable, at least within certain limits.[149]

Law argued that, as Hughes' systems approach recognised, technologies may sometimes be a *cause* of social change, and not merely – as is suggested by social constructivism – a reflection of social interests.[150] To this extent, therefore, he stated that he favoured a systems rather than constructivist approach:

> In explanations of social change the social should not be privileged ... Although it may at times be an important – indeed the dominant – factor in the growth of the system, this is a purely contingent matter and can be determined only by empirical means. Other factors – natural, economic, or technical – may be more obdurate than the social and may resist the best efforts of the system builder to reshape them.[151]

Law went on to develop an actor-network approach similar to Callon's, with an emphasis on the "conditions and tactics of system building", and on both social and technical aspects of the actor-network – what he referred to as *heterogeneous engineering*.[152] He stated that whilst the actor-network approach drew greatly on Hughesian systems analysis, it differed from it in important ways. Firstly, it dealt with conflict in a different way: it viewed the environment around the network as hostile, and the elements within the network as susceptible to dissociation. In addition, unlike the systems approach, the actor-network approach addressed natural and social phenomena using the same analytical vocabulary, since "from the standpoint of the network those elements that are human or social do not necessarily differ in kind from those that are natural or technological".[153] Law argued that "the social elements in a system should not be given special explanatory status"[154], and that therefore, analysts should adopt a 'symmetrical' approach to the treatment of human and non-human elements of the network. Within this, he recognised that certain elements were more "durable", or less susceptible to dissociation than others, and that "the success achieved by one side or the other are a function of the relative strength of the components in question".[155] He added, however, that "this is not ... to suggest that it is always the social that is malleable and the

149 ibid:113
150 ibid:131
151 ibid:113
152 ibid:113
153 ibid:114
154 ibid:130
155 ibid:129

technological or the natural that is durable. It is rather to stress that the relationship between them is one of contingency, and that it is important to find a way of treating all the components in a system on equal terms".[156]

A common criticism of both actor-network and constructivist approaches is that they concentrate on small-scale projects, and are less suited to analysing larger-scale technologies.[157] One of the notable exceptions in this regard was the actor-network analysis by Law and Callon of a British rocket technology project.[158] In studying the development of such an overtly political technology, Law and Callon were forced to consider the role of political institutions as well as project level dynamics. In doing so, they attempted to deal with the interaction of macro/micro dynamics in a different way to the system/context division of Hughes' approach; they argued:

> It is too simple ... to say that context influences, and is simultaneously influenced by, content. What we require is a tool that makes it possible to describe and explain the convolution of what are usually distinguished as sociotechnical context and sociotechnical content.[159]

In this effort, Law and Callon introduced the concepts of *global* and *local* networks. They stated that the global network included government ministries, geopolitical factors, the interests of nation states, and international technological changes, whilst the local network included local institutions, such as contractors, agencies and institutes, and also scientific and technical expertise, and tools, equipment and papers.[160] They suggested that in the course of a technological project, actors attempted to *mobilise* the global network in order to obtain resources with which to build a project at a local level:

> The success and shape of ... [the] project ... depended crucially on the creation of two networks and on the exchange of intermediaries between these networks ... from the global network came a range of resources – finance, political support, technical specifications ... [that] were made available to the project and generated a negotiation space ... within which a local network might be built.[161]

They suggested that the technological project itself operated as an intermediary between the local and global networks, and that the success of the project depended on the degree to which it could establish itself as key link between the two networks:

---

156 ibid:130

157 This issue is discussed further in 2.4.4 below.

158 John Law and Michel Callon, 'The Life and Death of an Aircraft: A Network Analysis of Technical Change' in W. E. Bijker and J. Law (eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp21-52

159 ibid:21

160 ibid:46-7

161 ibid:41-42

> The shape and fate of technological projects is a function of three interrelated factors: the global network, local network, and the ability of the project itself to impose itself as an obligatory point of passage between the two, providing some reward for the global from the local ... It is the degree and form of mobilization of the two networks and the way in which they are connected that determines both the trajectory and success of the project.[162]

Jane Summerton applied many concepts and methods of systems, constructivist, and actor-network theory in an analysis of the development of a particular electricity generation technology project – a district-heating project in a Swedish town.[163] Whilst Summerton adopted much of the language of both systems and actor-network theory, she developed her own conceptual approach based on the particular features of grid-based technologies.[164] She suggested that these could be characterised in part technically, in part institutionally, as examples of *grid-based multiorganisations (GBMOs)*: groups of organisations linked together by common goals, and their shared participation in the system. Within the GBMO, no single organisation had overall control, and the different organisations were drawn together in a complex interdependence. She argued that this meant that although committed system builders were vital to the project's success, the dynamics of GBMOs were therefore somewhat different from the dynamics of systems or actor-networks where one individual system builder or engineer-sociologist was a prime-mover:

> The system was *not* configured solely on the basis of the basis of the plans or schemes of the all powerful manipulatory system-builders. Instead [the] multiorganization was shaped to a large extent through negotiations among interdependent actors.[165]

Summerton suggested that the physical grid of GBMOs was paralleled by an "invisible grid", based on the interdependence between the different organisations involved.[166] In common with many other analysts drawing on social constructivism, Summerton also rejected any primacy of influence for 'technical' as opposed to 'social' dynamics on the process of technological change:

---

162 ibid:46, 47. Mikael Hård has also recently argued that technological change should be seen as an outcome of the interaction of global and local dynamics. In an analysis of the development of diesel engines, Hård identified different constituents of technical work as a mixture of global orientations and knowledge, together with local practices and skills. He concluded that stability of technological design was arrived at through a process in which global orientations provided design goals and trajectories which were then interpreted in accordance with local traditions. (Mikael Hård, 'Technology as Practice: Local and Global Closure Processes in Diesel-Engine Design', *Social Studies of Science*, Vol.24, pp549-85, 1994)

163 Jane Summerton, *District Heating Comes to Town: The Social Shaping of an Energy System*, Linköping University Studies in Arts and Sciences, No.80, Linköping, Sweden, 1992

164 ibid:74

165 ibid:259, emphasis in original.

166 ibid:258

> Amidst the flux, all the components – plants, people and permits – have to somehow fall into place. If they do not ... despite the best efforts of system builders, adjustments must be made. One might be tempted to assume that the physical artifacts are less flexible or 'malleable' ... than actors' decisions or actions. In a technological deterministic vein, this would mean that 'hard' physical artifacts – their design, the pace at which they are installed, and their positioning in the system – are harder to steer than are 'soft' human actors ... [This] case offers evidence to the contrary.[167]

Indeed, in the design of the actor-network, she argued, "the physical artifacts were essentially 'soft' while actors - such as certain customers - sometimes proved 'hard'".[168] She suggested the more overtly social aspects of system building were often more difficult and time consuming than physical or technical aspects: "'institutional' and 'organisational' aspects of shaping grid-based systems (such as political decision-making and regulatory processes) have lead times that are at least as long as the lead times of the physical artifacts".[169]

Summerton argued that important factors in the district heating project's eventual success were an assured first market, strong professional and institutional support structures for the technology, and the successful mobilisation and enrolment of powerful figures external to the project, such as energy company directors and managers, and state energy officials.[170] She emphasised that the assurance of a market was critical to attracting investment to the project, given the economics of energy technologies: "with their long lead times and high fixed costs, grid-based energy systems are particularly sensitive to competing technologies ... system builders strive to obtain monopoly rights ... to assure the ability to recover high investment costs".[171]

Summerton also discussed the established vested interests in energy provision – in particular those concerned with the dominant technological forms of electricity generation in Sweden in the 1980s, hydro and nuclear power – and how these were circumvented by making government Electricity Office officials actively involved in the project, in other words "'neutralising' the opposition by enlisting it".[172] Despite the absence of an overall system 'champion', Summerton argued that there was a marked compatibility of concerns among the different actors involved in the district heating project. She identified regulators as particularly important actors: "when regulators

---

167 ibid:95
168 ibid:252
169 ibid:256
170 ibid:243
171 ibid:252
172 ibid:248

readily approved system-builders plans, expanding the system went smoothly. When they objected, the result was a halt (or threatened halt) to further growth".[173] Summerton argued that the successful prosecution of the project was surprising, given the diverse and complex parts that had to be brought together for it to progress. She concluded that it was a "complex, at times fast-paced process in which technical, economic, political and institutional issues were ... closely intertwined".[174]

2.4.3 Criticisms of Constructivist and Actor-Network Approaches

Even the critics of constructivist and actor-network approaches have recognised that such perspectives have some analytical merit. Langdon Winner, for example, stated that constructivism had served as an "antidote to naïve technological determinism".[175] He added that the research efforts of constructivists had helped to reveal the social interests behind technological development, and recognised that "constructivist interpretations of technology emphasise contingency and choice rather than forces of necessity in the history of technology".[176] Similarly, Williams and Russell, whilst also being critical of constructivism, conceded that it had provided a "much-needed refutation of autonomous and determinist notions concerning technology", and added that constructivist approaches had drawn attention to the "problematic nature of technological advance, the possibility of redirection at any point, [and] the plasticity of outcomes".[177]

Nevertheless, these analysts and others have been critical of a number of aspects of constructivism and actor network approaches. Particular concern has been expressed with the use of concepts from the sociology of scientific knowledge which underlie constructivism. Williams and Russell pointed to particular difficulties associated with the use of the concept of 'closure' as applied to technological change.[178] This was problematic, they argued, because technology operates over a much larger and more complex social sphere than science. In particular, they argued that "when implementation and use are taken into account, the range of social groups involved and affected by technological change expands enormously, going far beyond anything recognisable as a

---

[173] ibid:250

[174] ibid:243

[175] Langdon Winner, 'Do Artifacts Have Politics?', in MacKenzie and Wajcman (eds.), *The Social Shaping of Technology*, op cit, pp26-38:36

[176] Langdon Winner 'Social Constructivism: Opening the Black Box and Finding it Empty', *Science as Culture*, Vol.3, Pt.3, No.16, 1993, pp427-452:436

[177] Robin Williams and Stewart Russell, 'Opening the Black-Box and Closing it Behind You: On Microsociology in the Social Analysis of Technology', Edinburgh University Research Centre for Social Sciences, PICT Working Paper, No.3, 1988:3. See also Stewart Russell, 'The Social Construction of Artefacts: A Response to Pinch and Bijker', *Social Studies of Science*, Vol.16, pp331-346, 1986

[178] Williams and Russell, op cit:5

technological community".[179] In applying such concepts, they suggested, constructivism therefore reduced technology to *technological knowledge*, "to the exclusion of its material manifestation, context, and effects".[180] Williams and Russell also criticised the non-typical choice of case-studies in the bulk of constructivist analysis. The detailed case-study accounts of constructivism, they suggested, tended to concentrate on the early stages of radical technology projects, ignoring the greater part of technological change, where incremental changes "proceed in a context of already strongly-articulated social and economic interests".[181] They also argued that constructivists tended to become overly absorbed in the internal project dynamics, and to project the relationships found in the research laboratory far more widely than was appropriate.[182]

Knut Sørensen and Nora Levold shared many of Williams and Russell's criticisms of constructivist and actor-network approaches. In particular, they argued that the use of concepts from the sociology of science overlooked the fact that "the social terrain on which scientists manoeuvre is much simpler than that of engineers", and that "technology usually is surrounded by a larger number of powerful economic and political actors than is science".[183] They also argued that because science was much less heterogeneous compared to technology, a more "complex concept of heterogeneity" was needed to capture technological change than Hughes' "seamless web".[184] They also considered the difficulty in adopting the call to "follow the actors" for analysts of technological change, and they suggested that "in the case of science, far more seems to be explained through the individual actions of scientists than in the case of technology".[185] Furthermore, they argued, even when successfully undertaken, a focus on engineers or technologists was capable of missing many of the influences on technological change. Like Williams and Russell, Sørensen and Levold also considered the difficulties of the use of the concept of "closure" in technological terms. They suggested that, in science, closure was associated with the successful resolution of the process of change, but that in technology some remaining "interpretative flexibility" may be desirable, and closure may never be achieved. They concluded that, given the complexity of the process of technological change, any one conceptual or analytical approach was necessarily limited, and a range of concepts and methods was appropriate:

179 ibid:6
180 ibid:5
181 ibid:10
182 ibid:6-7
183 Knut Sørensen and Nora Levold, 'Tacit Networks, Heterogeneous Engineers, and Embodied Technology', *Science, Technology, and Human Values*, Vol.17, No.1, pp13-35, Winter 1992:19, 16
184 ibid:19, 17
185 ibid:29

> The problem is that the terrain on which engineers and technological scientists move has been thoroughly shaped by previous actions. To encounter the historical processes that have brought about, for example, the available infrastructure of competence, skills and knowledge through observation of engineers/scientists, is – to put it mildly – difficult. For this task, a heterogeneous mix of historical, ethnographic, economic, and sociological competencies seems required.[186]

Winner has been a particularly outspoken critic of constructivism, which has he referred to as the "social determination of technology".[187] In particular, he has objected to what he considered to be an overemphasis on interpretative flexibility, and the disregard of other approaches which offered more politically informed and structurally aware analysis of technological change – such as the insights offered by his own concept of technological autonomy (2.2.2).[188] In this regard, he added, constructivism had effectively narrowed the conceptual bounds of research and analysis into technological change. He stated that "perhaps the helpful insight ... [constructivists] want to offer is simply that choices are available, that the course of technological development is not fore-ordained by outside forces, but is instead a product of complex social interactions. If that is the point of their enquiries, then constructivists are now repeating it *ad nauseam.*".[189] Winner concluded that constructivism was unable to recognise less obvious structural influences on technological change:

> Although ... [constructivism] succeeds in finding contingency rather than necessity in the course of technological change ... it disregards the possibility that there may be dynamics evident in technological change behind that revealed by studying the immediate needs, interests, problems and solutions of specific groups and social actors.[190]

Wolfgang Rudig criticised the absence of comparative study within the most constructivist case-studies. Rudig described as "indefensible" the denial by constructivist analysts of the influence of macro-economic and political influence, "on the basis of studies which are usually limited to one particular case occurring in one particular country at one particular time".[191] He also stated that "there seems to be little ground for

---

186 ibid:32

187 Langdon Winner, 'Social Constructivism: Opening the Black Box and Finding it Empty', *Science as Culture* , Vol.3, Pt.3, No.16, pp427-452:27, 1993

188 ibid:443-447

189 ibid:448-9. Thomas J. Misa has also expressed unease about the empiricism of social constructivism, and of the glut of case-studies centred on research laboratories. Misa argued that it was difficult to identify what additional knowledge or critical questions was being added by such empirical contributions. (Thomas J. Misa, 'Theories of Technological Change: Parameters and Purposes', *Science, Technology, and Human Values* ,Vol.17, No.1, pp3-12, Winter 1992:5)

190 Winner, "Social Constructivism', op cit:442

191 Wolfgang Rudig, 'Towards a 'New' Political Science of Technology', University of Strathclyde Papers on Government and Politics, No. 63, 1990:15 In this regard, Stewart Russell was critical of the absence, in Summerton's analysis of a district heating technology project (see 2.4.2 above), of a broader analysis of Swedish energy policy, or

the aggressive rejection of all so-called 'macro-structural' approaches".[192] Nevertheless, Rudig argued that there was room for accommodation within constructivism for a greater recognition of macro-structural influences, and he stated that "Pinch and Bijker's model of 'relevant social groups' is so general that macro groups and dynamics could be integrated".[193]

Mikael Hård argued that, although social constructivism had presented a useful perspective on conflict associated with innovation, this lacked a discussion of power, stratification, and hierarchy, and that consequently, the differing power of the various 'relevant social groups' was underplayed: "[the] insistence on not only discussing engineers and capitalists but also allowing for the influence on technological change of various user groups and social movements is very well taken, but it must not be brought to a point where the relative power of the social groups is lost".[194] Hård was also critical of the overemphasis, in constructivism, on consensus as a means of resolving conflict.[195] He stated that "by regarding closure as an outcome of consensus, Pinch and Bijker suddenly and regrettably drop their conflict perspective. Once stabilization around a technological solution has emerged, conflict disappears".[196] Hård argued that this aspect of constructivism, borne out of the import of theory from the sociology of scientific knowledge, was mistaken when applied to technology:

> The formation of consensus is only one of several possible closure mechanisms – closure through the exercise of force being another ... considering that social groups being affected by and involved in the development of technological artifacts and systems are, usually, both large in number and quite dissimilar, it does not seem likely that technological closure should always be of the consensus kind.[197]

Nevertheless, Hård argued that social constructivism was "very far removed" from technological determinism, or even what he saw as the functionalism of Hughes' systems theory (2.3.4), and he added that "its agency orientation has proved empirically useful".

---

any comparative case studies. (Stewart Russell, 'Heating Networks', *Social Studies of Science*, Vol.24, pp587-595, 1994:594)

192 Rudig, op cit:12

193 ibid:10

194 Mikael Hård, 'Beyond Harmony and Consensus: A Social Conflict Approach to Technology', *Science, Technology and Human Values*, Vol.18, No.4, Autumn 1993, pp408-432:415

195 John Law argued that the importance of conflict was recognised within the actor-network approach, since it viewed the environment around the actor-network to be hostile (2.4.2). Nevertheless, since it shares with systems and constructivist approaches a preoccupation with the construction and maintenance of the network, actor-network theory is also concerned primarily with the *resolution* of conflict.

196 Hård, 'Beyond Harmony and Consensus', op cit:415

197 ibid:415

Hughes has also recently expressed criticism of constructivism.[198] He argued that whilst it had "provided an invaluable corrective" to technological determinist interpretations of history, it shared with determinist approaches a failure to recognise the complexity of technological change, and like Winner, he suggested that it tended towards social determinism".[199] Hughes considered the limitations of both determinist and constructivist approaches in terms of their interpretation of the 'technical core' of systems. He stated that whereas technological determinists see the technical core as *causing* social change, constructivists see it as an *effect* of social interests. In reality, Hughes stated, the core was both cause *and* effect.[200] He concluded that although constructivist interpretations corresponded more closely to the early stages of system development, and determinist interpretations later stages, both provided a limited way of examining technological change, and he stressed instead the value of his own concept of *momentum*:

> A technological system can be both cause and effect; it can shape or be shaped by society. As they grow larger and more complex, systems tend to be more shaping of society and less shaped by it ... The momentum of technological systems is a concept that can be located somewhere between the poles of technical determinism and social constructivism. The social constructivists have a key to understanding the behaviour of young systems; technical determinists come into their own with mature ones. Technological momentum, however, provides a more flexible mode of interpretation and one that is in accord with the history of large systems.[201]

At the same time, Hughes expressed greater satisfaction with actor-network theory, which, he argued, shared more essential characteristics with his technological systems approach.[202]

2.4.4 Micro- and Macro-Level Analysis

A recurrent theme in criticism of constructivist and actor-network analyses of technological change is their perceived over-attention to micro-level project dynamics, and their neglect of macro-level economic and political structures. Williams and Russell, for example, described this neglect as "mistaken and unnecessary", and added that "we do not believe that institutions such as those of the state ... can be treated in the same way as an individual actor".[203] They suggested, for example, that this meant that Callon's actor-

---

198 Thomas P. Hughes, 'Technological Momentum', in Merrit Roe Smith, and Leo Marx, (eds.), *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp101-113
199 ibid:102, 104
200 ibid:106-7
201 ibid:112. Hughes' ideas concerning the momentum of technological systems were discussed earlier (2.3.3, 2.3.3).
202 ibid:104
203 Williams and Russell, op cit:1, 13-14

network analysis of an electric vehicle project in France (2.4.2) lacked sufficient recognition of the power of entrenched interests behind established technologies. They suggested that greater recognition of the role of social structure and institutional power was essential to understand the development and durability of technological systems: "analyses of broader structures are essential to understanding the context within which detailed interactions take place ... interactions cannot be explained in their own terms".[204] For Williams and Russell the neglect of structural influences within constructivism meant that there was exaggeration of the power and autonomy of local actors – especially scientists and engineers – which ironically amounted to a new form of technological determinism.[205] They concluded:

> An interactive model of the relation between context and action is the key to overcoming the separation of micro and macro approaches to understanding technology as a social product, with different but consistent forms of analysis appropriate to each, rather than an application of the same action concepts regardless of level.[206]

In defence of the actor-network approach, Callon et al. claimed that in adopting such a perspective, the distinction between macro and micro levels of analysis disappeared, since the same analytical terminology and methodological approach was used for all the influences on technological change, including individuals, organisations, and non-human actors. Conventional analysis, they argued, in which different analytical forms are adopted according to scale, tended to privilege large-scale dynamics, and thereby "conceal the processes by which growth occurs, and the uncertainties that are involved in maintaining power and size".[207]

In a review of micro and macro analyses of technological change, Thomas J. Misa identified an association between the choice of analytical perspective and the analyst's views towards technological determinism.[208] Misa stated that "those ... [analysts] adopting a 'macro' perspective are the ones who allow technology a causal role in historical change. They deploy the Machine to make history. This causal role for the Machine is not present and is not possible in studies adopting a 'micro' perspective".[209] Even in disciplines sensitive to the social influences of technology, Misa argued, "those

---

204 ibid:11, emphasis added.

205 ibid:9

206 ibid:25-26

207 Michel Callon, John Law and Arie Rip, 'Putting Texts in their Place', in Michel Callon, John Law and Arie Rip (eds.),*Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World*, Basingstoke, MacMillan, 1986:228

208 Thomas J. Misa, 'How Machines Make History, and How Historians (and Others) Help Them to Do So', *Science, Technology and Human Values*, Vol.13, Nos.3 &4, pp308-331,1988

209 ibid:308

studies placing technology in a causative role maintain a macro view of history, whereas the ones rejecting technological determinism affirm 'the importance of the microcosm'".[210] He added, however, that some recent work in technological history had transformed the concept of technological determinism – in particular, Hughes' concept of 'momentum'. Misa suggested that constructivist, actor-network and systems approaches enabled recognition of the heterogeneous nature of technology:

> Accounts such as these are not content merely to explain the 'social' by the 'technical' (technology as a social force), or the 'technical' by the 'social' (technology as a social product) ... [they] shift to an interpretative framework presenting technology at once as socially constructed and society-shaping. They view technology as a social process.[211]

More recently, Misa stated that "in distinguishing between the macro and the micro, it is essential to emphasize that the issue is not merely the size of the unit of analysis".[212] He suggested that:

> Besides taking a larger unit of analysis, macro studies tend to abstract from individual case studies, to impute rationality on actor's behalfs or posit functionality for their actions, and to be order driven ... [by contrast] micro studies tend to focus solely on case studies, to refute rationality ... [and] functionality, and be disorder-respecting.[213]

He added that the evidence provided by many recent micro-level case studies had provided a necessary refutation of the determinism implicit in macro-level analyses of technological change:

> Properly understood, 'technology' is a shorthand term for the elaborate sociotechnical networks that span society. To invoke 'technology' on the macro level of analysis, is to compact into one tidy term a whole host of actors, machines, institutions and social relations. To expand 'technology', on the micro level of analysis, is to regain the complexity and messiness of the compacted whole. Insofar as people are necessary parts of the networks, to say that 'technology' causes social change is really to say that people – through the sociotechnical networks they create and sustain – cause social change.[214]

Whilst offering broad support for micro-level analyses of technological change, however, Misa also warned against the limitations of such a perspective: "micro studies, in the

---

210 ibid:318

211 ibid:322

212 Thomas J. Misa, , 'Retrieving Sociotechnical Change from Technological Determinism', in Smith, Merrit Roe and Marx, Leo, (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp115-141:119

213 ibid:119

214 ibid:140-1

attempt to demonstrate the socially constructed nature of technology, often omit comment on the intriguing question of whether technology has an influence on anything".[215] He concluded that "what we choose to study ... strongly influences whether technology emerges as socially constructed or as society-shaping".[216]

Donald MacKenzie rejected the micro/macro divide as a "probably false and potentially damaging dichotomy"[217], and instead suggested that a satisfactory analysis of the process of technological change required analysts to "fuse and transform the kinds of concerns habitually divided up into 'micro' and 'macro'".[218] MacKenzie suggested that rather than micro versus macro, this problem was better conceived of as the reconciliation of *local* and *delocalised* social research. In these terms, he suggested that neither an exclusively local nor non-local approach was appropriate to technology studies – since technological change was precisely concerned with *delocalisation* – the shift from local to non-local dynamics.[219] Similarly, Ham and Hill argued that there was no real choice to be made between micro and macro perspectives, and added that all social research required consideration of dynamics operating at different levels of aggregation:

> It is necessary to focus on different levels of analysis, namely the micro-level of decision-making within organisations, the middle-range analysis of policy formation, and macro-analysis of political systems ... It is the interaction between levels which is particularly significant and problematic.[220]

Sørensen and Levold argued that established approaches to the analysis of technological change tended to focus either on individual companies or scientists on the one hand, or on the national economy and government on the other – in other words, on either micro-level action or macro-level structure.[221] They suggested that in both of these approaches, there was a neglect of "very important 'intermediate' institutions and institutional arrangements (networks) involved in technological innovation", such as banks, venture capitalists research institutes, which were "neither fluid nor determined".[222] Sørensen and Levold asserted "the necessity of paying attention to this *meso* level and ... institutional aspects of technological innovation".[223] Meso-level institutions, they stated "can be seen as a visible

---

215 ibid:138
216 ibid:139
217 Donald MacKenzie, "'Micro' versus 'Macro' Sociologies of Science and Technology', Edinburgh University PICT Working Paper No.2, 1988:9
218 ibid:9
219 ibid:3
220 C. Ham and M. Hill, *The Policy Process in the Modern Capitalist State*, Hemel Hempstead, Harvester Wheatsheaf, 1984:174
221 Knut Sørensen and Nora Levold, 'Tacit Networks, Heterogeneous Engineers, and Embodied Technology', *Science, Technology, and Human Values*, Vol.17, No.1, pp13-35, Winter 1992:14
222 ibid:14-15
223 ibid:21, emphasis added.

embodiment of the heterogeneous nature of technology".[224] They argued that the failure of both constructivist and macro-level approaches in this regard was a measure of their limited usefulness in analysing the process of technological change:

> To understand the process of technological innovation without emphasizing meso-level relationships may lead to two important and far-reaching mistakes, either to overstating the potential of the individual company (or entrepreneur, scientist or engineer) or to overstating the efficiency of national policies. Both these mistakes are common in the literature.[225]

Elsewhere, Sørensen has argued that actor-network approaches tend to downplay the role of the *consumers* of technology, or "what happens after the lab".[226] He suggested that this was particularly relevant to the highly politically-shaped technologies of electricity generation, which could be described as emerging "out of parliament rather than out of the laboratory". He pointed out that the dominant electricity generation technologies in Norway – hydro-electricity, energy conservation technologies, and combined heat and power – owed much of their 'success' to sustained support by national and local government over many years.

Misa has also recently called for a focus on meso-level institutions and dynamics in analyses of technological change – what he defined as "the region conceptually intermediate between the macro and the micro ... [and] the institutions intermediate between the firm and the market or between the individual and the state".[227] Misa suggested that "a focus on meso-level institutions and organisations that mediate between the individual and the cosmos ... offers a framework for integrating the social shaping of technology and the technological shaping of society".[228] In recent years a number of approaches to the analysis of technological change have emerged which are concerned to address this institutional or meso level. A few of these approaches, of greatest relevance to the present study, are now considered.

---

224 ibid:31-32

225 Sørensen and Levold, op cit:32.

226 These ideas emerged in part from personal discussions with Professor Sørensen. See also *Trials and Transformations: The Consumption of Technology*, a lecture delivered at Edinburgh University in February 1995, and *Technology in Use: Two Essays on the Domestification of Artifacts*, University of Trondheim Centre for Technology and Society, STS-arbeidsnotat 2/94. Like Hughes and others, Sørensen has also argued that change or inertia may be embedded in technologies – whilst they may act as agents or catalysts for opening-up and rearranging social relationships, they can also act to reinforce and stabilise existing social arrangements; he added that technologies may be seen as "vehicles" though which one may analyse how societies change or stay the same.

227 Thomas J. Misa, 'Retrieving Sociotechnical Change from Technological Determinism', in Merrit Roe Smith and Leo Marx, (eds.), *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp115-141:139

228 ibid:140-1

2.5 Institutional Approaches

2.5.1 Stewart Russell's Institutional Interests Approach

Stewart Russell offered an institutional analysis of technological change in an analysis of the development of combined heat and power (CHP) and district heating (DH) technologies in Britain.[229] Russell was particularly concerned to explain the negligible adoption of CHP/DH in the UK, in contrast to their widespread use in many other European countries. He argued that understanding this pattern required a historically and structurally informed analysis of the British energy sector:

> An explanation of the neglect of CHP/DH requires ... a historical and structural analysis of its context: the energy sector and its broader social and economic role ... [it] must be situated in the organizational and technical development of the key institutions ... These characteristics and relations must in turn be linked to the specific character of the British economy and state.[230]

Russell analysed the fortunes of CHP/DH technology from the early-twentieth century up to the mid-1980s by studying the actions of various government departments, energy sector organisations, local authorities, expert committees, and other bodies. He argued that the absence of a key organisation with national responsibility for heat supply and conservation had meant that the development of CHP/DH in Britain was left to organisations for which it was a marginal activity, and that consequently, it had been awarded little institutional, financial, or political support. Investment in the technology was primarily the responsibility of local authorities, which had many other pressing demands for investment, and which were often subject to close financial control by central government. Russell pointed out that this was in stark contrast to the sustained institutional and economic support afforded to the dominant energy technologies in Britain over the same period, particularly nuclear power.[231]

Although CHP/DH technology had been marginalised in Britain throughout the century, Russell found that the attitudes of particular institutions to the technology were contingent, and had changed over time with changing circumstances. For example, the National Coal Board (NCB) was hostile to CHP/DH in the 1940s, but had supported its development in the 1960s – reflecting, he argued, a change in the NCB's perception of the

---

229 Stewart Russell, 'Writing Energy History: Explaining the Neglect of CHP/DH in Britain', *British Journal of the History of Science*, Vol.26, pp33-54, 1993. (See also Stewart Russell, 'Power Politics: Explaining the Introduction – or Absence – of Energy Technologies', University of Wollongong, Department of Science and Technology Studies, Working Paper No.2, April 1991.)

230 Russell, 'Writing Energy History', op cit:34

231 ibid:52

technology from a threat into an opportunity.[232] He also suggested that the attitude of the large generating boards to the technology also changed with time, and whilst they were never strong supporters of the technology, they were not always actively opposed to it. In general, he stated, an understanding of technological change in energy supply required an analysis of the changing interests of the different institutions involved:

> We need first a broad picture of the major objectives and programme ... [the institution] defined for itself, and its evolving relation ... with Government and with the rest of the sector. That must be combined with a quite detailed analysis of the different circumstances in which it was confronted with proposals for CHP, and of the ... challenges with which the technique was bound up.[233]

Russell concluded that without an institutionally and structurally informed analysis of the energy sector, it was impossible to account for the periodic changes experienced in the technologies of energy provision in Britain.[234] He also argued that it was only through an institutional-level analysis that it was possible to determine if the exclusion of CHP technology in Britain was *accidental* (in that a different outcome could have been realised without significant changes in the structure of the industry) or *systematic* (characteristic of the structure). He concluded that in the case of CHP/DH technology adoption in Britain, there was a mixture of both accidental and systematic exclusion:

> The option was excluded in part through the normal operation of institutions going about their main business, and to that extent unintentionally. In part it was kept out through active resistance, because of the challenges its introduction would represent to established interests in the sector and more widely, the political demands with which it was associated, and the economic and organizational changes its adoption would require.[235]

Although he found that there were some changes in the attitudes of the institutions towards different technological options, Russell concluded that energy technology choice was dominated throughout the century by a small number of producer organisations:

> Much energy politics ... [consists of] interests organised around production and consumption processes, and relations between these as regulated by the state ... Producer industries have generally sought to consolidate and maintain the structure of the sector in vertically integrated chains ... the dominance of producer interests has been maintained even when the state

[232] ibid:52
[233] ibid:52
[234] ibid:52
[235] ibid:53

> has intervened ... Changes in the organization ... tended to preserve its basic relations and the dominance of the producer industries.[236]

In the light of his analysis of the adoption of CHP/DH technology, Russell went on to consider other approaches to the analysis of energy technology, and also more general forms of analysing technological change. He was critical of the implicit technological determinism prevalent in much analysis of energy technology:

> That conflicts of interests in the sector are often channelled through technical debates does not mean that facts determine policies; rather it underlines the need to understand how competing knowledge claims are constructed and deployed, and how they come to be aligned to institutional interests – how policies may determine the facts ... The view developed here rejects the technological determinism prevalent in energy literature, much of which depicts the history of energy technologies as a logical progression in a natural order and with increasing size as technical economies of scale are achieved. Rather it attempts to show the complex of interaction of economic, political and social forces that shape ... [the] development and adoption of technologies in particular forms and with particular features, and propel them along particular trajectories of 'advance'. It implies that certain courses of action and technological options may be more or less systematically excluded or actively resisted because of the challenges they represent to established interests within the sector and beyond.[237]

As well as rejecting technological determinist accounts, Russell was also critical of constructivist and actor-network approaches (as discussed earlier, 2.4.3). He argued that the prevalence of microsocial approaches in technology studies necessitated a reassertion of "the importance of the 'macro'", and of the need for analysis at different levels of aggregation, with "different concepts and methods appropriate to each".[238] He concluded:

> An understanding of broader structures and processes is *necessary*, both as a level of explanation in itself of the general characteristics of a societies technology, and also as an essential part of a full explanation of detailed actions and outcomes, providing the context which fundamentally shapes them ... It is *possible* to reconcile the macro and the micro without collapsing one into the other: to have different forms of analysis which are none the less consistent.[239]

Russell also drew attention to the need to consider political values and institutional interests laying behind 'economic forces', and the enrolling of economic justifications for or against particular technologies. He suggested that these interests were revealed by the

---

236 ibid:48-49. Although he did not study technological change in the post-privatised British ESI, Russell anticipated that in such a context, "CHP will remain an intriguing window on the social processes behind energy provision" (ibid:53).

237 ibid:49-50

238 ibid:50

239 ibid:51. Emphasis in original.

imposition of certain financial criteria rather than others in deciding between technology choices. Although he found that ostensibly economic judgements were decisive in the choice between alternative generation technologies, these masked underlying political and institutional interests. As a result, he rejected any economic determinism of generation technology in the British ESI:

> Economic judgements usually decided the fate of DH [district heating] projects, and as that viability was so often marginal, it is necessary to examine their fine detail to know what tipped the balance. But there was no single method or universal set of criteria. The terms of appraisal were clearly dependent on the performing institution and the precise constraints on it. It is not sufficient to ask whether the option was 'economic'. We need to ask for whom its economics were assessed, and why narrowly defined economic criteria were used and whether they were appropriate. We should consider why they were applied with such rigour and demanding parameters [to DH], when another option like nuclear power was forced through when its economics was at best dubious and at times recognized even by the nuclear industry as an inadequate justification by itself.[240]

2.5.2 Mikael Hård's Social Conflict Approach

As discussed earlier in the chapter (2.4.3), Mikael Hård was critical of both constructivist and systems approaches for suggesting that conflict was essentially detrimental to the process of technological change. In offering a statement of his criticisms, Hård went on to describe the outlines of a "conflict theory of technology", which, he argued, offered a complementary approach to the consensus orientation of constructivism.[241] Hård outlined the view of technological change upon which this conflict perspective was based:

> Technology and technological change are resources used by some groups to retain or rearrange social relations. This means that *technology is formed by social groups in conflict and that technological change is never a socially neutral process*. In this view, the application of technology is not, in the first place, defined as a means of using natural resources or as a tool for the alleviation of physical strain. Rather, it is seen as a tool for establishing and influencing social relations.[242]

Unlike constructivist and systems approaches, Hård drew on social theory which emphasised that social conflict was an essential part of technological change. From such a

---

240 ibid:52

241 Mikael Hård, 'Beyond Harmony and Consensus: A Social Conflict Approach to Technology', *Science, Technology and Human Values*, Vol.18, No.4, Autumn 1993, pp408-432

242 ibid:416-7. Emphasis in original. Hård went on to consider various forms of social conflict – such as antagonistic/unifying, disintegrating/unifying, manifest/latent, conscious/subconscious, and direct/indirect. He also discussed the way in which technology could be used as a means of inclusion or exclusion, control, liberation, subordination and polarisation (ibid:419-20).

perspective, he stated, bureaucracy could be seen to be largely inimical to innovation: "in a highly bureaucratized society or firm ... [or] from an unchallenged monopolist, very little technical change is to be expected".[243] Hård also argued that the most conducive organisational form for the promotion of innovation was *not* perfect competition, but one featuring uneven power distribution, and some barriers to entry:

> Highly asymmetric and stable power relations are, generally, detrimental to technical change ... perfect symmetry (or, in economic terms, perfect competition), is however, also disadvantageous to change. Compared to a society in which one group is totally dominant or an arena in which power is equally shared, *it is more likely that technical change occurs in a society or an arena in which power and influence are unequally distributed among a relatively large number of agents* ... Industries with moderate concentration or barriers to enter tend to foster a higher level of innovative activity.[244]

Hård argued that economic and social conflict perspectives on technological change were by no means incompatible – indeed, he stated, "because economic competition is one form of conflict, a social conflict approach should not be seen in opposition to economic explanations".[245] However, he added that economic explanations alone were unable to explain certain important features of technological change, such as the bias towards labour-saving innovations in Western technology. A social conflict approach, by contrast, drew attention to non-economic factors, such as labour unrest, as a motivation for change. By stressing the conflicts of different interest groups, he argued, this view allowed innovation to be seen not only as an outcome of market competition:

> The ability of a society to favor technical change is a result of conflicts taking place in a large number of arenas and concerning not only monetary gains but also property rights and the control of production processes ... as well as political power and authority.[246]

As well as conflict associated with labour unrest, Hård also suggested that "technological change is often driven by professional 'status groups' fighting for influence and control".[247] This was often a result, he argued, of the asymmetries within and between professional groups such as engineers and managers. Hård also stated that "latent conflicts may become manifest when new technical opportunities appear", and that the introduction of new techniques may be promoted by certain professional groups, in order

---

243 ibid:418, 423

244 ibid:422-3. Emphasis in original

245 ibid:422 He also suggested that a social conflicts might be of some value to evolutionary economic theories, in that they could be seen to influence a firm's search and selection processes (ibid:422).

246 ibid:418

247 ibid:423

to gain "positional advantage".[248] He concluded that the social conflict perspective was a useful means of revealing the ways in which "technology is applied and technological change is fostered by groups to preserve or alter social relations ... [and] governed by the interests and ideas of certain groups in society".[249]

2.5.3 Donald MacKenzie's Historical Sociology of Technology

In his 1990 book *Inventing Accuracy*, Donald MacKenzie presented a detailed account of the evolution of nuclear missile guidance technology.[250] In the course of the study, MacKenzie outlined his *historical sociology* analytical perspective on technological change, the aim of which, he stated, was to understand technology "as a historical product and social creation".[251] Like Hughes, MacKenzie was critical of narrow 'internal' histories of technology – he argued that analysts who adopted such an approach typically assumed that technology developed along 'natural' pathways in response to technical developments – an essentially technological determinist view. Alternatively, he added, military technology was often studied as a direct response to government policy – a political determinist view. Both approaches, he stated, failed to consider the complexity of technological change. MacKenzie was also critical of Winner's suggestion of the autonomy of nuclear technology; he stated that "the nuclear world ... is not the product of technology developing autonomously ... a technology is not social up to the point of invention and self-sustaining thereafter. Its conditions of possibility are always social".[252]

In outlining his own approach, MacKenzie stated that he aimed to view technology as "the product of a complex process of conflict and collaboration between a range of social actors including ambitious, energetic technologists, laboratories and corporations, and political and military leaders and the organizations they head ... [technology] has been a shaping force, but has itself been shaped".[253] He then went on to justify the need, in striving for a more informed analysis of technology, of both *historical* and *sociological* perspectives.

---

248 ibid:428

249 ibid:409

250 Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, Cambridge MA, MIT Press, 1990. See also D. MacKenzie, 'Towards a Historical Sociology of Nuclear Weapons Technologies', in N. P. Gleditsch and O. Njolstad (eds.), *Arms Races: Technological and Political Dynamics*, Oslo and London, Prio and Sage 1990

251 MacKenzie, *Inventing Accuracy*, op cit:2

252 ibid:4

253 ibid:3

In justifying the historical analysis of the evolution of technologies, MacKenzie argued that case studies of the development of one particular technology project typically restricted their consideration of events to just a few years, and treated as constant those more slowly evolving forces. By freezing time' in this way, he stated, case studies tended to omit consideration of a "key category of political actor, the organizations within which such technical changes take place".[254] To avoid this, he claimed, a historical perspective was necessary – to unfreeze time, and view the present "not in isolation from the past but as a moment in a continuing process".[255]

A sociological perspective, MacKenzie stated, was clearly necessary, given the wide range of 'social' influences on technological change:

> Technological change is simultaneously economic, political, organisational, cultural, and legal change, to enumerate just some of the aspects of 'the social' ... Changes in technology go hand-in-hand with changes, small and large, in the preconditions of their use, in the ways they are used, and in the reasons for their use ... the way technology changes cannot be explained in isolation from the economic, political, and other social circumstances of that change.[256]

In addition, however, MacKenzie justified an explicitly sociological perspective as a response to developments in the sociology of scientific knowledge – he suggested that "if a sociology of scientific knowledge is possible, so should a sociology of technological knowledge".[257] Indeed, he added, such analysis was *necessary*, because of the special status awarded to technological knowledge and expertise:

> Along with scientific, mathematical, and medical knowledge, but no other areas, our society treats technological knowledge as a 'hard fact' ... it is ... a vital resource of technologists (as distinct from political leaders, generals, or corporate executives) that in questions of weapons design they are the arbiters of what is feasible as distinct from the 'softer' issues of what is acceptable, needed, or affordable.[258]

---

254 ibid:8

255 ibid:8

256 ibid:9. He added that "while social science disciplines contain useful resources to help flesh out the issues ... no single approach or framework has a monopoly on insight" (ibid).

257 ibid:10

258 ibid:10

Whilst recognising that technologists' capacity to 'speak for the facts' constituted was a vital resource in their negotiations with politicians, MacKenzie stressed that this 'hardness' was an illusion, and that, in principle at least, they were without exception open to challenge.[259] He declared that "there are always grounds for challenging any knowledge claim", and continued:

> Why some knowledge claims are challenged and some are not, and why some challenged succeed and some fail, thus become interesting empirical questions. Central to the answers ... are matters of the interests, goals, traditions, and experiences of the social groups (technological and other) involved ... and of the relative prestige and credibility of different links in the network of knowledge.[260]

MacKenzie emphasised that "technological knowledge ... is social through and through", and added that this was "an ineradicable aspect of all technological knowledge", even where there was no open technological controversy.[261] As a consequence, he added, analysts should avoid contrasting 'technical' and 'social' or 'political' reasons for the choice of a particular design or artifact, or explaining choices of technology in terms of their inherent 'technical superiority'.[262] He added:

> Technical reasons for a course of action, technical superiority, and technical efficiency are all vitally important; in practice, they often seem sufficient to determine a given outcome. But it is important, as far as possible, to investigate why a given technical reason was found compelling, when, abstractly, it could have been challenged; and to ask what counts as superiority and efficiency in particular circumstances.[263]

At the end of *Inventing Accuracy*, MacKenzie reflected on the process of change in missile guidance systems, and on the more general insights missile technology offered into technological change. He argued that his evidence undermined both technological and political determinist notions, and that whilst "manifestations of technological determinism are everywhere to be found in discussions of the arms race", they were often used as a resource for those who wished to justify development.[264] He pointed out that both the opponents and proponents of developments typically engaged in debates on

---

259 ibid:417. The 'hardness' of certain scientific and technical facts was recently reasserted by Walter G. Vincenti in 'The Technical Shaping of Technology: Real-World Constraints and Technical Logic in Edison's Electrical Lighting System', *Social Studies of Science*, Vol.25, pp553-574, August 1995

260 MacKenzie, *Inventing Accuracy*', op cit:10-11

261 ibid:11

262 ibid:11

263 ibid:11

264 ibid:383. A number of analysts have analysed the political uses of technical expertise. See, for example, Dorothy Nelkin, 'The Political Impact of Technical Expertise', in Boyle, G., Elliott, D., and Roy, R. (eds.), *The Politics of Technology*, London, Longman/The Open University, 1977, pp189-205. Here, Nelkin stated that "developers seek expertise to legitimize their plans and they use their command of technical knowledge to justify their autonomy ... the extent to which technical advice is accepted depends less on its validity and the competence of the expert, than on the extent to which it reinforces existing positions." (ibid:202).

deterministic terms – for example, in identifying a need to resist or follow "technological imperatives". He concluded that "the single most important lesson" to emerge from his analysis was the "fallacy of ... technological determinism ... technological change is social through-and-through. Take away the institutions that support technological change of a particular sort, and it ceases to seem 'natural' – indeed it ceases altogether".[265]

MacKenzie then turned to a consideration of mature technologies. It was with these, he stated, that the notion of technological autonomy was most powerful – since "here we do typically find the continuous, predictable, apparently inexorable technological change ... the phenomenon that gives the notion of a 'natural trajectory' of technology its plausibility".[266] Whilst he recognised the continuity of change in mature technologies, MacKenzie rejected autonomous or natural trajectory notions to explain this. Rather, he argued, this reflected the dependency of even mature technologies on their surrounding institutions. Different institutional settings with different priorities gave rise to very different technologies – civil guidance technologies, he pointed out – developed in an institutional setting which emphasised reliability and economy above extreme accuracy – had evolved quite differently to their military counterparts. He concluded that "what appears to be a natural trajectory ought instead to be seen ... as an institutionalised pattern of predominantly incremental technological change involving, centrally, a self-fulfilling prophecy".[267]

Like Hughes, MacKenzie emphasised that technological continuity was maintained through the identification of barriers to progression, and on painstaking efforts to remove them – a process which gave rise to a pattern of incremental technological change, often then extrapolated into the future.[268] As he pointed out, however, such extrapolations were based on the assumption of continued institutional support – in particular "the existence of a relatively stable organisational framework within which the technological change

---

265 MacKenzie, *Inventing Accuracy*, op cit:384. He added that his study suggested that technological change was as much a matter of "social engineering" as "technical engineering", and added that this social engineering took different forms in different situations: for developments already recognised as desirable, it amounted to a persuasion of *possibility* and *practicability*, in others however, it also involved the persuasion of *desirability* (ibid:384).

266 ibid:385 The term "natural trajectory" was first used to describe the stability and conservativeness of much technological change by R. Nelson and S. Winter, as part of their theories of *evolutionary economics* (R. Nelson and S. Winter, *An Evolutionary Theory of Technological Change*, Cambridge MA, Harvard University Press, 1982). In evolutionary economics, an innovating firm is conceived of as behaving like an organism constantly under threat, using whatever means – particularly new technology – to perpetuate its existence and growth. Nelson and Winter suggested that at any given time, firms are seen to operate on a natural trajectory common to their industry, within which they have scope to develop their particular strategy and competitive advantage. Changes in the trajectory occur as a response to changes in the socio-economic conditions under which the firm operates. Nelson and Winter referred to this as changes to the firms' *selection environment*. (see Nathan Rosenberg, *Inside the Black Box:Technology and Economics*, Cambridge University Press, 1982, especially pp3-33:'The historiography of technical progress'; Chris Freeman, *The Economics of Industrial Innovation* ,London, Frances Pinter, 1982 (2nd Edition), especially Chapter 1 pp3-26:'By Way of an Introduction'; Norman Clark, *The Political Economy of Science and Technology*, Oxford, Basil Blackwell, 1985; Rod Coombs, Paolo Saviotti and Viv Walsh, *Economics and Technological Change* , Basingstoke, MacMillan, 1987)

267 ibid:385-6

268 ibid:386

takes place ... [and] the channelling of resources to support this".[269] He then considered the conditions that had supported the "institutionalization" of technological change in the case of missile guidance technology. He identified the long-standing stability of the various military and technological institutions involved, and also sustained state interest in enhanced missile accuracy, sufficient to secure continued resource provision. He claimed that "if that [state] interest had not existed, the technological trajectory ... would have ceased".[270]

However, in addition to organizational and financial support, MacKenzie also identified a self-fulfilling belief at the heart of institutionalised technological change. He stated that "organisations are created and sustained, and resources flow, to the extent that it is believed that the predicted change in technology will become, or at least has a chance of becoming, a reality".[271] He added that, by using their expert knowledge, technologists attempted to maintain the "credibility of the prophecy" to politicians and policymakers. If the credibility of this prophecy was successfully established and maintained, he argued, it became essentially self-fulfilling:

> To think of a matter of technological change as a 'natural trajectory' is to miss everything that is interesting about it and which makes it possible: the interplay of interests, the flow of resources, and the credibility of predictions. The reason why a pattern may nevertheless appear natural ... lies in the self-fulfilling nature of the prophecy at the core of a trajectory. If it comes to be believed that there is only one way to advance a technology, then that one way has at least a chance of becoming a reality. The others do not, and soon their disadvantage may become irreversible.[272]

On a more theoretical theme, MacKenzie then went on to consider the difficulties confronting the articulation and analysis of the various influences on technological development – in particular the problematic issue of technological and social boundaries. He argued that his research offered support for the view that there was no analytical separation to be drawn between 'technology' and 'society':

> The view of technology as an external, autonomous force cannot be sustained ... The political, organisational, economic, and legal circumstances – the 'social' circumstances – of technological development, shaped that development from its most general patterns to its most specific details.[273]

---

269 ibid:386-7
270 ibid:387
271 ibid:387-8
272 ibid:391. MacKenzie suggested that a particular technological trajectory could be "unpicked" by comparing it to other major forms of similar technologies, or by cross-national comparison (ibid:392).
273 ibid:411

At the same time, he stated, whilst technology was not an independent cause, neither was it a "dependent effect", called into being to serve a socially-defined need.[274] Indeed, he added, in certain radical cases of innovation, the 'need' was often constructed at the same time as, or even subsequent to, the introduction of the technology itself. MacKenzie concluded that no separation between technical and social influences was tenable, and he expressed support for actor-network and constructivist analysts who adopted the use of more abstract terms such as 'network' and 'system' to emphasise their interconnectedness:

> Technology ... is not above politics as an autonomous determining factor, nor beneath it as a dependent effect, but part of it. Furthermore, as we enter the black box we find that the distinction between politics and technology becomes harder and harder to make ... To that extent, therefore, I am wholly in sympathy with the argument that it is too weak a position even to see technology and politics as interacting: there is no categorical distinction to be made between the two. The web has no intrinsic seams.[275]

MacKenzie stressed, however, that "we cannot stop with that observation"; he recognised that boundaries between technological and other social domains *were* constructed and institutionalised. Indeed, he added, those involved in technological change actively seek to *maintain* such boundaries: "out of the seamless web, participants do construct relatively separate spheres of the 'technical' and 'political'. It is a distinction central to how they talk ... [and] central to their success or failure".[276] He then considered the various ways in which this separation was maintained. In part, he stated, this was achieved through the division of labour, which meant that other than the 'heterogeneous' activities of a few system builders, technologists were largely able to get on with exclusively 'technical' work, and to leave 'politics' to others.[277] He also suggested that there was a "pervasive way of thinking about technology that lends itself to the maintenance of separate spheres. This involves seeing politics as intruding on technology either when there is no single best technical solution, or when the best solution is not adopted".[278] In this way, MacKenzie observed, technologists often blamed the failure of technological projects on political interference. On the same theme, he added:

> Perhaps the most important reason for the separation of technology and politics is that technologists and program managers work hard to maintain it. It is greatly in their interests ... for their sphere of activity to be seen as one of purely technical work and technical decisions. Program managers,

[274] ibid:411-2
[275] ibid:412-3
[276] ibid:413
[277] ibid:413
[278] ibid:413

in particular, try to shape this work and those decisions so that the separation will be maintained.[279]

MacKenzie saw this effort on the part of technology program managers as a response to the perceived threat of interference from the political system. By 'black boxing' their projects, he argued, program managers aimed to ensure that the technological process itself was left as an essentially 'autonomous' realm for technologists – in other words, "to smoothly supply the technical output that their environment demands, and thus to keep receiving the necessary input of resources ... without giving that environment reason to inquire into the details of the process".[280] He added that the desire to keep the black box firmly closed typically resulted in a reluctance to adopt radical technical options or unfamiliar project goals – a "pervasive conservatism on the part of program managers" – which was sometimes inappropriate to the circumstances they faced.[281] He concluded that "technology is shaped so as to maintain the separation between technology and politics".[282]

Elsewhere, MacKenzie has given particular consideration to the role of financial and economic criteria in shaping technological change. A number of technology studies analysts – whilst giving detailed attention to various political and institutional interests – leave 'economic forces' aside as an independent force outside the scope of social influence. Hård, for example, in his consideration of the role of social conflict, conceived of the "economic influence" as a parallel force operating alongside political and institutional interests (2.5.2). As MacKenzie and Judy Wajcman pointed out, however, the 'economic' influence on technological change is *itself* socially constructed and maintained:

> The social shaping of technology ... [occurs] both directly – as when the maintenance or creation of a desired social relation entered into the choice of technologies – and indirectly – as when prevailing social relations affected the framework of costs within which the economic calculations were performed ... *The economic shaping of technology is, in fact, the social shaping of technology*.[283]

[279] ibid:414

[280] ibid:414

[281] ibid:415

[282] ibid:415. MacKenzie pointed out that the efforts of technologists to black-box their programs presented analytical problems for constructivism – in particular Pinch and Bijker's call to identify the various 'relevant social groups' associated with alternative technological designs, since, as he stated "technology may be shaped specifically so as to prevent this" (ibid:416).

[283] Donald MacKenzie and Judy Wajcman, *The Social Shaping of Technology*, op cit:23,15; emphasis added.

In a more recent paper, MacKenzie commented on the importance, for technology studies analysts, of giving consideration to this 'social construction' of financial criteria applied to technology choices – what he referred to as *ethnoaccountancy*, or "the study of how people do their financial reckoning, irrespective of our perceptions of the adequacy of that reckoning".[284] He added that "the general issue of whether accounting practices highlight one particular class of cost, thus channelling innovation towards the reduction of that cost, is of considerable significance ... ethnoaccountancy is one aspect of the much larger topic we might call the construction of the economic".[285] As an example its importance, he suggested – like Russell – accounting practices which "highlighted" labour costs might act to accelerate mechanisation, whilst presenting a barrier to capital or energy-saving technologies.

For MacKenzie, ethnoaccountancy was an area which had been largely neglected by mainstream economics and sociology. At the same time, he argued that it offered a means to further the convergence between recent micro-social and micro-economic analyses of technological change:

> Studying how people actually do the financial reckoning of technological change would bring together the economist's essential concern for the financial aspects of innovation with the sociologist's equally justified empiricism ... ethnoaccountancy would not be a marginal enterprise ... but ought to throw light on central questions such as the practical definition of profit and the relative rate of technological change in different historical and national contexts.[286]

On the convergence of the sociology and economics of technological change, MacKenzie went on to suggest that recent economics and sociological methods were approaching the same subject from opposite directions, and with different analytical strengths. Whereas economics was essentially concerned with the analysis of stable networks, the attention and methods of sociology (specifically microsocial constructivism) were oriented towards instability.[287]

---

284 Donald MacKenzie, 'Economic and Sociological Explanation of Technical Change', in *Technological Change and Company Strategies: Economic and Sociological Perspectives* , Rod Coombs, Paolo Saviotti, and Viv Walsh, (eds.) London, Academic Press, 1992, pp25-48

285 ibid:37

286 ibid:40

287 ibid:38-39

2.5.4 Arie Rip and René Kemp's Technological Regimes and Radical Innovation

In a review of various theories of socio-technical change, Arie Rip and René Kemp called, like Sørensen and Levold (2.4.4), for an analytical focus on the intermediate meso-level.[288] Rip and Kemp conceptualised the meso-level in terms of technological *regimes*, which they described as a "stabilized interdependencies ... [including] a complex of engineering practices ... technologies ... skills and procedures ... embedded in institutions and infrastructures".[289] They added that "regimes are intermediary between specific innovations ... and overall sociotechnical landscapes. They embody dynamics at the meso-level".[290]

For Rip and Kemp, the concept of regimes provided the basis for a theory of sociotehnical change in which technological novelty evolves within existing regimes starting at the micro-level of local practices. As this novelty spreads and becomes embedded, it may lead to a change of regimes, or even, in some cases, transformation of the wider 'sociotechnical landscape'. Rip and Kemp added that only a few particular innovations – such as the computer – were capable of sociotechnical landscape transformation.[291] They also argued that the building-up a 'constituency' for change within regimes at the intermediate meso-level was critical to the success or failure of technological innovations. In this sense, meso-level regimes acted as conduits between the creation of novelty at the micro level, and the establishment of higher-level sociotechnical landscapes. As a consequence, they argued, neither micro- nor macro-level analytical perspectives could properly account for technological change; rather, "[the] technological regime is the necessary entrance point".[292]

Rip and Kemp went on to give particular attention to the circumstances under which technological novelty, developed within existing regimes, could go on to transform regimes, and possibly landscapes. They stated that "[the] introduction of novelty has been studied in great detail, but ... for the question of success, however, it is the *adoption* of novelty which is decisive, not its introduction".[293] A key part of this process, they suggested, was the emergence of *irreversibility* in technological systems as they become

288 Arie Rip and René Kemp, 'Towards a Theory of Socio-Technical Change', limited circulation monograph, School of Philosophy and Social Science, University of Twente and MERIT, University of Limburg, May 1996. Published in edited form as Chapter 4 of *Human Choice and Climate Change*, prepared by Batelle Pacific Northwest Labs., Washington DC.

289 ibid:19

290 ibid:19

291 ibid:19

292 ibid:66

293 ibid:20. Emphasis in original.

stabilised. Rip and Kemp charted this process in terms of "the multi-layered backdrop of novelty and irreversibility".[294]

In a later part of their review, Rip and Kemp discussed in some detail the different conditions that gave rise to radical innovations. They distinguished here between "more or less stable situations, where the shape of technology can be explained inductively, as a continuation of ongoing development, and situations in flux, where predictability is much less".[295] They defined radical innovations as those which "challenge the existing paradigm or regime which ... gradually grow and see the paradigm replaced".[296] Within the overall process of radical technological change, they argued, the "conditions of challenge and overthrow" were more interesting than the source of innovation. Indeed, they suggested, the technological variety on which radical changes were built were often already available, but that a change in *selection environment* – such as was caused by war – was necessary for their deployment. Under such circumstances, they added, actors were forced "against their inclination" to look for novel solutions.[297]

Rip and Kemp also argued that 'outsider' institutions were more likely to be risk-taking in respect of radical innovations. For established organisations, they stated, "radical inventions may ... endanger current activities ... and for that reason be rejected or delayed".[298] They added that because existing 'leaders' were "locked into the earlier paradigm", then "thresholds are temporarily low when paradigms change, and windows of opportunity may be open for new participants".[299] At the same time, they pointed out that broader factors were important to the development of radical technology: "radical innovations can often not be sustained by traditional market mechanisms and firm strategies ... a series of steps are necessary ... including modifications in infrastructure which require institutional and regulatory changes".[300] In this context, they referred to the important role of government in "inducing a technological regime shift".[301]

A particular aspect of radical innovation highlighted by Rip and Kemp was the transfer of advances in technology – particularly engineering and materials – from one regime to another. They stated that "innovations which are radical for a regime may themselves have been constructed out of incremental use of various complementary technologies".[302]

[294] ibid:21
[295] ibid:45
[296] ibid:48
[297] ibid:48
[298] ibid:49
[299] ibid:54
[300] ibid:50
[301] ibid:59
[302] ibid:48

They went on to suggest conditions favourable to the development of radical innovations, such as the perception of a pressing technical or market problem which could not be met with available technology, and the reaching of technical limits or increasing marginal costs with existing trajectories. In this way, they observed:

> New technologies are always introduced *against the backdrop of existing regimes* and socio-technical landscapes. They do not come into the world with their possibilities well defined, rather they come into existing systems, and their success is in some way linked to structural problems or even crises of that system.[303]

In surveying a range of established social and economic approaches to the analysis of technological change, Rip and Kemp also offered some more general comments on the nature of technological change. Like MacKenzie and Law, whilst adopting a social shaping perspective, they recognised the distinctive influence of technological dynamics in the wider process of social change:

> Technical change has its own dynamics, somewhat independent from firm strategies and actor goals in general ... what is misleading is the assumption that technology is infinitely malleable, and that it is malleable by demand ... one should speak of the co-evolution of supply (and the technology behind the supply) and demand.[304]

They went on to make a statement on the limits of social science enquiry into the complex process of technological change. In doing so, they suggested some guidelines for the analysis of radical changes in technology:

> Explanations of the eventual shape of technology ... have the status of glosses on specific case studies, informed by general sociological theories. Much more than this may not be possible, given the complexities of technological development and its co-evolution with societal developments ... For hierarchies in flux ... prediction on the basis of internal characteristics is impossible ... in the end, the historian's art and the sociologist's analysis should prevail to trace and explain formative movements, critical junctures, and the reasons for the emergence of periods of relative stability ... It is difficult to do more than diagnosis, but ... it should be a historically informed diagnosis.[305]

Rip and Kemp concluded that "the multi-actor processes of technical and social adaption in which problems and conflicts are gradually overcome can be understood as a process of co-evolution of technology and society".[306]

---

303 ibid:75. Emphasis in original.
304 ibid:37-38
305 ibid:45-46
306 ibid:76

2.6 Summary and Research Design

2.6.1 Summary and Review

This chapter has presented a review the technology studies literature in accordance with what Street described as a "spirit of eclecticism" (2.1). It has been argued that, in the analysis of technological change that, as Sørensen and Levold stated, "a heterogeneous mix of historical, ethnographic, economic, and sociological competencies seems required" (2.4.3). This may be thought to be particularly appropriate for the British ESI privatisation case, which clearly involves interacting technical, economic, institutional and political forces.

To the extent that they are recurrent themes in the analysis of technology, autonomous and determinist notions seem to capture something of the experience of technological change (2.2.1, 2.2.2). At the very least, their persistence – especially as applied to energy technologies – requires some consideration in the context of the present study. Whilst many analysts adopting autonomous and determinist views are content to argue on the basis of a naïve notion of technology, a more elaborate defence of autonomous concepts has been offered in recent years by Langdon Winner (2.2.2). Winner argued that once the development of 'inherently political technologies' such as nuclear power was underway, they became essentially autonomous: technical criteria became dominant over economics and politics, and they became institutionally and financially self-supporting. Whilst he explored the autonomous thesis at some length, Winner retained a perspective on technological change – featuring high-level generalisations and presumptions of intent – that, as Misa pointed out (2.4.4), is characteristic of analysts holding similar such views, such as Ellul, Galbraith and Mumford. As many critics of autonomy and determinism have observed (2.2.3) such a perspective is an inherently limited basis for the examination of the social process of technological change, and it is evident that to be of real value to a detailed case-study analysis, any approach must be based on socially-shaped perspective. Nevertheless, Winner's suggested autonomy of nuclear power offers a clear thesis for the general direction of technological progress, and this will be returned to for consideration in the context of the present case in Chapter 7.

A range of concepts and models adopting a socially-shaped view of technology were considered in the rest of the chapter. Many of these offer similar insights and observations on the process of change. Arnold Pacey's *technology-practice* approach (2.2.3) highlighted the close association of technical and organisational form, the irregular pace of change, and the existence of critical periods during which changes in technological and social form progress rapidly together. Like MacKenzie and others, Pacey considered the political and institutional use of technological expertise, particularly way in which the use of terms such as 'technological imperative' can serve technocratic interests. Pacey also identified (again in common with many others) the close association between bureaucratic authority – such as that of the Central Electricity Generating Board – and conservative and incremental change. In all of this, Pacey's analysis is of considerable relevance to the British ESI case studied here.

Thomas Hughes provided an empirically and conceptually rich account of the early development of electricity supply technologies (2.3). Although he made only a "loosely structured" use of theory, Hughes' sociotechnical systems model offers a number of valuable insights into the process of technological change. In common with others (see especially the comments of Paul N. Edwards in 2.2.3), Hughes drew attention to the role of technology as an *embodiment* of prevailing economic, institutional, and political values (2.3.1). In this area, Hughes showed sympathy with Winner's view of the inherent politicisation of technological artefacts. However, where Winner went on to make 'stronger' claims concerning the autonomy of technology, Hughes instead characterised the influence of sociotechnical systems in terms of a socially constructed and maintained *momentum* (2.3.2). He also repeatedly emphasised that even in the most powerful systems, this momentum was capable of being overturned by sudden changes in environmental circumstances (2.3.3).

A number of analysts have pointed to weaknesses associated with Hughes' systems approach (2.3.4). In part, these criticisms are associated with the difficulties associated with the demarcation of the 'system' from its 'environment' (2.3.3). This was highlighted, for example, by Michel Callon, in distinguishing the systems approach from his own actor-network model (2.4.1). The separation and categorisation of influences in the analysis of technology is unavoidably problematic: if too strictly applied, it results in a functionalist and determinist perspective; Mikael Hård has been the most outspoken critic of Hughes in this regard (2.3.4). Hughes himself, in his later work, recognised the problems of separating system and environment, and called for a "seamless web" view of technology and social relations (2.3.3). At the same time, however – Bijker and Law pointed out (2.4.1) – the identification and characterisation of distinctive influences on technological change is an essential and unavoidable part of the analytical process, and in the gaining of insight into an otherwise incomprehensible process. In this respect, much of the analytical strength of *Networks of Power* – such as Hughes' observations concerning technology as both a cause and effect of social change, and also on the similarities and differences between systems developed in different regions – is *predicated* on the demarcation of the sociotechnical system and its environment, and between internal and contextual influences on change. This is confirmed by the absence of similar such insights arising from constructivist and actor-network approaches. Similarly, Hughes' insight on the unanticipated consequences of technological development is based on his identification of a *technical core* of sociotechnical systems, and his suggestion that this may carry with it unpredictable consequences, particularly when transferred to novel environments (2.3.2). In addition, as MacKenzie pointed out, it is undeniable that very real and observable divisions between technological and other social spheres *are* constructed and maintained (2.5.4). For the present study, I have judged that the analytical strength of concepts developed in *Networks of Power*, such as momentum, the technical core, and contextual influences on change, is sufficient to justify their cautious use. Again, I return to these issues in Chapter 7.

Another common criticism of the systems approach – its focus on system building and particularly on the perspective of the system builder (2.3.4) – is more problematic for the present study. For Hughes' analysis of the development of early electric power systems – which was characterised by progressive expansion and centralisation – it may be thought of as appropriate. As critics such as Misa and Rudig argued, however, such a perspective tends to interpret the process of change exclusively in terms of the development or retardation of the system and the efforts and intentions of the system-builder, and fails to give adequate attention to alternative technological possibilities (2.3.4). In his later work, Hughes himself recognised the difficulties of applying his model to declining or radically reconstructed systems (2.3.3). For the present case – characterised by radical institutional reorganisation and dramatic changes in technological form – the assumption of a central control and direction of the system is inappropriate. Indeed, as Summerton suggested, a mature network industry may be better characterised in terms of mutual interdependencies between a number of different powerful groups and individuals (2.4.2). I therefore chose to avoid a system building perspective here.

As even their critics have acknowledged constructivist and actor-network approaches provide useful insights into the process of technological change. In particular, both offer powerful refutations of autonomous and determinist notions (2.4.3). Social constructivism focuses attention on how competing technological designs act as representatives of particular values and interest groups, and how the eventual emergence of a dominant design represents the triumph of certain groups and interests over others. In introducing the constructivist approach, Bijker and others emphasised the interconnectedness of technical and social change (2.4.1). However, by seeing the process of change as primarily a response to the preferences of different social interest groups, constructivism tends to underplay the influence of technical dynamics themselves in the innovation process, resulting in what Winner described as "social determinism" (2.4.3).

Actor-network theory, by contrast, places technical factors at the centre of analysis, and as Callon suggested, it is a valuable counter to the limitations of conventional sociological treatment of technological change (2.4.2). In particular, actor-network theory forces recognition of the influence of technical elements in the process of change, and on the interdependency of 'technical' and 'social' elements. Nevertheless, both constructivist and actor-network approaches offer limited analytical perspectives. As both Williams and Russell, and Sørensen and Levold, pointed out (2.4.3), such approaches tend to exaggerate the influence of microsocial actors, and focus on observable actions, rather than less obvious structural and institutional aspects of change. Sørensen added that micro-level approaches focusing on 'the laboratory' are inappropriate to the energy sector, where technology choices are greatly influenced by the institutional interests of large generators and government (2.4.3). Both constructivism and actor-network theory also share the weakness of Hughes' systems approach in viewing the process of change almost exclusively from the perspective of those trying to establish particular technological projects – whether known as *relevant social groups*, *engineer sociologists*, or *heterogeneous engineers*. Again, in this aspect Summerton's emphasis of the interdependency of organisations in the case of grid-based technologies is of more relevance for the present study (2.4.2).

Law and Callon's concept of *local* and *global* networks goes some way to overcome the failure of the actor-network approach to discriminate between influences at different levels of aggregation and the relative power of different interests (2.4.2). (Bijker's attempts to graft structural elements onto the constructivist perspective (2.4.1) have been less successful in this regard.) Nevertheless, to the extent that they emphasise action and choice rather than structure and inertia, both constructivist and actor-network approaches are less appropriate than systems theory as applied to mature industries featuring entrenched institutional power. These weaknesses are of particular importance to the present study of radical changes affecting a mature industry – a process greatly influenced by established organisational interests. I therefore chose not to adopt a constructivist or actor-network approach for the basis of this study, although they will be returned to for consideration in the context of the present case in Chapter 7.

In response to the perceived shortcomings of both micro- and macro-level perspectives on technological change, a number of analysts, such as Sørensen and Levold, and Misa, have recently argued that emphasis be given to the intermediate meso-level (2.4.4). As Stewart Russell's study of combined heat and power technology demonstrated (2.5.1), a detailed consideration of institutional interests is an essential part of understanding technological change in the British energy sector, and it is a focus that I have attempted to maintain throughout the present study. Russell argued that although institutional affiliations to particular technologies were contingent and variable with time, the general direction of change in the British energy technology had reflected a consolidation of the dominance of producer-organisations. The continued validity of these observations in the course of ESI privatisation will be considered in Chapter 7.

For Mikael Hård, the consensus-orientation of both systems and constructivist approaches required, in response, an emphasis on the importance of social conflict in the process of technological change (2.5.2). To the degree to which it involved the confrontation of opposing interests, the privatisation of the British ESI is well suited to Hård's explicit focus on conflict. Particularly pertinent aspects of Hård's approach for the present case are his suggestion that technological change is most encouraged where power is unevenly distributed, and where there are moderate barriers to entry. (Like others, he argued that monopoly power was associated with incremental and conservative innovation.) In addition, Hård suggested that technological change could enable latent conflict between institutions or professional groups to become manifest. Although these are valuable and relevant points for the present case, an exclusive interpretation of technological change in terms of social conflict provides a limited and one-sided perspective. In particular, despite Hård's arguments to the contrary (2.5.2), such a focus would tend to underplay competitive market forces in technology development and choice. I have therefore used Hård's ideas here as an adjunct to other approaches, such as Hughes' systems approach, which Hård rightly identified as weak in its treatment of conflict.

Donald MacKenzie's *historical sociology* approach (2.5.3), although designed for the analysis of the development of a military technology, offers a number of valuable insights for the present case. (The suitability of MacKenzie's approach here reflects the high degree of politicisation of both energy and military technologies.) In his 'soft' use of theory, and in the richness of his empirical investigations and analytical insights, MacKenzie's approach bears some similarity with that of Hughes. Although he studied a contemporary technology, MacKenzie, like Hughes, stressed the importance of a historical perspective in order to understand the changing pattern of organisational interests involved in technological change. However, MacKenzie went further than Hughes in exploring the institutional use of technical knowledge and expertise, and in stressing the need for analysts to test the validity of technical knowledge claims.

MacKenzie also made a more powerful rejection of autonomous and determinist notions than Hughes, and where Hughes discussed the action of the technical core and the internal momentum of well-established technological systems, MacKenzie instead emphasised the dependence of such systems on supportive institutional and financial conditions. In addition, he explored the apparent autonomy of mature systems in terms of an institutionalised self-fulfilling prophecy. He suggested that technologists were closely involved with constructing and maintaining the credibility of such a prophecy, both in terms of carrying-out appropriately restricted research and development work, and also in their use of technical knowledge and expertise in promoting their own interests.

Whilst he rejected determinist and autonomous notions, and expressed sympathy with the 'seamlessness' of actor-network and constructivist approaches, MacKenzie – unlike many other social shaping analysts – also made explicit recognition of the distinctiveness of technological dynamics and institutions. In-part, he found explanation of the distinctiveness of technological and political dynamics in terms of the vested interests on the part of technological programme managers – observing that "technology is shaped so as maintain the separation between technology and politics". In all of this, MacKenzie's approach is of considerable value to the present case. In analysing recent changes to the British ESI have therefore attempted to maintain both historical and sociological perspectives throughout. In Chapter 7, some more specific aspects of MacKenzie's analysis are considered further.

MacKenzie also emphasised the need to adopt a socially-constructed view of economic and financial influences on technological change. In the literature review presented above – and in the presentation of the British ESI case in subsequent chapters – there has been no separate consideration of the economics of technological change. Rather, I felt that for the present study, it has been more appropriate to discuss economic factors alongside technological, institutional and political influences, within an overall social shaping of technology perspective.[307]

[307] For a more economic/financial examinations of British ESI privatisation, see George Yarrow, 'Privatization, Restructuring, and Regulatory Reform in Electricity Supply' in Bishop M., Kay J., Mayer C., (eds.), *Privatization and Economic Performance*, Oxford, Oxford University Press, 1994, pp62-88. Given the wide range of possible social science approaches to the ESI privatisation case, it was clearly necessary to restrict the range of research questions to those pertinent to a technology studies perspective. For more general treatments of ESI privatisation, see Surrey, J. (ed.),*The British Electricity Experiment: Privatisation: The Record, The Issues, The Lessons*, London, Earthscan, 1996; MacKerron, G. and Pearson P., (eds.) *The UK Energy Experience: a Model or a Warning?*, London, Imperial College Press, 1996; Henney, A., *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994

As MacKenzie and Wajcman emphasised, from a technology studies perspective, it is important to recognise that "the economic shaping of technology is, in fact, the social shaping of technology" (2.5.3). Similarly, Stewart Russell, although he conceded that financial/accounting criteria played a powerful role in technology choice, rejected any straightforward economic determinism, adding that "there was no single method or universal set of criteria. The terms of appraisal were clearly dependent on the performing institution and the precise constraints on it" (2.5.1). MacKenzie went on to propose the detailed analysis of "financial reckoning", or ethnoaccountancy, as a means of revealing the institutional, cultural, and political interests.[308] As will be discussed in later chapters, the reorganisation of the British ESI ahead of privatisation was associated with a radical change in the financial appraisal of generation technology. Whilst this process is discussed throughout the ESI case, as presented in Chapters 4, 5, and 6, it is returned to for separate consideration in Chapter 7 (7.5.3).

Like a number of other analysts, Arie Rip and René Kemp offered a perspective on technological change focussed on the intermediate meso-level. In their case, this was conceived in terms of socio-technical regimes (2.5.4). Rip and Kemp's emphasis on the importance of intermediate-level dynamics and institutions for the successful deployment of micro-level novelty has been implicitly followed in the analysis of the ESI case presented here. Furthermore, like Rip and Kemp, I have felt that in cases of radical technological change (of which the present case is an example), it is the *deployment* of technology, or the "conditions of challenge and overthrow", which is of more interest than the source of novelty itself (2.5.4). The focus in what follows has therefore been primarily on the deployment of different forms of generation technology within the particular setting of the British ESI. I have also followed Rip and Kemp's guidelines for the analysis of technological change in periods of flux, and I have accepted their cautions on the inevitable limitations on social science inquiry in such circumstances. More specific aspects of Rip and Kemp's characterisation of radical innovation are returned to in Chapter 7 (7.5.4), for consideration in the context of the British ESI privatisation process.

308 A number of independent analysts argued that during the early-1980s, the CEGB presented its accounts in a form favourable to nuclear power. See J. W. Jeffery, 'Dubious Economic Advice: The 'decision' on Sizewell 'B'', *Energy Policy*, Vol.16, No.5, pp516-523, October 1988

2.6.2 Research Design

The research methodology adopted here developed from two basic concerns: firstly, the underlying analytical issues concerning the role of technology as agent and effect of socio-economic change, and secondly, the most appropriate means of approaching these concerns in the British ESI privatisation case. In practice, the research method emerged from the iterative interaction between my reading of the themes and concepts of the technology studies literature, as presented in this chapter, and my early investigations of the case. The eventual form of the research was settled only after a period of flux in which various possible approaches and methodologies were considered.

My early reading of the technology studies literature was concentrated on those analysts – such as Winner, Hughes and Russell – who had given particular attention to electricity generation technology. At the same time, I was also guided by a desire to address generic technology studies issues, such as technological autonomy and determinism, and the distinctiveness and conceptual 'separability' of technology as a force for socio-economic change. In addition, I was concerned to capture the way technology was implicated as both cause and effect in the reconstruction of the British ESI upon privatisation, and how various influences, each with distinctive origins and characteristics, had come together to shape the process of technological change in the industry.

Given my underlying concern to address the role of technology in the broader process of socio-economic transformation, I was drawn from the outset to those analysts – such as Hughes and MacKenzie – who seemed to offer a sufficiently broad conceptual framework with which to consider this question. In particular, I felt that Hughes' system/context model offered a means with which to consider the interaction of techno-economic dynamism with changing organisational and legislative context in the British ESI case.

As my reading of the technology studies literature continued, however, I became increasingly aware of criticisms of the contextual approach, and of the debate between constructivist/actor-network and contextual/structuralist theorists (as reviewed in 2.3.4, and 2.4.3, above). Emerging from these two 'schools' of technology studies – contextualism and constructivism – two distinctive research methods seemed to suggest themselves for the present case: firstly, in the actor-network tradition, a predominantly micro-level study of one or two individual generation technology projects; or secondly, in the structural/contextual tradition, an institutional/sectoral analysis of the political process of privatisation, and the role of generation technology within this.

Whilst my underlying theoretical concerns led me to favour the latter, sectoral analysis, I was also aware of the possibility of using a project-level study as a more accessible and achievable means of addressing broader issues. I therefore carried out research on two contrasting generation technology projects – the Dounreay PFR, and the Wilton CCGT plant – which together seemed to embody the stark differences in generation technology associated with the move from nationalised to privatised ESI.

In the course of this research (involving both on-site interviews and published/unpublished literature), I became aware of the limitations of an exclusively project-level approach. At both Dounreay and Wilton, I felt that, whilst project-level study gained access to particular technical, economic and institutional issues, it failed to capture other, underlying legislative and structural factors that related to the success or failure of particular forms of generation technology. Echoing Williams and Russell's criticisms of constructivism (2.4.3), I found that micro-social perspectives could not, on their own, provide a fully satisfactory explanation of the causes of change. Rather, I felt that many of the important changes were located somewhere within the political process of privatisation, and that the analysis of these changes required a wider sectoral and institutional focus.

In searching for an appropriate method with which to capture these dynamics (since my direct access to the individuals and institutions involved would clearly be restricted), I became aware of the resources offered by parliamentary papers, particularly House of Commons debates (Hansard), and the written and oral evidence submitted to various parliamentary Select Committee inquiries. The next stage of my research therefore consisted of a library-based review of official papers related to ESI, with a particular focus on the role of generation technology in the wider privatisation process. At the same time I carried out a review of other including industry/academic and technical/policy literature related to ESI privatisation. I also undertook a small number of additional personal interviews, to address themes where I felt that the official and published literature was weak.

In parallel with this heterogeneous fieldwork, I also continued to refine a heterogeneous analytical perspective. In particular, my research confirmed that the changes in generation technology in the British ESI associated with privatisation were an outcome of the interaction of 'top-down' changes in the organisational and legislative context of the industry, with 'bottom-up' developments in the technology and economics of generation. In addition, these dynamics were mediated at the intermediate meso-level by distinctive institutional interests. In searching for analytical insight into this complex pattern of influences, I returned to those analysts – such as Hughes and MacKenzie – who, whilst rejecting technological autonomy and determinism, recognised the analytical separability of influences on change, and the distinctive character of techno-economic dynamism alongside broader socio-economic context.

In summary, my research design emerged from the practical application of a range of technology studies concepts and methods to the particular case of British ESI privatisation. The result of this process was the employment of an essentially contextual rather than constructivist analytical framework. This choice reflected the complexity of causal factors in the ESI case – in particular, the interaction of bottom-up and top-down forces, mediated at he meso-level. It also related to my broad underlying concern with the role of technology in socio-economic transformation. At the same time, it was clear that the different approaches each had particular strengths and weaknesses, and that as MacKenzie stated, "no single approach or framework has a monopoly on insight" (2.5.3). I therefore felt that the British ESI case could be used to 'test' the different theories, to the extent that it offers supporting or undermining evidence.

Although the context for electricity generation technologies has changed considerably with privatisation, I felt that any understanding of the recent transformation of the industry required, as a starting point, a recognition of the fact that, as Sørensen and Levold stated, "the terrain ... has been thoroughly shaped by previous actions" (2.4.4). I have therefore found greatest sympathy with those analysts, such as Hughes and MacKenzie, who chose to adopt a broad-based historically informed social shaping perspective.

Neither Hughes nor MacKenzie made an extensive statement of their research method, but both suggested desirable elements of such an approach. Hughes, for example, highlighted the value of both inter-regional and inter-temporal comparison, arguing that "variations in the basic essentials often reveal variations in resources, traditions, political arrangements, and economic practices from one society to another and from one time to another".[309] Similarly, MacKenzie emphasised the importance of cross-national comparison: "a straightforward, though not failsafe, way of grasping the role of the social in technical change is to see how different societies develop the same technology".[310] MacKenzie also suggested the value, in uncovering social shaping, of comparing rival technical forms.[311]

---

[309] Thomas Hughes, *Networks of Power: Electrification in Western Society 1880-1930*, Baltimore, John Hopkins University Press, 1983:2

[310] Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, Cambridge MA, MIT Press, 1990:5

[311] MacKenzie stated that "unpicking the 'technological trajectory' of increasing missile accuracy, and comparing it to the other major form of change in inertial technology, together provide one window on the nature of technological

In the present study, rather than considering international comparisons of changes in generation technology, I have focused on the analysis of competing technical forms in the *British* ESI before, during, and after the privatisation process. In other words, I have concentrated on inter-temporal comparison and the analysis of rival technical forms as means of uncovering the social shaping of technology. The omission of international comparison – whilst inevitably restricting insight into the peculiarities or commonalities of the British case[312] – was a choice in part based on practical limits on what was achievable, but also on the unparalleled and highly contingent nature of British ESI privatisation, which meant that the process of change in the industry was inevitably a response to peculiarly 'local' circumstances. A focus on the main rival technical forms of electricity generation in the British ESI – as they shared similar changes to their economic, institutional, and political environments – therefore offered an appropriate means of analysing the social shaping of technology. This focus was encouraged by the presence of three major forms of large-scale electricity generation technology – coal-fired steam turbines, nuclear power, and combined-cycle gas turbines – each having distinctive histories, economic properties, and institutional and political affiliations.

The parliamentary papers provided a rich resource for a historical analysis of the changes affecting the industry as they unfolded, and gave otherwise unobtainable access to the most powerful industrial and political figures involved. By comparison, first-person interviews inevitably involved a retrospective retelling of events. In certain areas, however, such as the development and implementation of particular technologies, the parliamentary material was less strong, and I have relied here to a greater extent on my personally-conducted interviews and a range of specialist literature. Together these provided the opportunity to gain access to particular perspectives on change within the industry, such as specific company interests (as far as these were made available to me), and also to ask specific questions on issues that were not covered satisfactorily in the parliamentary committee inquiries. They also allowed me to focus in some detail on particular technological projects, in order to examine the working-out, in particular settings, of the various forces involved in ESI privatisation.

---

change" (ibid:392). At the same time, he conceded that "opening the 'black box' of technology in this way is no easy matter", and he added that it required from the analyst a detailed understanding of the technical field, and access to data of a kind difficult to obtain without in-depth interviewing of those involved (ibid:11).

312 A comparative analysis of liberalisation and privatisation in a number of European ESIs is offered by Atlé Midttun, (ed.), *European Electricity Systems in Transition: A Comparative Analysis of Policy and Regulation in Western Europe*, Oxford, Elsevier Science Ltd., 1997

In presenting the British ESI case, in Chapters 3 to 6, I have an essentially narrative approach, rather than an exposition of a particular theoretical position. I have therefore restricted my analytical observations in these chapters to a consideration, at the end of each chapter, of the various technical, economic, institutional and political influences on changes in generation technology. Following this, in Chapter 7, the theoretical concepts and models explored in the present chapter are returned to for reflection in the context of the present case.

CHAPTER 3:

GENERATION TECHNOLOGY

IN THE BRITISH ESI BEFORE PRIVATISATION

3.1 Introduction

This chapter traces the evolution of electricity generation technology within the British ESI, from its emergence in the late-nineteenth century, up to the period just before privatisation in the mid-1980s. Within the overall thesis, this review serves to place into context the more recent changes to the industry associated with privatisation. Indeed, rather than attempting a comprehensive history of the industry, I have highlighted certain developments which were to prove significant in the privatisation process. Particular attention has been given to episodes of significant changes in the technology of generation, such as the emergence of nuclear power in the postwar period. At the same time, consideration has also been given to the changing organisational form of the industry, and on the relationship between technology and organisation. In undertaking this, a range of official and parliamentary papers have been used to examine policy rationales, and political and industry debate at different points in the ESI's history. I have also drawn on a number of established histories of the industry.

I have adopted a basically chronological ordering of the chapter. Section 3.2 reviews development of generation technology in the British ESI before nationalisation in 1945. Section 3.3 reviews generation technology from postwar nationalisation up to the 1960s. Section 3.4 considers the period after 1970 up to the mid-1980s. Although it played only a very minor role in electricity generation in Britain before privatisation, gas turbine technology was central to the subsequent changes affecting the industry. Section 3.5 therefore reviews the development of gas turbine generation technology ahead of privatisation, both internationally, and in the British ESI context. Finally, Section 3.6 is a summary of the development of electricity generation technology in Britain, and a consideration of the various influences involved.

3.2 Generation Technology in the ESI before Nationalisation

3.2.1 Generation Technology in the early ESI

Unlike almost all previous innovations, electricity underwent systematic scientific study for many years before it was commercially developed.[1] However, despite its inherently superior transmissibility and transformability as compared to other forms of power[2], the early steps towards the commercialisation of electricity were hesitant and uncertain.[3] The first commercial generators were not introduced until the 1870s, for small-scale localised applications such as mining. The early generators were driven by established reciprocating steam engines. This was always something of a compromise, since conventional reciprocating engines ran at slow speeds, whereas to work most efficiently, electrical generators needed to be rotated at high speed. This was partly overcome by using drivebelts to multiply the speed of engine rotation, but drivebelts took up considerable space, and they could not be controlled accurately enough to prevent power surges and dips.[4]

In the late-nineteenth century, the technical and economic feasibility of large-scale electricity supply was greatly improved by the simultaneous introduction of two technologies – the steam turbine, and high voltage alternating current transmission.[5] The first practical steam turbine was introduced in 1884, by Charles Parsons of Newcastle.[6] Parsons also developed his own generator, and according to David Landes, "the two together ... made possible an efficient, large-scale electrical power industry".[7] The key technical feature of Parsons' turbogenerator was the feeding of high pressure steam into a series of turbine blade sets arranged along a single axis, coupled directly to the generator. This design offered a highly efficient means of transforming the thermal energy of steam into rotational motion, and the fast speed of rotation it provided was well-suited to electrical generators.[8] The first steam turbines in a public electricity utility were installed

---

[1] In this respect the ESI represents a fundamental change in the industrial economy for many observers. Lord Hinton, for example, claimed that "the scientific age may be said to have begun with electricity" (Lord Hinton of Bankside, *Heavy Current Electricity in the UK: History and Development*, Oxford, Pergamon Press, 1979:5)

[2] David Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*, Cambridge, Cambridge University Press, 1969:282

[3] Leslie Hannah, *Electricity Before Nationalisation: A Study of the Electricity Supply Industry in Britain to 1948*, London, MacMillan, 1979:1-2

[4] Bob Gordon, *One Hundred Years of Electricity Supply 1881-1981*, Hove, South Eastern Electricity Board, 1981:39

[5] I. C. R. Byatt, *The British Electrical Industry 1875-1914: The Economic Returns to a New Technology*, Oxford, Clarenden Press, 1979:108

[6] R. A. S. Hennessey, *The Electric Revolution*, Newcastle, Oriel Press, 1971:106

[7] Landes, op cit:278-9

[8] Hinton, op cit:20; B. Bowers, *A History of Electric Light and Power*, Stevenage, Peter Peregrinus, 1982:166

in Newcastle in 1890. As licensing agreements were struck with overseas electrical manufacturers, larger turbine-based power stations followed across Europe and the USA.[9]

Although they were inherently efficient, the earliest steam turbines offered no significant economic advantages over high speed reciprocating engines specifically designed for electricity generation, which had become standard in Britain by the 1890s. High speed reciprocating engines, however, were difficult to build in large sizes (above around 200kW), and more powerful reciprocating engines could only operate at much slower speeds, requiring the use of large generators for efficient conversion. The great advantage of turbines was to allow the use of much smaller generators, and as the demand for electricity grew in the early-twentieth century, the turbine came into its own as a capital-saving technology.[10]

A recurring theme in accounts of the early British ESI is the relative backwardness of the electricity supply infrastructure in Britain as compared to her major industrial competitors. Landes stated that "in the early decades of electric power, [Britain] was notorious for the diversity of her system of generation and the smallness of her central stations".[11] The relative underdevelopment of the early British ESI requires attention to what Henry Self and Elizabeth Watson referred to as "the particular constitutional and economic situation ... when the electricity supply first came into existence".[12] By the time electricity became a commercial prospect, Britain was already an urbanised industrial society, and thus potentially a large market for electricity. Yet, as Byatt pointed out, there were particular economic, institutional and political circumstances in Britain which made electricity less attractive than elsewhere, and which inhibited the relative growth of the British ESI.[13] Politically, the ESI emerged at a time of strong municipal authority power in Britain, as was manifest in the earliest legislation to address the industry. The 1882 Electric Lighting Act was closely modelled on earlier legislation for public service industries. It granted franchises to local suppliers for a fixed period, after which time the local authority was able to buy-out the franchise.[14] The Act reflected both municipal

---

9 Thomas P. Hughes, *Networks of Power: Electrification in Western Society 1880-1930*, Baltimore, John Hopkins University Press, 1983:211,235,454

10 Byatt stated that the cost of foundations and buildings for power stations using turbines was about half that for stations of similar output using reciprocating engines (Byatt, op cit:110-111).

11 Landes, op cit:434-5

12 Self, Sir Albert Henry, and Elizabeth M. Watson, *Electricity Supply in Great Britain: Its Development and Organisation*, London, Allen and Unwin, 1952:12

13 Britain had a well established industrial and urban infrastructure: gas lighting was relatively cheap, steam railways were well-developed, and the British economy was dominated by coal mining and cotton textiles – established industries which were slow to adopt electricity. (Byatt, op cit:1-2)

14 Byatt, op cit:197

authority influence, and also Liberal Government attempts to prevent the creation of powerful local monopolies, and their view of electrical lighting as a public good.[15]

Many observers argued that the 1882 Act greatly inhibited both private and public investment in the early electricity supply and electrical manufacturing industries in Britain.[16] However, Byatt rejected any simplistic 'legislative determinism' to explain the backwardness of electricity supply in Britain. He argued that legislation should be seen within its social and political context – in the case of the 1882 Act, "as part of an attempt to regulate natural monopolies in the public interest, in an economic atmosphere still dominated by 'laissez-faire' views".[17] Similarly, Thomas Hughes stated that Britain's early ESI "accorded nicely with prevailing British political values and the regulatory legislation that expressed them ... [and] reflected the traditional high value in British politics for the power of local government".[18]

As Hennessey pointed out, the 1882 Act also reflected the prevailing state of generation and transmission technology – small-scale direct current distribution from local power stations was the only feasible system for electricity supply when the Act was introduced. Within a few years, however, this was transformed by the introduction of steam turbines and alternating current transmission. Together, these offered significant economies of scale which could only be captured by larger franchise areas. Hennessey described this as the "technological stroke that cut the ground from beneath the 1882-8 system, simply by destroying its technical rationale".[19] However, rather than a case of technological determinism – as Hennessey seems to suggest – it was the *interaction* of regulatory, economic, and technical dynamics at this time that created difficulties for the 1882 Act, and held back the development of the British ESI. Self and Watson concluded that "legislation in itself was not alone responsible for the unsatisfactory position which had developed. Technical advances in transmission had by then made it possible to give an economic supply over considerable distances".[20]

---

15 Hennessey op cit:33. Self and Watson stated that "from the provisions of the Act and from the practice followed in its interpretation it can clearly be seen that electricity supply was regarded from the first as a public service, within the political limits then accepted" (op cit:10).

16 Self and Watson, for example, argued that the Act "had a stultifying effect on the new industry, which resulted in seriously impeding normal development until the restriction on private financial enterprise was removed" (Self and Watson, op cit:10)

17 Byatt, op cit:197

18 Thomas P. Hughes, 'The Evolution of Large Technological Systems' in W. E. Bijker, T. P. Hughes, and T. Pinch, (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987, pp51-82:79

19 Hennessey, op cit:34-5

20 op cit:51

The first decade of the twentieth century saw the emergence of an established technological form for electricity generation which was to endure throughout the century. Bowers claimed that, such was the ESI's subsequent technological continuity, "since 1903 the history of power station development has been one of improvement in details and increases in size rather than radical changes in principles".[21] By 1910, steam turbines represented four-fifths of all new plant capacity installed in Britain.[22] At the same time, however, the British ESI remained relatively small-scale, and was still characterised by divided ownership. By this time, Hinton argued, "the ultimate form of the electricity supply system was ... held back not by technological limitations but by policies (supported by legislation) that were often narrow, selfish, and shortsighted".[23]

Before 1914, the British electrical plant manufacturing industry was also much less concentrated than elsewhere. Internationally, four major plant manufacturing companies emerged in the early-twentieth century: General Electric and Westinghouse of the USA, and Siemens and AEG of Germany. All had British subsidiaries, and all were major importers of electrical equipment into Britain. As a result, Byatt argued, a strong indigenous electrical engineering industry in Britain was no longer needed.[24]

3.2.2 The Interwar Years

The First World War was to act as a catalyst for change in the British ESI. During the war, control of the industry was passed to the Ministry of Munitions. Generation plant and production capacity increased greatly under the massive expansion of weapons production, and according to Self and Watson, "the actual prosecution of the war effort itself revealed the inherent weakness of the electricity supply industry".[25] Hughes argued that the First World War "cleared away the political, economic, and other non-technological factors that prevented or retarded the utilization of existing technologies ... [it] broke a conservative crust that had restrained adjustments in course and velocity".[26] He added that at this time, "the political forces that were brought to bear more than matched the internal dynamic of the system".[27]

---

[21] Bowers, op cit:169
[22] Byatt, op cit:111
[23] Hinton, op cit:37
[24] ibid:166,218
[25] Self and Watson, op cit:31
[26] Thomas Hughes, *Networks of Power: Electrification in Western Society 1880-1930*, Baltimore, John Hopkins University Press, 1983:285-6
[27] ibid:80

Towards the end of the war, a number of parliamentary committees began investigating the problems of electricity supply in Britain. A Coal Conservation Sub-Committee Report concluded that the existing system of electrical power supply was "technically wrong and commercially uneconomic", whilst a Ministry of Reconstruction Committee report called for "a single unified system, organized and conducted upon commercial lines".[28] The outcome of this series of reports was the Electricity Supply Act of 1919. This allowed for the establishment of District Boards, to be responsible for the coordination and development of electricity supply. On a national scale, the Act appointed five Electricity Commissioners, responsible for promoting and regulating the supply of electricity, and the designation of electricity districts. Introduced by the Liberal Government under Lloyd George, the 1919 Act was *enabling* rather than *enforcing* – it relied on voluntary action on behalf of the utilities and private suppliers, and persuasion by the Commissioners.[29] In the event, its intentions were largely frustrated and there was little reform of consequence.

The inaugural meeting of the World Power Conference in London in 1924 presented embarrassing evidence of the relative inefficiency of the British ESI.[30] It reported that there were almost 600 separate electricity supply undertakings in Britain, over half of which were owned by local authorities.[31] In analysing the causes of this pattern, Hannah stated that "the technocratic tradition of cooperation which had proved such a strength in Germany had failed to develop in ... [a British ESI] deeply divided against itself by historical and political, as well as local and personal, factors".[32] Similarly, in accounting for the much more advanced ESI in Germany, Landes referred to German proficiency in electrical engineering, and the "technological rationality" of her industrial enterprise.[33] In his comparison of different ESI's at this time, Hughes stated that "London's electrical supply was disordered and small scale ... [whilst] the Chicago and Berlin utilities were acquiring franchises that were coextensive with technological limits".[34] He concluded that in London, "the proponents of local government authority, of municipal socialism, and of private enterprise confronted one another in a pluralistic debate, that from the point of view of the forces of technological change produced a stalemate".[35]

---

[28] P. Ford and G. Ford, *A Breviate of Parliamentary Papers*, Oxford, Basil Blackwell, 1951:237-8
[29] Hughes, op cit:321
[30] Hennessey, op cit:45
[31] ibid:45
[32] Hannah, op cit:85
[33] Landes op cit:436
[34] Hughes, op cit:227
[35] ibid:260

In 1924 the government appointed a small committee headed by Lord Weir to consider the "national problem" of electricity supply. The Weir Report argued that "cheap and abundant energy could be made widely available by reform of the ESI".[36] It went on to discuss a number of different possible structures for the industry, from wholesale nationalisation of generation, transmission, and distribution, to nationalisation of transmission alone. A wholly market-based structure was dismissed as "inadequate and unstable"; wholesale nationalisation was also rejected, on the grounds that "it might lead to stereotyped practice, check development and progress ... remove incentive ... and tend to bureaucratic administration".[37] Instead, the report recommended that a national *Central Electricity Board (CEB)* be established, to be responsible for buying electricity from selected power stations, and for selling electricity to authorised distributors at cost prices. At the same time, the report added that the ownership of power stations should remain in private hands, so as to "preserve ... the incentive of private enterprise".[38] Technically, the report stated, power output should be concentrated in a small number of large power stations, with the minimum necessary standby plant – a system that could only be achieved with the interconnection of stations. It therefore called for the construction of a high voltage transmission 'gridiron'.[39]

The Government accepted all of the main recommendations of the Weir report. The Electricity (Supply) Act of 1926 established the Central Electricity Board and instigated the construction of the national transmission grid.[40] Self and Watson described the establishment of the CEB as a "critical turning point" in the history of the British ESI.[41] For the first time, the industry had a body with power to shape its development on a national scale. The national grid became operational for most of the country by 1934.[42] Under the supervision of the CEB, the grid promoted reform of the ESI to an extent not envisaged by its proponents in the 1920s. As frequency and voltage were standardised, the technical advances found in the best power stations were more widely applied, and the amount of spare plant was greatly reduced.[43] Although originally intended to facilitate the *regional* integration of electricity supply, the grid increasingly became a *national* network. In 1938 a national control centre was established in London, and the CEB reported that the grid was being regularly operated as a single nationwide integrated system.[44]

[36] Ford and Ford, op cit:238
[37] Hannah, op cit:134
[38] ibid:94
[39] Hannah, op cit:93
[40] Ministry of Transport, *Memorandum on the Electricity (Supply) Bill*, Cmnd 2605, 1926
[41] Self and Watson, op cit:63
[42] Hannah, op cit:121
[43] ibid:126-9
[44] Hinton, op cit:65

There was great complementarity between developments in generation and transmission technology at this time. High voltage transmission technology meant that the bulk transfer of electricity over hundreds of miles became economical, and in turn, this stimulated the development of larger and more remote power stations.[45] Coal-fired steam turbines were the only form of large scale generation technology. According to Hannah, "the essence of inter-war progress in electricity was improvement and economy rather than fundamental innovation, but the effect of such steady progress on efficiency could none the less be large".[46] Improvements provided for thermal efficiency gains in the best steam turbine plant from around 20% in the mid-1920s, to just under 30% a decade later.[47]

As production costs fell, new markets opened up, and demand for electricity grew rapidly. The more diverse use of electric power in domestic, transport, and industry applications greatly improved the supply system usage, or 'load factor'.[48] By the end of the 1930s the ESI had been transformed by new technology, market growth, and rationalisation.[49] In analysing this period, Hughes argued that the ESI built up considerable momentum, as the industry's increasingly institutionalised and coordinated research and development efforts were directed at incremental improvements to established technological forms.[50] He also suggested that the technology and institutions of electricity supply evolved in harmony, as "the growth of organisations ... added to the momentum of [the] technology ... [institutions] with expert knowledge of, and vested interest in, the technology became committed to its growth".[51] Elsewhere, he stated:

> The high momentum systems of the interwar years gave the appearance of autonomous technology ... an inner dynamic seemed to drive the course of development ... Such systems appeared to be closed ones, not subject to influence from external factors or from the environment. These systems dwarfed the forces of the environment not yet absorbed by them.[52]

Despite the rationalisation of the British ESI during the 1930s, there was continuing pressure for further reform. Critics of the existing structure of the industry saw the

---

45 ibid:133

46 Hannah, op cit:132

47 ibid:134. Technical improvements in generation were focussed on the use of higher steam pressures and temperatures, made possible by improvements in metal alloys. Other significant developments included the use of steam-cycle reheating, and coal pulverisation, which significantly improved boiler efficiency (ibid).

48 In 1919 only 12% of households in Britain had an electricity supply. By 1938 over 65% were connected. (Bowers, op cit:267-68). The *load factor* is that proportion of total system capacity in use over a certain period of time.

49 Hennessey referred to the great expansion of electricity supply during these years as the *Electric Revolution* (Hennessey, op cit:118).

50 Hughes, *Networks of Power*, op cit:372

51 ibid:385

52 Hughes, 'The Evolution of Large Technological Systems', op cit:79

remaining local diversity as a check on further efficiency gains, and according to Hannah, there was a rising tide of opinion which favoured the takeover of power stations by the CEB.[53] Hinton, for example, referred to the "motley collection" of private companies, consultants, and municipalities who were responsible for the design and construction of generating plant at this time.[54]

3.3 Generation Technology in the Nationalised ESI

3.3.1 Postwar Nationalisation

The Second World War brought about an unprecedented degree of central planning in the British ESI. In 1942 the industry came under government control, alongside other key industries, under the newly formed *Ministry of Fuel and Power*.[55] Throughout the war the grid was operated as a single national network. At the same time, immediate wartime demands resulted in cut-backs in new station investment, and repairs and maintenance to existing plant.[56]

The postwar Labour Government was committed to nationalisation of all key industries. The nationalisation of the ESI was deferred until after coal industry nationalisation and the setting up of the National Coal Board. The King's Speech of November 1947 announced the introduction of legislation to nationalise the ESI "as a further part of the concerted plan for the co-ordination of the fuel and power industries".[57] In the debate that followed, Clement Attlee stated that he saw ESI nationalisation as completing the part-finished work of the 1926 Act; he stated that the Government was "taking a further step to complete the integration for the provision of fuel, heat and light".[58] The Government made clear that it saw ESI nationalisation as the best organisational form for the exploitation of the economic potential of electricity generation and supply technologies.[59] Douglas Jay stated that "we can only get technical progress and proper reorganisation if we integrate the present innumerable units of all sorts and sizes and ownerships into one organisation under government control".[60] Herbert Morrison, the chief architect of the postwar nationalisation programme, stated that "in electricity, public ownership is ... a

---

53 Hannah, op cit:138
54 Hinton, op cit:72
55 Eric Hobsbawm, *Industry and Empire: An Economic History of Britain since 1750*, London, Weidenfield and Nicolson, 1968:208
56 Self and Watson, op cit:98
57 HC Debates (Hansard), Vol.430, 1946-47, c8
58 ibid:c36
59 Hannah, op cit:353
60 HC Debates, Vol. 430, 1946-47, c424

question of practical commonsense ... it is ... the most simple, the most straightforward and complete case for public ownership".[61]

However, many Conservative MPs saw the ESI as a less suitable case for nationalisation than others, such as the coal industry – where there had been a long history of acrimonious industrial disputes – and doubted that ESI nationalisation could offer any additional benefits that could not be gained under continued private ownership. The Conservative Party leader, Winston Churchill, stated that his party would "meet the proposals for [ESI] nationalisation ... with strenuous and uncompromising opposition", and added that public ownership would "thrust the clumsy butter-fingers of the state into ... intricate apparatus".[62] Harold MacMillan also argued that the state should not interfere in the direction and operation of particular industries.[63] Another Conservative MP opposing the Electricity Bill, argued that it "takes away from the consumer that vital safeguard of competition".[64]

Within the industry itself, there was considerable support for nationalisation. Self and Watson, for example, argued that given conditions at the end of the war "the case for national co-ordination ... [could] hardly be denied"[65]; they added that "the only real controversy was the form and terms of nationalisation ... the main principle had been widely accepted by most progressive bodies of thought".[66] According to Hannah, nationalisation "struck a responsive chord" within the ESI, with its long tradition of public service; he added that "electrical engineers had by this time formed an influential professional community with their own technocratic support for greater central control".[67]

The 1947 Electricity Act created the *British Electricity Authority (BEA)*, to be responsible for electricity generation and transmission in England, Wales, and the south of Scotland. The BEA took over ownership of all power stations from private and municipal owners; it inherited over three hundred generating stations – under forty of which accounted for more than half of all electricity generated.[68] It was also given controlling authority over

61 ibid:c899
62 ibid:c31
63 ibid:c868
64 HC Debates, Vol.432, 1946-47, c1444 (Colonel Lancaster)
65 Self and Watson, op cit:9. Sir Henry Self was appointed inaugural Deputy Chairman of the BEA.
66 ibid:103
67 Leslie Hannah, *Engineers, Managers and Politicians: The First Fifteen Years of Nationalised Electricity Supply in Britain*, London, MacMillan, 1982:3-4
68 Self and Watson, op cit:85-87

the 14 newly-created Area Distribution Boards.[69] The BEA and Area Boards were vested in April 1948. Reflecting its commitment to greater worker participation in state owned corporations, the Government appointed Lord Citrine, a former trades union leader, as inaugural Chairman of the BEA.

Rising postwar demand, combined with wartime cutbacks in investment, meant that the BEA immediately faced a chronic capacity crisis. Electricity supply failed during winter peak demand for many years in the 1940s and 1950s.[70] Priority was given to the early construction of new capacity, and in an attempt to speed-up construction times, the Government issued an Order restricting the approval of new electricity turbine units to 30MW or 60MW sets with prescribed steam conditions.[71] The Order prevented the adoption of bigger, more advanced plant designs, and Hinton claimed that there was "nothing more damaging" in the history of restrictive legislation affecting the industry.[72] The restrictions remained in place for four years between 1947 and 1951. Even after it was revoked, however, the BEA was cautious in adopting more advanced generation technology; Hannah referred to "entrenched conservatism in generation plant design" in the postwar period.[73]

At the same time as the capacity shortages, the BEA also faced a fuel crisis. In the severe winters of the early-1950s, National Coal Board supplies proved inadequate, and high cost coal imports had to be brought in. Under apparently long-term fuel supply difficulties, the Ministry of Fuel and Power and BEA began to seek out alternative fuels, and plans were developed to construct oil-fired steam turbine power stations. By 1956, the BEA was planning to build 17 oil-fired power plants.[74] During this period, some research work was undertaken into gas turbines, but, according to Self and Watson, they were not considered economically viable.[75]

---

69 Hannah, *Electricity Before Nationalisation*, op cit:349 A single integrated generation and distribution board, the *North of Scotland Hydro Electric Board*, had been created in 1943 to serve the north of Scotland.
70 Hannah, *Engineers, Managers, and Politicians*, op cit: 23,28
71 Hinton, op cit:68
72 ibid:68-9
73 Hannah, op cit:103-4
74 Central Electricity Authority, *8th Report and Statement of Accounts*, Reports XVI, HC 367, 1955-56
75 Self and Watson, op cit:158-9

3.3.2 The Introduction of Nuclear Power

The origins of the British civil nuclear programme lie in the British independent atomic bomb project which started in the mid-1940s. Many of the early decisions regarding nuclear power were made in secret between a few senior politicians and research scientists, and little was announced publicly before the mid-1950s.[76] The first proposals for a programme of nuclear power were presented by nuclear research scientists based at the Atomic Energy Research Establishment at Harwell in Oxfordshire in the late-1940s.[77] According to Margaret Gowing, these "offered the possibility" that the cost of nuclear power would be lower than coal-fired stations by a considerable margin.[78]

In these early years priority was given to proving the workability of nuclear technology, over and above any economic considerations; Valentine stated that "the British nuclear power from its beginnings ... [was] exempt from the normal constraints of commerce and industry".[79] Gowing stated that such was the technical uncertainty at this stage, it was thought that there was little point to consider costs before the technology was shown to work.[80] In this uncertain environment there was scope for optimism. Gowing reported that "the people within the project ... had their feet firmly on the ground", and she added that, as research work progressed, insiders came to recognise that cheap nuclear power was unlikely. By contrast, she claimed, the project's political masters saw nuclear power technology as a means of recapturing national prestige. This optimism was reflected in media reporting of the technology – according to Hannah, "Britain's nuclear pioneers were heralded in the press as guarantors of a cheap energy future".[81]

In March 1953 the recently installed Conservative Government approved the construction of the first sizeable nuclear power plant, Calder Hall, near Windscale.[82] The design of the plant was optimised for plutonium production for use in atomic bombs rather than providing electricity. Gowing stated that, in the British nuclear power programme, "the

---

76 The early development of nuclear power in Britain is described in detail by Margaret Gowing, in *Britain and Atomic Energy 1939-45*, London, Macmillan, 1964, and (assisted by Lorna Arnold) in *Independence and Deterrence: Britain and Atomic Energy, 1945-52*, London, MacMillan, 1974. The subsequent development of the British nuclear power programme is analysed by Roger Williams, in *The Nuclear Power Decisions: British Politics 1953-1978*, London, Croom Helm, 1980

77 Gowing, *Independence and Deterrence*, op cit:268

78 ibid:301

79 John Valentine, *Atomic Crossroads: Before and After Sizewell*, Merlin Press, London, 1985:187

80 Gowing, op cit266. At the same time, she added, the problems of the treatment of nuclear waste "seemed manageable", whilst decommissioning of old reactors was "too remote to engage attention" at this time (ibid:299).

81 Hannah, op cit:174

82 Williams, op cit:38 The design of this and earlier prototypes – gas-cooled, graphite-moderated, running on natural uranium – was in large part a result of post-war shortages in Britain. Other countries, notably the USA, favoured water cooled reactors. (Williams, op cit:34-35)

intertwining of military needs and power considerations was apparent from the outset".[83] MacKenzie and Wajcman argued that the development of nuclear power was "directly military in inspiration", and added that "state interests closely shaped reactor design, at least in the early years of nuclear energy".[84]

Within government, the early responsibility for the nuclear power programme lay with the Ministry of Supply. In 1954, reflecting the special status of nuclear power, the government created the *Atomic Energy Authority (AEA)*. According to Williams, the AEA was granted, from the outset, an unusual degree of autonomy. He added that when Bill to create the AEA was presented to parliament, a number of MPs expressed their opposition to the AEA's creation, and that with the loss of Government control, there was a dangerous potential for a "new form of technocracy" to emerge.[85] By contrast to the central role awarded to the AEA, the BEA had little involvement in the early civil nuclear programme.[86]

By the mid-1950s nuclear power was seen by government as having a central role in the diversification of the ESI away from coal-fired generation and dependency on the NCB as fuel supplier. In July 1954 the Minister of Fuel and Power, Geoffrey Lloyd, told Parliament that in expanding the ESI, the Government intended to "give pride of place to atomic development".[87] The first British nuclear power programme was announced in a White Paper published in February 1955. The White Paper stated:

> Nuclear energy is the energy of the future ... The exact lines of future development in nuclear energy are uncertain, but this must not deter us from moving on with its practical application wherever it appears promising ... [It] now appears practicable on a commercial scale at a time when the country's great and growing demand for energy, and especially electric power, is placing an increasing strain on our supplies of coal.[88]

The White Paper went on to outline a provisional programme of 12 reactors to be built between 1955 and 1965, with a total capacity of 1.5GW to 2GW. These *Magnox* reactors (so known because of their magnesium oxide fuel cladding) were based on the Calder Hall design. They were to be commissioned and operated by the Central Electricity

---

83 Gowing, op cit:263

84 Donald MacKenzie and Judy Wajcman, (eds.), *The Social Shaping of Technology*, Milton Keynes, Open University Press, 1985:18

85 Williams, op cit:24

86 Nevertheless, the BEA's *Annual Report* for 1953-54 stated that "although many technical problems have to be solved, and costs are somewhat uncertain, there appears to be no doubt about the widespread use of nuclear energy for the generation of electricity". (Hinton , op cit:75).

87 HC Debates, Vol.529, 1953-54

88 Ministry of Fuel and Power, *A Programme of Nuclear Power*, Cmnd 9389, 1955:1

Authority (formerly the BEA)[89] under expert advice from the AEA. The Government claimed that, allowing for an (unspecified) credit for plutonium produced by the reactors, the cost of nuclear power would be "about the same as the probable future cost of coal-fired power stations".[90] The White Paper concluded:

> The development of nuclear power has reached a stage where it is vital that we should apply it commercially with all speed if we are to keep our position as a leading industrial nation ... whatever the immediate uncertainties, nuclear energy will in time be capable of producing power economically.[91]

In parliament, Lloyd stated that "the successful use of atomic energy on a commercial basis is of crucial importance to the future of the national economy".[92] The House of Commons unanimously approved of the government's proposed programme.[93] A succession of MPs paid tribute to the brilliance of British nuclear scientists, and declared that nuclear power was the answer to the nation's fuel shortage problem.

3.3.3 The Creation of the CEGB

The Conservative Government returned to power in 1951 was dissatisfied with the structure and performance of the nationalised ESI it had inherited. In 1954 the Ministry of Fuel and Power set up a committee to investigate the industry, headed by Sir Edwin Herbert.[94] The Herbert Committee report, published in 1955, criticised the CEA's management of power plant technology, and in particular the long-lead times required for plant construction.[95] The report also described the CEA's provision for research and development as "inadequate"; it argued that the CEA was overly dependent on plant manufacturers for technical improvements to plant, and suggested that "in such a technical industry science should be represented at the highest level of management".[96]

The Herbert Committee also considered the early nuclear power programme. It found that the CEA had committed itself to a programme of nuclear power without knowing the details of the technology, but argued that this investment was justified on the basis of

---

89 In 1954 the Electricity Reorganisation (Scotland) Act transferred the BEA's Scottish assets to a newly created *South of Scotland Electricity Board*. The *British Electricity Authority* then became the *Central Electricity Authority (CEA)*.
90 Cmnd 9389, 1955, op cit:5
91 ibid:5
92 HC Debates, Vol.537, 1954-55, c187-191
93 HC Debates, Vol.537, 1954-55, c1625-1677
94 Ministry of Fuel and Power, *Report of the Committee of Inquiry into the Electricity Supply Industry*, Cmnd 9672, 1955
95 ibid:60
96 ibid:127-128

potential fuel savings. It added that "nuclear power has arrived in time to meet the country's growing demand for power".[97] However, the Committee stated that the CEA should gain greater knowledge of nuclear power, so as to lessen its dependence on the AEA, and it recommended that the nuclear power should be given a higher profile within the industry's organisation, since "a new approach is required for the solution of the diverse and novel technical problems which are bound to arise in nuclear power engineering".[98]

The Committee recommended that the ESI be reorganised with the creation of a *Central Electricity Generating Board (CEGB)*, to be responsible for generation, transmission and bulk supply. In addition, it recommended that a reconstituted *Central Authority* be formed, with powerful supervisory responsibilities, including the approval of the CEGB's tariff setting, development programmes, and capital and research budgets. Membership of the Central Authority, it argued, should not be open to members of the CEGB or Area Boards. Separating out the executive and supervisory functions of generation and transmission in this way, the Committee argued, would allow for "much firmer and closer supervision" of the industry.[99] The Committee also recommended greater delegation to the regions and divisions of the CEGB than in the CEA, and also greater freedom for the Area Boards.

The return of the Conservative Government in 1955 made reorganisation of the ESI inevitable. The Government outlined their proposals for reform in a White Paper published in November 1956.[100] Whilst they agreed with Herbert Committee's proposals for the creation of the CEGB, and also the granting of greater autonomy to the Area Boards, the Government rejected the Committee's plans for a powerful Central Authority. It was argued that "this would confer on that body great power over the industry with little corresponding responsibility", and that it would operate against the development of "initiative and responsibility" within the Area Boards.[101] Instead, the Government proposed to set up an *Electricity Council*, made up of representatives of the CEGB and Area Boards, as well as independent representatives. The Council was to have an essentially advisory role.[102]

---

[97] ibid:131
[98] ibid:135
[99] ibid:54
[100] Ministry of Fuel and Power, *Proposals for the Reorganisation of the Electricity Supply Industry*, Reports, Vol.XXVI, Cmnd 27, 1956
[101] ibid:3
[102] ibid:3

The restructuring of the ESI in late-1956 coincided with the *Suez Crisis,* during which Britain appeared to be facing an urgent fuel supply shortage. In Parliament, the Government came under pressure to announce an early expansion of the nuclear power programme. The second reading of the Bill to create the CEGB took place in December 1956 at the height of the Suez Crisis.[103] The debate was dominated by fuel scarcity concerns, and the potential of nuclear power to offer a secure source of supply. Although he made no direct reference to the Suez Crisis, the Minister for Fuel and Power, Geoffrey Lloyd, made clear that the Government's proposals for ESI restructuring were in part a response to the need for an expanded programme of nuclear power:

> At this time of all times ... there is a particular reason for looking critically at [the ESI] ... There is now added to the task of generation and the responsibility for the entire industry the nuclear power programme ... The Government are anxious to move as fast and as far as we practically can in this matter ... If we are to obtain all the benefits of nuclear power ... it is ... important to speed up the operation of the ... [ESI] machine.[104]

Lloyd criticised the lead times for plant construction under the CEA, and stated that "if we are to speed up the nuclear power programme, which our circumstances require, this time must be abridged".[105] He argued that this could only be achieved under a specialist body with control of generation and transmission. Lloyd discussed doubling or trebling the initial nuclear programme, and more speculatively suggested "if we expand as fast as we want and as I hope we shall, we shall soon begin to reach a point when there is not enough baseload for the number of atomic energy stations".[106] He praised the "brilliant success" of the AEA, and the high public esteem in which it was held, and indicated that he would select the CEGB chairman from "those who have led the way in the development of atomic energy".[107]

For the opposition, James Callaghan criticised the Government's proposed structure for the industry as being too weak in the centre, and argued that the Electricity Council should be granted more power, along the lines of the Herbert Committee proposals.[108] However, Callaghan agreed that "to an increasing extent the organisation [of the ESI], particularly the generating side, must be built around ... [the nuclear] programme".[109]

---

103 HC Debates, Vol.562, 1956-57, c938-1057
104 ibid:c940-941
105 ibid:c941
106 ibid:c970
107 ibid:c973
108 ibid:c956-60
109 ibid:c962

Parliamentary debate on the Government's proposals was dominated by the Suez Crisis and the consequent need for expansion of the nuclear power programme. Former scientists and engineers were highly prominent in the debate, and a number of non-technically educated MPs willingly deferred to the views of their scientific peers. The former physicist Sir Ian Horobin reminisced about the "certainties and the comparative simplicities of nuclear physics" compared to intractable political problems, and emphasised that nuclear power was "something under our own control".[110] Horobin added that "the main function of the [proposed] Generating Board ... is to be a nuclear energy producer", and that "the whole fuel policy" and "the whole investment policy" of the country should be built around nuclear power.[111] Several MPs urged the Government to announce expansion of the nuclear power programme; one MP stated that the Minister "is not likely to be criticised in this House or in the country for going too far in the direction of expanding this programme".[112]

In March 1957 Geoffrey Lloyd announced to a strongly approving House of Commons, that "in the light of technical progress", the nuclear power programme would be trebled in size, to a target operational capacity of 5-6 GW by 1965.[113] Although there was no direct mention of the Suez Crisis in the statement, it was stated that nuclear power expansion was aimed at reducing the cost of fuel imports. Hannah described the Government's decision as "a technological lifebelt offering protection from the consequences of Suez".[114]

The Electricity Bill received Royal Assent in July 1957; it abolished the CEA, created the CEGB and Electricity Council, and granted operating independence to the 12 Area Distribution Boards. The CEGB was given a statutory responsibility to "develop and maintain an efficient, coordinated and economical system of supply of electricity".[115] The new structure for the British ESI became operational in April 1958; it was to endure essentially unchanged for over thirty years, until the changes associated with privatisation.

---

110 ibid:c995-997

111 ibid:c997, 999

112 ibid:c902 (Dr. Bennet)

113 HC Debates, Vol.566, 1956-57, c184-90

114 Hannah, op cit:181-2

115 Statutory Public General Acts, 1957, Ch.48, *Electricity Act*, p2

3.3.4 Generation Technology in the late-1950s and early-1960s

At the beginning of 1957 nuclear power occupied a central role in the British ESI's plans for future generation technology development. Within just a few months, however, the case for expansion of the nuclear programme was being reconsidered. Fears for the security of oil imports receded quickly after the Suez crisis, and coal shortages also reduced as National Coal Board output reached record levels, at a time when other uses of coal fell. Contrary to postwar forecasts, there was a sharp decline in coal demand from the mid-1950s onwards, as its domestic and industrial markets shrank; consumption reached a peak in 1956. From the late-1950s onwards, measures were taken to restrict both coal imports and further investment in oil-fired plant. At the same time the CEGB was put under pressure from government to take a higher level of NCB coal output. Under these measures coal output stabilised at around 200mt p.a. until 1963, but fell steadily again thereafter.[116]

During the mid-1950s there were considerable gains in the average performance of coal-fired steam turbine plant. Materials shortages eased, and advances in alloys and welding techniques allowed for higher steam temperatures and pressures, and economies-of-scale savings were also made as the standard size of power stations rose to 120MW by 1958.[117] Williams argued that there was a failure on the part of Government to anticipate the gains in conventional generation technology:

> By 1957 the economics of nuclear power had already begun to worsen relative to conventional power, and this deterioration continued thereafter ... it should really have been better appreciated that the nuclear stations were probably going to meet a more severe challenge from conventional plant than had been allowed for in 1955.[118]

In the late-1950s a series of delays were announced in the rate of expansion of the British nuclear programme. In April 1957 the Ministry of Fuel and Power announced the deferment of the expanded nuclear programme targets by one year.[119] In its first annual report, the CEGB announced a further deferment.[120] The following year, the CEGB stated that it has been "evident for some time that costs of electricity from nuclear stations currently being built would be greater than those of electricity from coal burning stations", partly because of increased nuclear costs, but mainly due to reductions in the

116 Ministry of Power, *Fuel Policy*, Cmnd 2798, 1965:5-6
117 Forrest, op cit:8
118 Williams, op cit:19, 72
119 Ministry of Fuel and Power, *Capital Investment in the Coal, Gas and Electricity Industries*, Cmnd 132, 1957
120 Central Electricity Generating Board, *First Report and Accounts 1958-59*, (Reports Vol.XII), HC 313, 1958-59:12

cost of conventional stations.[121] A third delay was announced by the Ministry of Power in June 1960. The new aim was to reach around 5GW nuclear capacity by 1968. The Ministry stated that "since 1957 coal supply has become plentiful and oil supply prospects have also improved", and that consequently, "the need for a sharp increase in nuclear power has passed".[122] However, the Government claimed that, although the earliest Magnox plants were more expensive than anticipated, the costs of the more recent plants were coming down, and nuclear power was likely to be cheaper than conventional power by around 1970.

Throughout the postwar period there was little financial scrutiny of investment in generation plant. The nationalised corporations were statutorily required to do no more than break even from year to year, and there was no financial assessment of returns to the BEA's plant construction programme. Under the 1957 Electricity Act the CEGB was broadly charged with providing a "economical system of supply", but within this individual investment projects received little assessment. In April 1961, a Treasury White Paper on the *Financial and Economic Obligations of the Nationalised Industries* set out new ground-rules for higher financial returns.[123] Under these arrangements optional expenditure, such as the choice of generating technique, was in theory required to make a 10% rate of return on investment. However, some decisions on 'optional' expenditure, justified on grounds of political expediency or technical advance were exempted from such appraisal. As a result the investment appraisal procedures for generation technology – nuclear and conventional – remained undemanding.[124]

In 1963 the Select Committee on Nationalised Industries carried out an inquiry on the ESI.[125] The Committee concluded that "the structure of the industry is sound, and ... criticism should be confined to its performance".[126] It pointed to "impressive reductions in the capital cost of coal-fired generation".[127] The Committee also stated that "despite the absence of a technical check, the present arrangements for examining the very large capital expenditure of the Generating Board appear to be satisfactory", but added that some consideration should be given to "the adequacy of professional scrutiny" in the industry.[128] The Committee reported that the Herbert Committee's call in 1956 for

121 Central Electricity Generating Board, *Report and Accounts 1959-60*, (Reports Vol.XIII), HC 316, 1959-60:16

122 Ministry of Power, *The Nuclear Power Programme*, Cmnd 1083, 1960. In 1963 the CEGB provided capital cost figures to the Select Committee on Nationalised Industries of £140/kW for the first two Magnox plant, compared to £37/kW for recent coal plant (HC 236, 1962-63:117)

123 Cmnd 1336, 1960-61

124 Hannah, op cit:207

125 Select Committee on Nationalised Industries, *The Electricity Supply Industry*, HC 236, 1962-63

126 ibid:16

127 ibid:41, 108

128 ibid:46

expansion of the generator's research effort had been met by the CEGB.[129] At the same time criticisms were made of under-forecasting of demand and poor standards of supply security provided the CEGB. The Committee also criticised the absence of real competition and the price-rings operating in the plant manufacturing industry.[130]

In the first half of the 1960s electricity demand rose sharply. By this time it was clear that nuclear power technology had limited scope for expansion. Instead, the CEGB embarked on a massive expansion of coal- and oil-fired steam turbine power stations. In 1958 the industry standardised on 500MW steam turbine sets, and by 1963 over thirty such sets had been ordered.[131] The size of the new power stations was such that the CEGB also undertook construction of a new 400kV "supergrid". According to Hannah, the rush of plant orders overstrained both the plant manufacturers capabilities and the CEGB's capacity to coordinate contractors. Plant construction was split between eight boiler-makers and five turbogenerator manufacturers, each working on different designs, and there were numerous design faults and construction delays. Typically, the new power stations took more than five years to commission.[132] The supply system remained under pressure, and there were further winter breakdowns of supply in the early-1960s.

3.3.5 The Advanced Gas Cooled Reactor Programme

In 1964 the Conservative Government published a White paper announcing plans for a second generation of nuclear reactors.[133] The Government reported that nine Magnox plants were now completed or under construction, with a total capacity of just under 5GW. The Government claimed that "although these stations will produce power at a higher cost than was originally planned, the generation of nuclear power, from a technical standpoint, has achieved all that was expected of it".[134]

The White Paper went on to discuss the various designs under consideration for the next phase of nuclear power construction in Britain. By this time a number of very different designs to Magnox had been developed overseas, including the American 'Boiling Water Reactor' and the Canadian 'Heavy Water Reactor'. The Government stated that whilst different designs were still under consideration, the CEGB would be offering first tenders

129 ibid:177
130 ibid:163
131 Cmnd 6388, 1975-76:11
132 Hannah, op cit:250-3
133 Ministry of Power, *The Second Nuclear Power Programme*, Cmnd 2235, 1964
134 ibid:2, emphasis added.

for the AEA-designed *Advanced Gas Cooled Reactor (AGR)*. It added that a programme of around 5GW of new nuclear plant was planned for the early-1970s. The White Paper concluded that "nuclear power is likely to have an economic place in the British electricity supply system by the early 1970 ... thereafter, it will become cheaper than conventional power for the generation of base load".[135]

The AGR design was very much a product of the AEA; no other body – including the CEGB – was closely involved in its development. It was essentially an upgraded Magnox design, employing enriched uranium fuel and higher operating temperatures, with the intention of producing a reactor that was cost-competitive with fossil fuels. According to Williams, the AEA encountered far greater technical problems than it had expected in its development of the AGR. He added, however, that the AEA had built up a "technological momentum" behind the AGR which made the choice of alternative designs difficult.[136] He also suggested that the design embedded the particular circumstances and "technical philosophy" of the British nuclear programme, which made any direct comparisons with overseas nuclear reactor designs inherently difficult.[137]

In May 1965 Frederick Lee, Minister for Power for the new Labour Government under Harold Wilson, announced that the AGR had been chosen for the next round of nuclear plant orders. Lee stated that the CEGB and AEA had informed him that the AGR "shows clear economic and technical advantages over the alternative systems and has good potential for further development. It will also generate base load power more cheaply than a contemporary coal-fired station".[138] By the mid-1960s there was some scepticism among MPs about claims for the benefits of nuclear power, and Lee's statement was met by repeated requests for more detailed and costed information regarding the proposed programme. Alf Roberts, for example, stated that "costing in the atomic energy industry is far from satisfactory".[139] Lee dismissed these concerns; he referred to the AGR as "our great success", and added that he was "quite sure we have hit the jackpot with this ... here we have the greatest breakthrough of all time".[140]

---

135 ibid:4

136 Williams, op cit:50

137 Williams argued that the choice of a gas rather than water coolant reflected a particular emphasis on safety in the British programme. He also stated that the initial choice of gas-cooled/graphite-moderated/natural uranium reactors in the Calder Hall and Magnox designs was conditioned by wartime and postwar shortages of materials such as heavy water and enriched uranium. (ibid:36, 50-56)

138 HCDebates, Vol.713 1964-65, c236

139 ibid:c237

140 ibid:c238

In two *Fuel Policy* White Papers published in 1965 and 1967, the Labour Government reaffirmed its support of an expanded nuclear power programme.[141] The 1965 White Paper stated that nuclear power "should give cheaper base-load electricity than future coal fired stations ...[it] is likely to become fully competitive with conventional electricity generation".[142] The 1967 White Paper stated that "a regular sequence of new nuclear stations is desirable if the full development potential of this new technology is to be realised ... nuclear stations will predominate in new capacity planned for the coming years".[143]

Four AGR stations were ordered by the CEGB between 1966 and 1969, from three different manufacturing consortia, each offering different designs; another plant was ordered by the SSEB. All quickly ran into chronic construction delays and technical difficulties – three of the CEGB's plants were not declared commercial until the late-1980s. Richard Eden and Nigel Evans offered three reasons for the problems of the AGR programme: the premature move from prototype to commercial scale, insufficient design work being completed before the start of construction, and the awarding to contracts to weak manufacturing consortia.[144] They concluded that the Government had chosen the AGR design on primarily political grounds: "there can be little doubt that political considerations had an impact on the decision, with the British AGR design clearly favoured by the Labour administration of the day".[145]

3.4 Generation Technology in the ESI after 1970

3.4.1 Introduction: The Breakdown of Continuity

Throughout the twentieth century, up to the late-1960s, the ESI had experienced essentially unbroken economic and technological continuity. Steadily rising demand for electric power had been met by well established technologies, notably coal-fired steam turbines, which had been progressively improved in specification and scale. Gordon MacKerron pointed out that "the rapid expansion of the electricity industry that took

141 The Labour Government of the mid- and late-1960s under Harold Wilson was overtly technocentric in outlook. Wilson himself famously referred to the "white heat of the technological revolution" driving forwards economic change at this time.

142 Ministry of Power, *Fuel Policy*, Cmnd 2798, 1965:23,27

143 Ministry of Power, *Fuel Policy*, Cmnd 3438, 1967:17-18

144 Richard Eden and Nigel Evans, *Electricity Supply in the UK*, Aldershot, Gower, 1986:13. Similarly, in his analysis of the "disastrous" decision to progress with the AGR programme, Alex Henney stated that AEA figures for AGR performance, given in 1965, were "baseless", and taken from just one years experience from the pilot plant. (Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994:131)

145 Eden and Evans, op cit:13

place from the early-1900s was achieved in conditions of continuously declining cost ... that endured until the 1970s".[146] MacKerron identified four main causes of falling cost: economies of scale, the development of the ESI network, better generation technology efficiency – due mainly to higher steam temperatures and pressures – and lower fossil fuel prices, arising from the opening up of new deposits and improved extraction technology. As Hannah described, in the late-1960s the continuity of these trends seemed assured:

> From the beginnings of the electricity supply industry in the 1880s up to the mid-1960s, the industry's decision makers had lived in conditions of unusually stable expectations. Managers and engineers had then known that improved steam conditions, and larger scale in generation would lead to continually falling costs. Even nuclear power was seen in the 1950s as little more than the logical extrapolation of these basic rules of the industry's existence.[147]

After the 1957 Electricity Act, the economic and technological continuity of the industry was paralleled by organisational continuity. By 1970 the institutional strength of the CEGB and AEA was such that they seemed capable of directing the future of the ESI almost at will. Valentine argued that "in the years 1965-70 the AEA, CEGB and [manufacturing] consortia all showed a breathtaking conviction in their own abilities, supported by an unshakeable faith in the inevitability of increasing electricity demand".[148] Henney suggested that the institutional strength of the CEGB was such that it was able to develop long term plans for the development of generation technology largely on the basis of its own technocentric preferences:

> By the 1970s the boards of the nationalised industries were dominated by managers who had spent their careers in the industries, and often had a technical background. They developed an engineering rather than a commercial culture, which resulted in costly attempts to push forward technological frontiers ... The CEGB became an 'enclosed order' with a closed mindset ... the headquarters was a managerial bureaucracy that suppressed dissent, particularly about generation options.[149]

In a speech to the Institution of Electrical and Electronics Technician Engineers in 1970, the then Chairman of the CEGB, Sir Stanley Brown, looked forward confidently to *The Next 25 Years in the Electricity Supply Industry*.[150] Brown anticipated continuation of the historic growth of the British ESI: he predicted that by 1995, the industry would have

---

146 Gordon MacKerron, 'Innovation in Energy Supply: The Case of Electricity'. Unpublished draft prepared for inclusion in M. Dodgson and R. Rothwell (eds.),*The Handbook of Industrial Innovation*, Cheltenham, Elgar, 1994.

147 Hannah, op cit:288

148 John Valentine, *Atomic Crossroads: Before and After Sizewell*, Merlin Press, London, 1985:187

149 Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994:34

150 Sir Stanley Brown, *The Next 25 Years in the Electricity Supply Industry*, London, CEGB, November 1970

trebled in size. He added that this huge growth required the industry to "operate at the forward edge of technological development".[151] He went on to consider the generation technology options in the years ahead. Within this, nuclear power assumed clear dominance. As compared to fossil fuel generation, Brown argued, nuclear power was a young technology with great potential for improvement:

> Nuclear energy ... with its very low fuel cost – even if at the moment at a relatively high capital cost and complexity – is firmly destined to be the fuel of the future. Increasingly fossil fuels will be only used on lower load factor plant ... with oil, coal and natural gas competing for second place according to price and availability.[152]

In the event, over the following years, the seemingly impregnable authority of the CEGB – and its preferred generation technology options – were to be increasingly challenged and eventually overturned. Hannah stated that "all [the] assumptions, built up over more than six decades of experience, proved false".[153] In the early-1970s, the ending of continuity for the industry was most dramatically marked by the *energy crisis.*

3.4.2 The 1970s 'Energy Crisis'

Between 1973/74 the Arab-Israeli war precipitated an OPEC oil embargo, which resulted in a four-fold increase in oil prices (see Figure 8, Appendix 1).[154] This first *oil shock* had a profound effect on energy policy throughout the industrial world; in Western Europe and the USA, security of supply concerns again became dominant. Although Britain was less import-dependent for her electricity fuel than many other industrial nations, the oil-shock led to a reemphasis within the ESI on coal-fired and nuclear power generation technologies.[155]

From 1974 onwards, the newly-formed Department of Energy was the focus for devising and implementing Government policy response to the energy crisis. The Chief Scientist at the Department of Energy during these years was Walter Marshall, an esteemed nuclear scientist and Deputy Director of the AEA. In July 1975, Sir Jack Rampton, Permanent Under Secretary of State at the Department of Energy, declared that "the days of cheap

---

151 ibid:6

152 ibid:19

153 Hannah, op cit:288

154 John G. Clark, *The Political Economy of Science and Technology*, Oxford, Basil Blackwell, 1985:230

155 The CEGB had built over 4GW of new oil-fired steam turbine plant capacity in the late-1960s and early-1970s. (Eden and Evans, op cit:15)

fuel are over"; the technology of choice in the new energy situation, Rampton argued, would be nuclear power.[156]

In 1976 the leading industrial, political, trades union and academic figures in the energy industries came together at a *National Energy Conference* in London.[157] A number of speakers warned against over-reaction to apparent supply shortages in the wake of the oil-shock. A small number of MPs, notably John Biffen, Frank Hooley and Enoch Powell, argued for a non-interventionist market-based approach to the energy sector.[158] Their views, however, were in a minority amongst the conference delegates, and were clearly not shared by the incumbent Labour Government. Indeed, the conference was dominated by fears for energy shortages and security of supply concerns, and a series of speakers argued that the energy crisis demanded expansion of the coal and nuclear industries.

In the same year the Department of Energy published the first in an occasional series of surveys of energy technologies, *Energy Research and Development in the United Kingdom*.[159] The review was written, as subsequent such reports, by the Energy Technology Support Unit (ETSU), a nominally independent part of the AEA, based at the Authority's Harwell site in Oxfordshire. The review adopted an overtly technocentric approach; in his forward to the report, Walter Marshall declared that "this paper must be primarily concerned with research and development. Therefore, the document does not include an analysis of the non-technological factors which influence the implementation of advances in technology".[160] ETSU went on to outline their recommendations for a national energy R&D strategy in response to the energy crisis. In devising this, the underlying assumption was the perceived shortage of fossil fuels – North Sea oil and gas was seen as offering only a short or medium term "breathing space", as reserves would begin to run out at around the turn of the century.[161] In this context, ETSU concluded that "nuclear energy assumes increasing importance on almost any view of the future".[162]

---

156 Department of Energy, *Energy: The Key Resource*, (Sir Jack Rampton), Energy Paper 4, July 1975

157 Department of Energy, *National Energy Conference, June 22nd 1976, London; Volume 1: Report of Proceedings; Written Contributions*, Energy Paper 13, 1976

158 Similarly, Sir Arthur Hawkins, the Chairman of the CEGB, argued that "realism is the key of a successful [energy] strategy ... there is today a world glut of energy, and for the foreseeable future the UK is richly endowed with large reserves of indigenous fuel" (ibid:10). Arthur Heatherington, the Chairman of the British Gas Corporation stated that "UK gas and oil reserves will increase substantially", and that therefore, their development should not be artificially restrained or its price controlled (ibid:12).

159 Department of Energy, *Energy Research and Development in the United Kingdom*, Energy Paper 11, 1976

160 ibid:5

161 ibid:12. At the same time, the report conceded the possibility that much higher reserves of North Sea oil and gas may be found – sustaining development "well into the next century" (ibid).

162 ibid:25

The Labour Government outlined its own energy policy in 1977.[163] The Secretary of State for Energy, Tony Benn, outlined a concept of a firmly Government-led energy policy, with an emphasis on universal access to cheap energy. The review went on to describe the two main elements of the Government's supply side policies for the energy industries. Firstly, the expansion of the British coal industry along the lines of *The Plan for Coal,* a tripartite agreement between the Government, National Coal Board and National Union of Mineworkers. Secondly, "ensuring access to nuclear technology", since "the optimum solution is likely to include a substantial nuclear contribution".[164]

The next Department of Energy/ETSU review of *Energy Technologies for the UK,* published in 1979, again predicted a future dependency on nuclear power for the British ESI, and concluded that "on an orthodox view of the future it is expected that coal-fired plant will lose its base-load role to nuclear power in the long-term".[165]

3.4.3 Generation Technology in the 1970s

In responding to the energy crisis, the British ESI faced a number of more local challenges. The historic growth in electricity demand was ended as the use of North Sea natural gas expanded, and as a result, the ESI faced overcapacity for the first time in its history. At the same time both coal-fired and nuclear power plants were facing chronic technical and economic difficulties.

The established means of technical progress for coal-fired steam turbine power stations – scale economies and improvements in steam conditions – were offering diminishing returns by the early-1970s. Steel alloys reached thermal limits of around 560°C, beyond which increasing problems of material failure were experienced. Although developments continued in advanced alloys for turbine blades and steam tubing, and also improved cooling methods, their extra costs now often outweighed the small efficiency gains they provided. All across the industrial world, the average thermal efficiency of steam turbine plant levelled-off at just under 35%.[166] In considering this development, Flavin and Lennsen stated that "the advances in [steam turbine] technology ... stemmed from a

163 Department of Energy, *Energy Policy Review*, Energy Paper 22, 1977

164 ibid:24

165 Department of Energy, *Energy Technologies for the UK: An Appraisal for Research, Development and Demonstration Planning*, Energy Paper 39, June 1979:43

166 Robert H. Williams, and Eric D. Larson, 'Aeroderivative Turbines for Stationary Power', *Annual Review of Energy*, Vol.13, pp429-489, 1988:438

surprisingly narrow frontier of advances", and added that "by the 1960s, this bag of tricks was nearly empty".[167]

In addition – as a number of parliamentary committees reported – the CEGB's fossil fuel plant construction programme was plagued by problems of industrial relations, low productivity, and poor plant design.[168] Together, these difficulties were responsible for huge construction delays and cost increases, and the availability of the 500MW turbine sets was greatly restricted.[169] Nevertheless, the CEGB continued to build bigger units: 660MW turbines were adopted after 1970, and sixteen such units were ordered in the early-1970s.[170]

At the same time the British nuclear power programme was also facing chronic design problems and cost increases.[171] Henney stated that "the problems of building the AGRs threw the British nuclear programme into disarray, and the 1970s were a period of claim, counterclaim, indecision, [and] confusion".[172] Alternatives to the AGR design were considered by Government in the mid-1970s – in particular, the steam-generating heavy water reactor (SGHWR), which had been under development by the AEA as an alternative to the AGR since the late-1960s, and also the American-designed pressurised water reactor (PWR).

In July 1974, following a series of detailed inquiries and debates concerning the relative merits of different reactor designs[173], the Labour Government announced that the SGHWR had been chosen for construction.[174] An initial programme of 4GW was planned, but it quickly became clear that the SGHWR was inadequately developed from prototype, and would prove considerably more expensive than either the AGR or PWR, Within a short period of time the Government had decided to reconsider its choice of plant design. Although the PWR now had the support of many nuclear engineers in Britain, most notably the Department of Energy's Chief Scientist, Walter Marshall, it was

---

167 C. Flavin and N. Lenssen , 'Reshaping the Electric Power Industry', *Energy Policy*, Vol.22, No.12, pp1029-1044, 1994:1030

168 Ministry of Power, *Delays in Commissioning CEGB Power Stations*, Cmnd 3960, 1969; Select Committee on Science and Technology, Generation *Plant Breakdown*, HC 223, 1969-70

169 David Collingridge, *The Social Control of Technology*, London, Pinter, 1980:115

170 Forrest, op cit:14

171 In the late-1960s and early 1970s the nuclear power programme was the subject of inquiries by both the Select Committee on Nationalised Industries: *United Kingdom Nuclear Power Industries*, HC 401, 1968-69, and the Select Committee on Science and Technology: *United Kingdom Nuclear Reactor Programme*, HC 381, 1966-67; *Nuclear Power Policy*, Report: HC 350, 1972-73, Evidence and Appendicies, HC 444, 1971-72 and HC 117, 1972-73.

172 Henney, op cit:132

173 Select Committee on Science and Technology, *The Choice of Reactor System* (Report: HC 145, 1973-74; Evidence: HC 73, 1973-74); also HC Debates Vol.872 1973-74, c1344-1450. The decisionmaking process that led to the choice of the SGHWR is analysed in detail in Williams, *The Nuclear Power Decisions*, op cit, Chapter 9.

174 *Nuclear Reactor Systems for Electricity Generation*, Cmnd 5695, 1974

opposed by others, including the Energy Secretary, Tony Benn, on safety and development cost grounds. In January 1978 the Government announced that the CEGB and SSEB would be sanctioned to build two more AGRs, whilst at the same time the AEA was authorised to undertake preparatory work on a future PWR.[175]

The 1970s also witnessed growing public opposition to nuclear power. As Williams pointed out, until this time, the British nuclear power programme had developed in an essentially "private world" of government and insider organisations. By the mid-1970s, however, this had been overtaken by a "distinctly public politics".[176] The opening up of debate on the future of nuclear power was most marked by the Royal Commission on Environmental Pollution 1976 report on *Nuclear Power and the Environment*.[177] For the first time in an official report, safety and pollution concerns regarding radioactive materials were given prominence, and the case against *any* nuclear power programme was discussed.[178]

3.4.4 The Plowden Report

In response its chronic problems, the Labour Government of the late-1960s and 1970s resolved to restructure the ESI. The first attempt at reform was made as early as July 1970, when the Minister of Power, Roy Mason, announced his intention to reorganise the industry along the lines of the 1956 Herbert Committee's proposals.[179] The proposed Bill was lost with the dissolution of parliament later in 1970, but the pressure for reform continued into the 1970s. In evidence to the Select Committee on Nationalised Industries' inquiry in 1973, the then Chairman of the Electricity Council stated that "if one were starting up afresh, I would certainly not advise you to set up ... [the industry] in its present shape".[180] The select committee reported that divisions in the industry were frustrating efforts to improve performance. After 1974 the reinstalled Labour government set up a committee headed by Lord Plowden (who had been inaugural chairman of the AEA in the 1950s) to investigate *The Structure of the ESI in England and Wales*.[181]

The Plowden Report, published in 1976, stated that the most frequent criticism it heard was the inadequacy of central direction and control, and concluded that "the basic

175 HC Debates, 1977-78, Vol.942, c1391-1408
176 Williams, op cit:17-18
177 Cmnd 6618, 1976 (Sir Brian Flowers)
178 Williams, op cit:278-287
179 Cmnd 6388, 1976:9
180 Select Committee on Nationalised Industries, *The Gas, Electricity, and Coal Industries*, HC 65, 1973-74:q333
181 Cmnd 6388, 1976

weakness of the industry's structure is slow and cumbersome central policy-making caused by divided responsibilities and a rigid statutory framework".[182] The Committee considered a number of possible alternative structures for the industry, such as the setting-up of a number of integrated regional power boards, or the breaking-up of the CEGB into two competing generating companies. The case for regional power boards was rejected because of the problems involved with inter-trading between boards: the Committee argued that the distribution of generation plant in Britain was such that some boards would be in too strong a position with respect to others. It was also argued that the central role played by the CEGB in power plant design and manufacture in the British ESI meant that a change to regional boards would present problems for the construction of new plant, since British manufacturers would be unable to take on responsibility for coordinating the design and construction of power plant technology. The report continued:

> The creation of power boards would not remove the need for a central approach to major design questions and would only complicate the process of taking the necessary decisions ... in countries where the investment plans of the electricity supply undertakings are only informally coordinated, the technical strength of the plant makers, relative to the undertakings, is far greater than in England or Wales.[183]

On splitting-up the CEGB, whilst the Committee conceded that this would "encourage competition of ideas on the generating side", it argued that this would "not address the industry's real weaknesses", but rather, would "perpetuate the existing division of responsibility and lack of central direction, and, indeed, make it worse on the generating side, where there is a special need for central decisions".[184] Within this, the perceived demands of nuclear power were clearly central to the Committee's reasoning:

> The CEGB's single organisation for power station design and construction must be preserved ... the country can no longer afford to try two different approaches to major strategic choices such as a new reactor type ... the electricity industry [should continue] to speak with one voice to match the increased concentration in the nuclear design ... there are many crucial areas where the industry must act as a whole according to a single national strategy.[185]

The Committee therefore recommended unification of the industry under a single statutory board which would take over the functions of the CEGB, Area Boards, and Electricity Council. The report concluded that it was now appropriate for the industry to

---

182 ibid:22
183 ibid:30
184 ibid:31
185 ibid:23

return to a more centralised structure, such as was introduced upon nationalisation in 1947.

The Government announced plans for reorganisation of the industry in a subsequent White Paper, published in April 1978.[186] The Government reported that there was "a strong current of opinion among both management and unions in the industry in favour of a change from the present fragmented structure to a unified organisation".[187] It proposed establishing a single body, the Electricity Corporation, to have responsibility for the industry as a whole, on the basis that "a stronger centre is needed to deal with the major strategic decisions facing the industry".[188] Just as in 1970, however, the Labour Government's wider difficulties prevented it implementing its proposed reforms of the industry; the Electricity Bill failed to proceed before the 1979 dissolution of parliament.

3.4.5 Generation Technology in the 1980s

The Conservative Party victory in the May 1979 General Election, under Margaret Thatcher, broke the postwar political consensus that had supported corporatism. During the long unbroken period in office that followed, Conservative Government would eventually transform the economic and organisational environment of the British ESI. However, in the first two Thatcher-led administrations (1979-83 and 1983-87) there was little reform of the industry of any real significance.

In the wake of the second oil-shock, during which the price of oil again rose suddenly (Appendix 1, Figure 8), and the widespread industrial unrest of the 'Winter of Discontent', the new Government quickly made clear its support for the continued expansion of nuclear power. In December 1979 the Energy Secretary, David Howell, gave consent for two second-generation AGR plants initially approved under the last Labour Government, with the promise of a first PWR power station order to follow on. Howell stated that "there must be continuing nuclear power station orders if our long term energy supplies are to be secured and current industrial difficulties are to be resolved".[189] He also described as a "reasonable prospect" the CEGB's stated desire for a 15GW nuclear

---

186 Department of Energy, Reorganisation *of the ESI*, Cmnd 7134, 1978. The Select Committee on Nationalised Industries also undertook an investigation into the industry at this time; the select committee reported that "the overwhelming view of witnesses was that reorganisation of the ESI is urgently needed".(*Reorganising the Electricity Supply Industry; Prelegislative Hearings*, HC 636, 1977-78:xxix).

187 ibid:4

188 ibid:5-6

189 HC Debates, 18th December 1979, c287

programme over the following ten years, through the ordering of one new PWR plant every year for a decade from 1982 onwards.[190]

At the same time Government support for the British coal industry also continued, and there was no real attempt to challenge the monopoly status of the National Coal Board as coal supplier to the CEGB. Indeed, in October 1979, the Government oversaw the signing of a 'Joint Understanding', under which the CEGB agreed to take 75mt p.a. of NCB coal for the following five years.[191] The agreement also effectively ensured the continued dominance of coal-fired steam turbine technology in the British ESI.

If the new Government's actual management of the ESI was little different than its predecessor, in its policy statements at least, a very different approach was outlined, stressing the role of competitive market forces. This was most clearly announced in a speech in June 1982 by the then Energy Secretary, Nigel Lawson.[192] Lawson stated that he did "*not* see the Government's task as being to try to plan the future shape of energy production and consumption ... [but] rather to set a framework which will ensure that the market operates in the energy sector with a minimum of distortion".[193] In general, Lawson declared, the aim was to regard fossil fuels as internationally tradeable commodities, and to base investment in generating technologies on commercial criteria rather than security-of-supply considerations. Within this, however, Lawson argued that "electricity poses special problems": given the restrictions on electricity importability and substitutability, diversity was of particular importance, and he argued that this meant that "nuclear power is critical both to diversification and to reducing costs".[194]

In 1982 the Government appointed Walter Marshall, former Chief Scientist at the Department of Energy, now Director of the AEA, as the new Chairman of the CEGB. Marshall was well known as a highly forceful advocate of PWR technology.[195] The first PWR, Sizewell B, was submitted to public inquiry in 1983. For Marshall and the CEGB it was only the first of a series of ten similar plants. The need for a large PWR series, however – particularly at a time when electricity demand was falling – had already been questioned by the Energy Select Committee.[196] The Committee suggested that the

---

190 ibid:c288

191 Mike Parker, and John Surrey, 'Contrasting British Policies for Coal and Nuclear Power, 1979-92', *Energy Policy*, Vol.23, No. 9, pp821-850, September 1995:824

192 Department of Energy, *Speech on Energy Policy*, (Rt. Hon. Nigel Lawson), Energy Paper 51, June 1982

193 ibid:4. Emphasis in original.

194 ibid:5

195 Henney stated that as a nuclear scientist rather than an electrical engineer, "Marshall appeared to be primarily interested in the CEGB as a means of providing the technological infrastructure and finance for building PWRs" (Henney, op cit:51).

196 House of Commons Energy Select Committee, *The Government's Statement on the New Nuclear Programme*, HC 114, 1980-81

CEGB's economic case for the PWR programme was dependent on a few highly questionable assumptions and projections concerning the relative cost of coal and nuclear plant.[197]

Other influential bodies were also questioning the decisionmaking of the CEGB by the this time. In 1981 the Monopolies and Merger's Commission had criticised the Board's performance in plant construction, consistent over-estimation of demand, and over-investment in capacity.[198] It also pointed to "serious weaknesses" in the CEGB's investment appraisal procedures, and concluded that "a large programme of investment in nuclear power stations ... is proposed on the basis of investment appraisals which are seriously defective and liable to mislead".[199] Although the MMC inquiry did not address the overall structure of the ESI or the wider energy sector, it suggested that "where nationalised industries, each having a virtual monopoly, deal with each other ... the purchaser may not resist the seller's demands as vigorously as it ought, since it can pass on its costs to its customers".[200]

Whilst it was reluctant to engage in any substantial restructuring, the first Thatcher Government did introduce a series of measures aimed at the liberalisation of utilities. In the case of the ESI, these measures were included as part of the 1983 Energy Act. The Act aimed to encourage independent generation by abolishing the CEGB's statutory monopoly on generation in England and Wales, and allowing private generators access to the CEGB and Area Board's transmission and distribution networks. In practice, however, no significant private generation emerged.

In reviewing the failure to encourage independent generation at this time, Elizabeth Hammond et al. concluded that because the CEGB had retained control of the transmission grid, it continued to exert "effective control of price and entry conditions".[201] Similarly, George Yarrow stated that the Act had failed to provide any regulatory mechanism so as to ensure that new entry to generation was made easier. Indeed, he added, it had allowed the CEGB to engage in predatory pricing in order to deter new entry.[202] Hammond et al. concluded that "the advantages of incumbency ... acted to frustrate the objectives of liberalization", and suggested that "the creation of a

---

[197] ibid:836

[198] Monopolies and Mergers Commission, *Central Electricity Generating Board*, HC 315, 1980-81

[199] ibid:292-3

[200] ibid:290

[201] Elizabeth Hammond, Dieter Helm, and David Thompson, 'Competition in Electricity Supply: Has the Electricity Act Failed?', in Helm, D., Kay, J. A., and Thompson, D., (eds.), *The Market for Energy*, Oxford, Oxford University Press, 1989, pp157-177:176

[202] George Yarrow, 'Privatization, Restructuring, and Regulatory Reform in Electricity Supply' in Bishop, M., Kay, J. and Mayer, C., (eds.), *Privatization and Economic Performance*, Oxford, Oxford University Press, 1995, pp62-88:79

market in electricity may therefore only be feasible if a more fundamental restructuring of the ESI is implemented".[203]

The defeat of the National Union of Miners in the 1984/85 coal industry strike meant that a major obstacle to more radical restructuring of the ESI had been removed. Although there were no immediate changes in the dominant position of the NCB/British Coal as supplier to the CEGB after the strike, Mike Parker and John Surrey identified a marked asymmetry in Government treatment of the coal and nuclear industries from 1985 onwards, involving a steady withdrawal of R&D funds to British Coal. They also argued that "strong downward pressure" was exerted on British Coal's spending and investment – and indeed, the British coal industry underwent rapid rationalisation in the second half of the 1980s. Nevertheless, in the face of technical, economic and political restrictions on coal imports, the CEGB remained overwhelmingly dependent on indigenous coal, and in 1986 it agreed to a revised Joint Understanding for 75mt p.a. of NCB coal for the following five years.[204]

Although it was subject to increasing criticism by the mid-1980s, the CEGB – alongside the AEA – remained in an institutionally commanding position in the ESI. The British nuclear industry was confident about its ability to progress with the proposed PWR programme; in 1985 Valentine remarked:

> One of the most striking aspects of nuclear power is the strength of the consensus that supports it. This consensus embraces all the parliamentary parties, all the major unions except the mineworkers', and the entire institutional and power structure ... [the] nuclear momentum seems to be bent on attempting to secure its own future.[205]

In May 1985 the CEGB's Managing Director, John Baker, argued that even if it was not needed on demand grounds, CEGB investment in PWR technology was economically justified as replacement for existing plant.[206] Baker claimed that nuclear power "was by far the cheapest generating cost on the system"[207]; he continued:

> Nuclear stations ... in particular PWR stations ... make substantial cost savings by displacing the use of higher cost fuels ... It therefore pays the electricity consumer handsomely for the CEGB to install PWR plant in anticipation of need and demand in order to reduce the costs of electricity

203 Hammond et al., op cit:176-77
204 Parker and Surrey, op cit:831
205 Valentine, op cit:193
206 John Baker, *Nuclear Electricity – How Much is Needed?*, London, CEGB, October 1985. Baker led the CEGB's representation at the Sizewell B public inquiry, and this paper summarised the Board's evidence to the inquiry.
207 ibid:2

generation ... It is apparent that, for a wide range of backgrounds, nuclear power is a good investment.[208]

Baker forecasted a looming capacity crisis in the English and Welsh ESI in the 1990s and beyond, as the large amount of plant commissioned in the 1960s was retired. He argued that this required the CEGB to build as soon as possible a "small family of PWRs", with subsequent further orders for coal-fired steam turbine and nuclear power plant. In the longer term, he outlined a "moderate" expansion of nuclear power over the next 35 years, so that by 2020, nuclear represented around 40% of total plant capacity, around the same share as coal-fired steam turbine plant.[209]

In 1986 the *Institute of Energy* produced a review of future energy supplies and the potential of different electricity generation technologies.[210] The report concluded that much of the new plant needed in the UK ESI "should be nuclear", but that given the strength of public opposition to nuclear power in the wake of the Chernobyl disaster, the choice lay instead between coal- or oil-fired steam turbine plant.[211] The Institute's report also made an attack on the Government's advocacy of market-based energy policy. It argued that since 1979, the Conservative Government had "virtually removed the little that remained of policy coordination" in the energy sector.[212] The Institute argued:

> It is not possible to leave policy decisions to the market as though energy were a matter of taste or personal preference, mainly because the longer term technical and commercial factors at work are too complex for the lay observer within the market to evaluate correctly ... [there is] a need for policy integration at the national level, for which government takes responsibility".[213]

In February 1987 the Department of Energy published another in the occasional series of ETSU reviews of energy research and development.[214] Even though oil and gas prices were falling rapidly in the course of their investigation (see Appendix 1, Figure 8), ETSU expressed support for the existing pattern of research spending in the ESI, which was overwhelmingly dominated by nuclear power technology.[215] ETSU claimed that there

---

208 ibid:3-4. Baker presented the following CEGB figures for generation costs: Sizewell B PWR: 2.94p/kWh; AGR: 3.67p/kWh; coal-fired steam turbine plant: 4.29p/kWh

209 ibid:7

210 Institute of Energy, *Energy for the Future* (2nd edition), London, Institute of Energy, 1986

211 ibid:31

212 ibid:12

213 ibid:34

214 Department of Energy, *Energy Technologies for the UK:1986 Appraisal of Research, Development and Demonstration*, Energy Paper 54, February 1987

215 According to Department of Energy figures, UK ESI expenditure on RD&D at this time was: (£m) Nuclear: 373, Fossil Fuel 54, Renewables 16. (Department of Energy/ Energy Technology Support Unit, *Background Papers Relevant to the 1986 Appraisal of UK Energy Research, Development and Demonstration*, ETSU R-43, London, HMSO, February 1987:B10)

were "high returns" to investment in AGR plant technology, and described spending on PWR plant development as "highly cost effective"; it added that PWR technology had "the potential to make a very substantial contribution to central electricity supply".[216] The report concluded that "in general, the results obtained for RD&D [research, development and demonstration] in the electricity production technologies indicate that it is both cost-effective and timely".[217]

In their Annual Report for 1986/87, published in mid-1987, the CEGB stated that following the recent approval of planning permission for Sizewell B PWR, they would be making applications for a further PWR, Hinkley Point C, and also two coal-fired steam turbine plants, at Fawley and West Burton.[218] The Board argued that the industry was now at a turning-point, with a return to demand growth and new capacity construction, after a decade of static demand and little new plant activity, and that as a result, ten new PWR and coal-fired stations would be needed by the year 2000.[219]

In retrospect the British ESI now stood at a much more radical turning point, and was about to enter circumstances beyond that which the CEGB might have thought possible. Before considering these changes further, however, it is first necessary to review the history of gas turbine generation technology – on both an international scale, and also its rather neglected position in the British ESI.

3.5 The Development of Gas Turbine Generation Technology

3.5.1 Introduction: Gas Turbines and Steam Turbines

In basic operation, the gas turbine is an essentially similar technology to the steam turbine – in both cases, hot, pressurised gas is passed through rotating turbine blades in order to power an electricity generator. Beyond this, however, there are significant technical and economic differences between the two – differences which, in part, explains their very different fortunes as electricity generation technologies during the twentieth century.

In a modern coal-fired steam turbine power plant, pulverised coal is mixed in a boiler with air, and then burnt to raise pressurised steam at around 560°C (Appendix 2, Figure 1). The range of temperatures and pressures experienced within steam turbines can be

216 ibid:B31, 36
217 ibid:B3
218 *CEGB Annual Report and Accounts*, London, CEGB, July 1987
219 ibid:7

withstood by normal steel alloys – an important factor in the economics of such plant. In a gas turbine power plant, by contrast, compressed air is mixed with gaseous or distillate fuel and burnt under very high pressure; the hot combustion gases (at well over 1000°C) are then fed directly across the gas turbine.

Because they are exposed to much higher temperatures and pressures, the components of gas turbines – notably the turbine blades themselves – are required to be far stronger than their steam turbine equivalents. In addition, the fuel used in gas turbines is required to be much 'cleaner' than in steam turbines, so as to avoid causing damage to the blade materials. The limits on material tolerance to high temperatures and pressures, and the absence of an appropriate (and affordable) fuel has greatly restricted the performance and use of gas turbines for much of the century.

In a *Combined Cycle Gas Turbine (CCGT)*, the hot exhaust gases from one or more gas turbines are fed into a boiler, or 'heat recovery steam generator', so as to raise steam for feeding into a steam turbine (Appendix 2, Figure 2). The use of gas and steam turbines together in this way makes the CCGT power plant, in principle, a highly efficient form of electricity generation technology. In practice, however, CCGT technology gained little use around the world up to the 1980s, and made no contribution whatsoever in the nationalised British ESI. Indeed, the British plant manufacturing industry played only a marginal role in the development of gas turbine/CCGT power plant technology. This section, therefore – unlike the preceding ones – considers technological development on an *international* rather than *national* stage. Subsection 3.4.2 considers the early development of gas turbine and CCGT technology; subsection 3.4.3 reviews the commercialisation of CCGT plant in the 1980s. Finally, subsection 3.4.4 returns to a focus on the British ESI, and considers the marginal position of gas turbine/CCGT technology in the industry before privatisation.

3.5.2 The early development of Gas Turbine Technology

Although they only ever had a very minor role in power generation up to the 1980s, gas turbines have a long history of development and use. Edward Constant II traced the origins of modern gas turbines back to the late-eighteenth century.[220] The commercialisation of steam turbines at the end of the nineteenth century (as described in 3.2.1) gave some impetus to the development of gas turbines for electricity generation, and a variety of gas turbine engines were introduced in the early twentieth century in

---

220 E. W. Constant II, *The Origins of the Turbojet Revolution*, Baltimore, The John Hopkins University Press, 1980:89

Europe and the USA – the most successful of which was developed in France.[221] General Electric investigated gas turbines in the early-twentieth century, but by the 1920s, they concluded that, such were their technical problems – in particular material intolerance to high temperatures, and grossly inefficient compression (in the early days compressors consumed more power than was supplied by the turbine) – that there was no practical possibility of an efficient gas turbine.[222]

Greater knowledge of aerodynamics in the inter-war years gradually allowed for more efficient compression, and by 1935-36, gas turbines powerful enough to run a small generator were successfully constructed.[223] The first commercial gas turbine generator was built in 1939 by Brown Boveri of Switzerland, and a number of other manufacturers developed similar designs in the 1940s.[224] All were modelled on steam turbine technology. The incoming fuel and air were mixed together in large boiler-like combustion chambers; after combustion, a valve was opened to allow the combustion gasses to be expelled at high pressure across a turbine. This was an inherently inefficient design, and gas turbines were unable to match the rapid improvements steam turbine technology during the interwar years (3.2.2).

The development of the turbojet in the late-1930s and early-1940s – by Frank Whittle in England, and around the same time by von Ohain, Wagner, and Schelp in Germany – marked a radical turning point in the development of gas turbines.[225] Turbojets were far smaller, lighter and more efficient than earlier gas turbine designs. In turbojets, incoming air is continually fed into a compressor, and then mixed with fuel in small combustors; the combustion gases are then continually driven across a turbine at high pressure. This design provided far greater airflow and power-to-size ratio than had hitherto been possible. From the 1940s onwards, gas turbine development took two distinct pathways – technically advanced aero engines, and larger, more robust, 'industrial' gas turbines for power generation.[226]

Combined cycle power plants also have a long history in power engineering. Horlock traced the history of combined cycle plants to the early part of the twentieth century.[227] General Electric built several combined mercury/steam cycle plants before 1950.

221 ibid:91
222 ibid:93
223 ibid:145
224 ibid:146
225 This 'turbojet revolution' is described in detail by Constant, op cit, pp178-20.
226 I. T. Haigh, 'Lighter Fuel: The Gas Turbine Comes of Age', *IEE Review*, 37,3,97-102, 21 March 1991:98
227 J. H. Horlock, *Combined Power Plants: Including Combined Cycle Gas Turbine (CCGT) Plants*, Oxford, Pergamon Press, 1992:xiii.

Although these achieved high thermal efficiency, substantial additional costs were involved with the mercury cycle, and Horlock concluded that "while magnificent engineering achievements ... [they] proved to be uneconomic in comparison with the developing conventional steam plants, which were gaining in efficiency as steam pressures and temperatures increased".[228] The first modern designs of CCGT plant were developed by Seippel and Bereuter whilst working for Brown Boveri in the 1950s.[229] However, natural gas was rare at this time, and in order to be competitive with steam turbines, it was widely accepted that gas turbines needed to be adapted to run on other, cheaper, fuels. Experiments were accordingly carried out on a wide range of candidates. At the same time, investigations were conducted on a variety of gas turbine plant design variations, using reheating and intercooling. In retrospect, Tyler concluded, these tended to detract from the potential of 'simple' gas turbines, and neither low-grade fuels nor complex cycles proved successful.[230] Gas turbines remained too small and too expensive to run for CCGT plant to be considered a serious rival to coal-fired steam turbine technology for large-scale generation.

Although industrial gas turbines found little application in the postwar period, the use of turbojets expanded dramatically, and turbojet technology underwent rapid improvements under the huge research programmes of the major aero-engine manufacturers – notably General Electric and Pratt and Witney in the USA, and Rolls-Royce in the UK – financed by secure long-term government defence contracts.[231]

Efforts to improve turbojet efficiency concentrated on increasing the maximum cycle temperature and raising the compression ratio. Maximum cycle temperature gains were achieved by improving blade materials and cooling techniques. According to Armstrong, the use of improved metal alloy turbine blades provided for average increases in the maximum cycle temperature of around 10°C per year after the war up to 1960.[232] When air-cooling of turbojet turbine blades was first introduced in the 1960s, it provided a further sudden jump in maximum cycle temperature of 100°C, and subsequent developments in cooling techniques enabled further average increases of around 20°C

---

228 ibid:xiii

229 C. Seippel and R. Bereuter, 'The Theory of Combined Steam and Gas Installations', *Brown Boveri Review*, No.47, pp783-789, 1960. Horlock argued that Seippel and Bereuter's work "gave considerable impetus to the development of combined plant" (Horlock, op cit:101)

230 J. R. Tyler, 'The Industrial Gas Turbine – Its Status and Prospects', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp65-74:65

231 Williams and Larson estimated that around $10bn was spent worldwide on turbojet engine development from 1940 to 1980. (Robert H. Williams, and Eric D. Larson, 'Aeroderivative Turbines for Stationary Power', *Annual Review of Energy*, Vol.3, pp429-489, 1988:442)

232 F. W. Armstrong, 'Gas Turbine Evolution', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference 1976-I, London, 4-5th February, 1976, pp1-15:3

each year thereafter.[233] In a thirty year period from the mid-1950s to the mid-1980s, gas turbine compression ratios rose threefold, maximum cycle temperatures rose from 750°C to 1150°C, and open cycle efficiencies from about 20% to over 30%.[234]

All of these improvements, however, were concerned exclusively with aero-engines. The massive research efforts of the turbojet manufacturers concentrated on technical refinements which did not serve the more robust demands of industrial gas turbine engines. Turbojets were ill-suited to power generation – they were too small, and were not designed for sustained continuous use. Even General Electric – who alone amongst the major manufacturers made both industrial and aero gas turbines – operated them as separate businesses serving different markets. At the same time, the research efforts of the large electrical manufacturers and utilities were concentrated – with considerable success – on steam turbine technology.

In the late-1950s and early-1960s large natural gas reserves were the discovered in the USA, Western Europe and the Middle East. In Europe, the largest discovery was the huge Dutch Groningen field, discovered in 1959. Greater availability meant that for the first time natural gas became a viable fuel for electricity generation. In the 1960s small 'aeroderivative' gas turbine engines, based on turbojet designs, were installed in considerable number by electrical utilities across the world, including the CEGB in Britain (this is discussed later in the chapter, 3.5.4). Although their running (i.e. fuel) costs were much higher than large coal-fired or oil-fired steam turbines, small gas turbine plant could be built relatively quickly. In addition, the response time of these engines – the time needed to achieve full power from start-up – was much quicker than for large conventional plant, so that they were generally used intermittently to meet peak loads, or kept as reserve plant.[235] At the same time, the abundancy of natural gas was now such that it was burnt in steam turbines instead of coal or oil. By 1973 natural gas fuelled 10% of all electricity generated in OECD countries, virtually all using conventional steam turbine plant.[236]

European and American manufacturers also installed a considerable number of small CCGT plant in the 1960s, often in combined heat and power (CHP) applications. Using one or more high efficiency aeroderivative gas turbine engines (in the 10-25MW range),

---

233 ibid:3

234 ibid:18

235 A severe power system failure in New York in November 1965 greatly boosted the appeal of gas turbines for meeting peak demand in the USA, and US utilities became increasingly dependent on gas turbines for meeting peak loads. By the early 1970s, gas turbines made up 10% of total US generating capacity. John R. Riley, et al., 'Can Manufacturing Capacity Keep Up with New Orders for CTs?', *Power Engineering* (US), April 1990, pp45-47:45

236 Gordon MacKerron, 'The Role of Gas in the Future of European Electricity Generation'. Unpublished draft of a paper presented to conference on 'Gas Powered Electricity Generation', London, February 24th-25th, 1993, pp2-12:2

combined cycle plant efficiencies of over 40% were possible. The largest CCGT plant in Europe at this time was a 75MW Brown Boveri plant, using two 25MW gas turbine units, at Korneuburg in Austria, commissioned in 1961. In the USA, a similarly-sized CCGT/CHP plant was built by General Electric in Texas for the chemical company Dow.[237]

By 1970 Wood highlighted a "trend to higher industrial ratings" among gas turbine manufacturers, such as recently introduced Westinghouse (58MW) and Stal-Laval (70MW) machines.[238] Wood predicted that "current delays in the delivery of large nuclear and fossil steam plant ... will no doubt ensure a continued demand for gas turbines ... in particular, base-load use in combination of the gas turbine with heat recovery".[239] Similarly, in 1973 Pfenninger argued that "combined cycle plants are an economically interesting proposition", and reported "growing interest" in larger CCGT plant for power generation, with a substantial number of recent orders in Europe for plant over 100MW.[240] He discussed, for example, the recently ordered Geertruidenberg power station in the Netherlands, a 120MW plant which had an overall thermal efficiency of 44%.[241]

The 1973/74 oil-shock greatly curtailed the use of natural gas for electricity generation across the globe. Even though the price of natural gas rose far less than that of oil in the immediate aftermath of the OPEC embargo (see Appendix 1, Figure 8), it was now considered by western governments to be a scarce fuel with poor supply security. In 1975 an EEC Directive prohibited the use of natural gas as a fuel for new power plants in the absence of exceptional technical or economic circumstances.[242] In the USA, the 1978 Power Plant and Industrial Fuel Use Act imposed restrictions on the use of natural gas for electricity generation, other than for meeting peak demand, or when alternative sources were unavailable.[243] CCGT plant construction ground to a near halt from the mid-1970s – only one utility CCGT plant was built in the USA between 1979 and 1986.[244]

Despite its prohibition for electricity generation, the research efforts of turbojet manufacturers ensured that aeroderivative gas turbine technology improvements

---

237 Horlock, op cit:267

238 B. Wood, 'Gas Turbine Developments', *Diesel Engineers and Users Association*, Publication 336, September 1970, pp4-9:4

239 ibid:6

240 H. Pfenninger, 'Combined Steam and Gas Turbine Power Stations', *Brown Boveri Review*, Vol.60, No.9, pp389-397, September 1973: 397

241 The Geertruidenberg plant was commissioned in 1975.

242 Directive 75/404/EEC

243 Alfred A. Marcus, *Controversial Issues in Energy Policy*, Newbury Park CA, Sage, 1992:42

244 R. Smock, 'Gas Turbines Dominate New Capacity Ordering', *Power Engineering* (US), pp23-28, August 1989:24

continued. The prospects of gas turbine technology were reviewed by an Institution of Mechanical Engineers conference in London in 1976.[245] The conference heard a wide range of views concerning the potential contribution of gas turbines to electricity generation. A number of speakers emphasised that, in the wake of the oil-shock, a cheaper alternative fuel to natural gas would have to be found before any significant progress could be made. For example, Armstrong suggested that "the use of gas turbines might be greatly extended if a satisfactory capacity for using low-grade fuels could be established ... This is especially true for base-load power generation, where the use of cheap fuel is vital to the economics".[246] Similar concerns prompted Tyler to suggest that "it might be expected that increased fuel costs ... will tend to reduce the proportion of gas turbine capacity that is economic".[247]

At the same time, a number of conference delegates reported a continuing trend towards larger gas turbine units, designed specifically for electricity generation, and which were beginning to incorporate advanced design features from aeroderivative engines. Spinks reported that five manufacturers were now offering heavy duty gas turbines in the 100MW class, and he added that "the 1000MW gas turbine power station, involving ten or less units, is therefore now possible".[248] Shorthouse stated that CCGT plants incorporating 100MW gas turbine units could achieve combined thermal efficiencies of 48%. He also suggested that environmental concerns would increasingly favour gas turbines in power generation, arguing that "where environmental restrictions and energy conservation measures are ever more stringently applied, the development of gas/steam combined cycles will inevitably progress".[249]

Tellingly, the most positive view of the prospects of gas turbines for power generation at the conference was offered by an overseas speaker, T. E. Thorén of the Swedish equipment manufacturer, Stal-Laval.[250] Thorén described "second generation" 100MW gas turbines, developed by Stal Laval and others in Europe and the USA, which employed advanced cooling techniques derived from turbojet engines. He pointed to the much greater efficiencies these enabled, compared to steam turbine plant: "combined

---

245 *Gas Turbines – Status and Prospects*, I. Mech. E. Conference 1976-1, London, I.Mech.E., 4-5th February, 1976

246 F. W.. Armstrong, 'Gas Turbine Evolution', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference 1976-I, London, 4-5th February, 1976, pp1-15:10

247 J. R. Tyler, 'The Industrial Gas Turbine – Its Status and Prospects', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp65-74:70

248 L. J. Spinks, 'Some Observations on the Selection of Gas Turbine Generating Plant', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp147-156:152

249 ibid:153

250 T. E.. Thorén, 'A New Maintenance Concept Applied in the Design of a New Industrial Gas Turbine in the 100MW Class', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp81-90. Stal-Laval later became part of ASEA, which itself subsequently became part of ASEA Brown Boveri (ABB).

cycle plants are now offered on the market with net plant efficiencies in excess of 47%, and 50% is probably within future reach. A modern steam station seldom achieves more than 40% net efficiency".[251] Unlike other speakers at the conference, Thorén also argued that gas turbine plant economics were "surprisingly insensitive" to fuel price increases.

Thorén then considered in turn the use of gas turbines for peak, intermediate, and base-load power generation. He argued that existing 'open-cycle' gas turbine units were already cost-effective for peak load use – where fuel cost was of little importance, and that existing CCGT plant was cost-competitive for intermediate ('mid-merit') use. Only for base-load use, he argued, were gas turbine fuel costs prohibitively expensive.[252] Thorén concluded that the development of the gas turbine was such that it was now set to gain far greater use in electricity generation:

> Fifteen years ago gas turbines were fairly expensive, rather unreliable power sources, most often put on standby or reserve duty. Over the years we have observed or participated in the evolution of the gas turbine, turning it into a reliable, relatively inexpensive, highly economical type of plant ... No immediate obstacles seem to slow down gas turbine development while steam turbine technology is fairly mature and benefits little from increased cycle temperatures or pressures ... Gas turbine plants will play a significant role in the new energy situation.[253]

Thorén's views were not widely shared, however – particularly in Britain. By the time of a 1979 Institute of Mechanical Engineers conference on *Power from Coal*, several large gas-fired CCGT plants were established in Europe (having a total output of over 100MW), but in Britain opinion on CCGT technology was still dominated by fuel scarcity concerns for natural gas (given renewed urgency after the second oil shock of 1978-79). The dominant view at the conference was that the contribution of CCGT technology to the British ESI was dependent on its adaption for coal gasification.[254]

3.5.3 The Development of CCGT Technology in the 1980s

The seeds for gas turbine/CCGT expansion in the 1980s and 1990s were sown, in part, by the legislative framework for energy policy constructed in the mid- and late-1970s, in response to fuel scarcity concerns. In the USA a number of significant measures were introduced as part of the 1978 *National Energy Act.* In an attempt to encourage the

251 ibid:81
252 ibid:81
253 ibid:81
254 *Power from Coal*, I.Mech.E. conference 1979-3, London, 10th April 1979

development of new reserves, the *Natural Gas Policy Act* initiated the deregulation of the US gas industry, by partly removing price controls on gas trading.[255] In combination with the *Fuel Use Act*, which restricted the burning of gas for power generation, the Natural Gas Policy Act led to greater supply and reduced demand for natural gas in the US – a 'gas bubble' – which lasted throughout the 1980s. Another important piece of legislation enacted in 1978 was the *Public Utilities Regulatory Policy Act (PURPA)*, which required US public utilities to buy some of their power from independent producers who used more efficient forms of generation.[256] This greatly encouraged independent producers to invest in small cogeneration plant using CCGTs, and by 1985, 4.6 GW of CCGT plant had been installed in the US ESI.[257]

At the same time as the prospects for gas turbine technology were improving, the traditionally dominant electricity generation technologies were experiencing chronic difficulties. After the Three Mile Island accident in 1979, US electricity utilities became increasingly concerned with the technical and economic risks involved with nuclear power, and US regulators imposed tougher regulations on the nuclear industry, including restrictions on the ability of utilities to cross-subsidise nuclear plant construction from other revenue.[258] Regulators were also aggressively restricting coal-fired power plant emissions by this time.[259]

As Williams and Larson pointed out, in the early-1980s – for the first time since the nineteenth century – power plant construction and operation in the US became a risky financial undertaking. Under combined threats from uncertain demand, environmental restrictions, rising capital costs, and a regulatory system which increasingly favoured independent power producers, US utilities sought to minimise investment risks, and were reluctant to expose themselves to the long lead times and upfront costs of large power plant. Between 1974 and 1985, 93 nuclear and 41 coal-fired plants were cancelled.[260] In such circumstances, small gas turbines – whose economics were largely scale insensitive, and which were capable of meeting tougher environmental and safety regulations – clearly presented a least-risk investment option.

---

255 Marcus, op cit:47

256 Williams and Larson, op cit:432. The PURPA also required utilities buy and sell electricity at prices that reflected the marginal costs of production (Marcus, op cit:47).

257 Williams and Larson, op cit:448

258 R. S. Johnson, *Natural Gas and its Role in Power Generation*, unpublished paper presented to the Institute of Mechanical Engineers, 12th December 1990:110

259 John R. Riley, et al., 'Can Manufacturing Capacity Keep Up with New Orders for CTs?', *Power Engineering* (US), April 1990, pp45-47:45; R. Smock, 'Gas Turbines Dominate New Capacity Ordering', *Power Engineering* (US), pp23-28, August 1989:26

260 Williams and Larson, op cit:430

In 1984 Witton stated that "events in the last decade have made the industrial gas turbine an attractive power source for a range of industrial applications ... [it is] a strong contender for new and refitted plant of all sizes and types".[261] He went on to report growing interest in gas turbines at annual conferences dealing with electricity plant, such as those of the *American Society of Mechanical Engineers* (ASME). Looking ahead, Witton argued that before the end of the decade, the application of established aeroderivative technology was capable of adding significant further improvements to industrial gas turbine performance. He pointed out that "few of the means being studied for this are entirely new, although the materials technology and analytical and experimental support for them incorporate considerable technical advances".[262]

In the course of the 1980s, natural gas supplies increased substantially all across the world, and it became clear that the scarcity of supply forecasts of the 1970s were misplaced. Following the second 'oil-shock' of the late-1970s and early-1980s, new non-OPEC oil and gas resources were developed, and at the same time the dependency of Western economies on oil and gas was itself reduced. By the mid-1980s, OPEC was increasingly divided, and unable to restrict oil and gas production amongst its member states. Under reduced demand and increased supply, oil and gas prices collapsed in 1986, and remained at low levels for the rest of the decade and into the 1990s (see Appendix 1, Figure 8).

This sustained fall in natural gas prices, together with new discoveries, transformed the economic prospects for gas-fired generation technology. In the light of increased availability, the restrictions on the use of natural gas for power generation introduced by the US Fuel Use Act were partially lifted in 1987.[263] US electricity supply companies were swift to take advantage of cheaper gas and supply industry deregulation, and this, in turn, further encouraged the development of new gas reserves. Similar changes followed in Europe and elsewhere.

A number of analysts have considered the radical change in the availability and cost of natural gas during the 1980s. Anne V. Roland stated that the restrictive legislation on gas use imposed by the US Government of the 1970s was "enacted in response to a mistaken belief that ... gas supplies were rapidly dwindling and needed to be preserved", and she concluded that "government regulation of natural gas production and use inevitably leads to serious market distortions ... prices determined in a free market seem to be the most

261 John Witton, 'Gas Turbines - Present and Future', *Process Engineering*, August 1984, pp18-21:18
262 ibid:21
263 Riley, et al., op cit: 46

attractive option".[264] Similarly, Peter Odell described the restrictions on the use of natural gas in Western Europe in the 1970s as "anti-gas expansion policies based on misconceived notions of the scale of the indigenous resource base"[265], and stated that a "self-justifying limitation was imposed on the prospects for gas ... in a system which virtually eliminated a competitive approach to markets".[266] Odell also argued that European energy utilities gave inadequate attention to research work which sought to expand the market opportunities for gas, and that, in particular, "the gas industry's research facilities ... [were] little concerned with work to improve the thermal efficiency of gas-fuelled combined cycle power plants".[267]

In an analysis of the failures of fossil fuel resource forecasts of the 1970s, Hans-Holger Rogner pointed to the failure of most energy models to take into account the effect of technical progress in the recovery and use of fossil fuels.[268] Rogner stated that "the omission of innovation and new technologies explains, at least partly, the poor track record of conventional energy studies".[269] He added that "accounting for technical progress in long-term energy scenarios has a considerable impact on the future prospects for the West European energy system".[270] According to Rogner, technological improvements in gas exploration and recovery substantially increased known reserves, and advances in the technology of use of natural gas were now transforming its market prospects. In particular, he argued, given the problems facing other generation technologies, CCGT technology was capable of dramatically changing the position of gas as an electricity fuel:

> The myth of the 1970s had it that natural gas is a scarce resource, and kept in the ground, would be worth more than in the market place ... Technology ... could be the vehicle to overcome these myths, turn submarginal resources into economically recoverable reserves, and thus pave the way for natural gas to become a globally dominating fuel.[271]

By the mid-1980s, encouraged by an expanding market and cheaper fuel prices, a small number of major international manufacturers were spending heavily on industrial gas turbine development. All were developing advanced industrial gas turbine units of around 100MW to 150MW, specifically for use in medium sized CCGT plant. The first of these

---

264 Anne V. Roland, 'Status Report on the US Natural Gas Industry', *Energy Policy*, Vol.16, No.3, pp226-229, June 1988:226
265 Peter R. Odell, 'The West European Gas Market', *Energy Policy*, Vol.16, No.5, pp480-493, October 1988:485
266 ibid:482-4
267 ibid:486
268 Hans-Holger Rogner, 'Technology and the Prospects for Natural Gas', *Energy Policy*, Vol.16, No.1, pp9-26, February 1988: 9
269 ibid:15
270 ibid:24
271 ibid:25

engines, such as General Electric's *Frame 9E*, and Brown Boveri's *13E* turbines units, appeared in 1986 and 1987.[272] Brown Boveri installed a prototype 13E 140MW gas turbine at Hemweg in Amsterdam in 1987, as an add-on to an existing 500MW steam turbine.[273] By August 1987 *Power in Europe* reported that the first-half of 1987 had seen the revitalisation of natural gas as an electricity fuel in Europe.[274]

3.5.4 Gas Turbine Deployment in the Nationalised ESI

In the early-1960s, after many years of struggling to meet demand, the British ESI was still facing chronic capacity shortages (3.3.1). After breakdowns in supply in the severe winters of 1961-62 and 1962-3, the CEGB decided to install 720MW of gas turbine plant capacity at ten power stations across the country.[275] This investment – based on the use of small aeroderivative 50MW and 70MW engines – represented the first significant use of gas turbine generation technology in Britain.[276] The CEGB stated that gas turbine plant was chosen as the only option that would be available by the winter of 1964-65, and also because it could also be brought up to full load very quickly.[277]

In 1963, as part of its inquiry into *The Electricity Supply Industry*, the Select Committee on Nationalised Industries investigated the CEGB's adoption of gas turbine plant.[278] The CEGB Chairman Lord Hinton told the select committee that the cost of fuel meant that gas turbines were only economic at load factors of under 2%, and stated that the CEGB had been "reluctant" to invest in them.[279] The select committee obtained figures which showed that gas-turbines power plants cost 40% less to build than coal-fired plants, but that their running costs were around three times higher. The committee concluded that "the use of gas-turbines by the generating board must be limited by the development of large power stations linked to an integrated grid system".[280] Indeed, as was discussed

---

272 Eric Jeffs, 'Nuclear Delays Expected to Speed Comb Cycle Growth', *Gas Turbine World*, July-August 1986, pp24-30

273 B. B. Pjipker and W. E. Keppel, 'Amsterdam to have First 140 MWe Gas Turbine', *Modern Power Systems*, pp28-33, May 1986. According to Pjipker and Keppel, the increasing interest shown in CCGT technology in The Netherlands in the late-1980s directly reflected decisions by Dutch utilities in the early-1980s to increase their fuel diversity and expand their use of natural gas (ibid:28).

274 *Power in Europe*, No.10, August 6th 1987. It reported, for example, that the Norwegian government had recently announced that the planned construction of new hydro-electric plant was to be cancelled, and replaced by a number of new CCGT plants.

275 Central Electricity Generating Board, *Annual Report and Accounts, 1962-63*, HC Reports Vol.XV, 1962-63

276 The first gas turbine for power generation used in Britain was a small aero-engine installed by the South West Electricity Board at a remote site on Dartmoor in the 1950s. (The 1957 Electricity Act allowed Area Boards rights to generate in exceptional circumstances). L. Hannah, *Engineers, Managers and Politicians*, op cit:195.

277 Central Electricity Generating Board, *Annual Report and Accounts, 1962-63*, HC Reports Vol.XV, 1962-63

278 HC 236, 1962-63, May 1963

279 HC 236, 1962-63:462-3

280 ibid:154

earlier in the chapter, the CEGB's principal response to the 1960s capacity crisis was a massive programme of new 500MW coal-fired steam turbine sets (3.3.4).

In the two *Fuel Policy* White Papers of the 1960s, gas turbine generation technology was mentioned only briefly – and only as a low capital, high running-cost technology, suited strictly for emergency and peak load use.[281] In August 1965 natural gas was first discovered in the North Sea. The 1967 White Paper referred to this as "a major event in the evolution of Britain's energy supplies".[282] Before this Britain had relied for its gas on relatively expensive 'town-gas' produced from coal or oil, and also some limited importing of liquified natural gas from the Middle-East. By 1967 a national gas pipeline transmission system was under construction, but natural gas was still not expected to make a significant contribution to electricity generation. Rather, the Fuel Policy White Papers restated the Government's view that nuclear power would occupy a central position in the future development of generation technology (3.3.4).

Nevertheless, the prospect of substantial UK gas reserves, together with the ongoing international development of gas turbine technology, now attracted some interest within the British ESI. In 1970, the then Chairman of the CEGB, Sir Stanley Brown, considered future generation technology options.[283] Although Brown was firmly committed to a dominant role for nuclear power (3.4.1), he also expressed some interest in CCGT technology, describing it as "currently quite promising", and a "very real possibility" for near-future mid-cycle plant.[284] Brown went on to consider the use of a 160MW CCGT plant, with a 120MW steam turbine and 40MW gas turbine, such as that now offered by Brown Boveri[285]; he stated:

> The attraction of such a cycle is enhanced by the rapid evolution of gas turbine technology in the direction of greater unit outputs and lower specific fuel consumptions. The economic incentive of such a plant rests partly upon its comparatively low first cost which, despite high running costs, can render it attractive – partly on account of the possibility of deploying it in comparatively small sizes and therefore, perhaps, more closely to the load than is possible with major stations ... Overall, CCGT may save sufficient capital cost to make it economic at annual load factors of over 30 per cent at present day ... [fuel] prices.[286]

281 Ministry of Power, *Fuel Policy*, Cmnd 2798, 1964-65; Cmnd 3438, 1967-68
282 Ministry of Power, *Fuel Policy*, Cmnd 3438, 1967-68, November 1967:1
283 Sir Stanley Brown, *The Next 25 Years in the Electricity Supply Industry*, London, CEGB, November 1970
284 ibid:14, 15
285 As installed for example, at the Geertruidenberg plant in the Netherlands.
286 Brown, op cit:14

In the event, the 1970s oil-shocks ended any immediate prospects for the introduction CCGT technology in the British ESI. The price of natural gas – although it increased less dramatically than that of oil (Appendix 1, Figure 8) – was closely linked to the international oil market. The British response to the energy crisis reflected the international consensus was that natural gas was a scarce 'premium fuel', suited only for particular uses, such as domestic heating and cooking. The dominant view of the British government and large energy producers was of the overriding importance of coal-fired and nuclear power generation technology (3.4.2). The 1976 Energy Act implemented the 1975 EEC Directive restricting the use of natural gas in power stations, and the use of natural gas for electricity generation in Britain remained strictly in terms of small 'peak-lopping' and standby plant.

The 1976 Department of Energy survey of *Energy Research and Development in the United Kingdom presented*, for the first time, a comparative analysis of the various technological options for electricity generation.[287] The review, written on the basis of technical assessments by the AEA's *Energy Technology Support Unit* (3.4.2), gave by far its greatest consideration to nuclear power technologies. In its consideration of fossil fuel combustion technologies, the review conceded that "no research is being carried out at present ... on alternative methods" other than coal-fired steam turbines.[288] Gas turbines were not given any specific mention in the report.

In its 1977 *Energy Policy Review*, the Labour Government stated that gas prices should be set at a level sufficiently high so as not to encourage the wasteful use of "this precious resource".[289] At times the review appeared to reflect a Government opinion of natural gas as an unwelcome threat to coal and nuclear expansion: consideration was given to the possibility of delaying gas pipeline construction, so as to avoid increasing the total level of gas supplied to Britain, which, it was argued, would "accentuate short term problems for coal and electricity".[290] The review concluded that "since gas is regarded as a premium fuel, it is perhaps unlikely that its consumption will increase significantly".[291]

In a speech delivered in 1978, the then Chairman of the CEGB, Glyn England, reviewed the CEGB's fifteen years of experience of using small aeroderivative gas turbines.[292] By this time the CEGB had 2.2GW of gas turbine capacity installed in 148 small aeroengine

[287] Department of Energy, *Energy Research and Development in the United Kingdom*, Energy Paper 11, London, HMSO, 1976
[288] ibid:71
[289] Department of Energy, *Energy Policy Review*, Energy Paper 22, London, HMSO, 1977
[290] ibid:28
[291] ibid:42
[292] Glyn England, *The Gas Turbine – A Successful Developing Technology*, London, CEGB, 1978

units, with a further 1.4GW under construction – providing a total of 5.5% of system capacity.[293] Although he recognised their low capital cost, England pointed to the low efficiency and high running costs of gas turbines, and he stated that the CEGB had experienced poor reliability with their use. England recognised that "the last decade has seen major developments in gas turbines", but he associated the relevance of these developments for the CEGB solely in terms of the possible adaption of CCGT plant for use with coal gasification technologies – a configuration, he concluded, which was "not able to gain any advantage" over conventional steam turbines. Given the prohibition of using natural gas, England dismissed any role for CCGT plants in the CEGB system:

> Many electricity supply utilities, in an attempt to improve the efficiency of the gas turbine, have installed combined cycle plant. The CEGB has not done so, because the combined cycle is uneconomic with the distillate fuel we would have to use.[294]

As well as CEGB, the British Gas Corporation was a powerful opponent to the use of gas for electricity generation in the 1970s, even in highly efficient combined heat and power plants. Having a statutory monopoly, they would only supply gas for what they considered appropriate applications, and to ensure this, under their supply contracts, they were permitted to inspect industrial premises. British Gas were known to have declined a number of fuel contracts for proposed industrial CHP plants in the 1970s.[295]

The 1979 Department of Energy/ETSU review of *Energy Technologies for the UK* reiterated the view that gas turbines were of only marginal importance as a future electricity generation technology. The review stated that above 10-15MW, gas turbines were more expensive than conventional steam turbines. It was also argued that, since "supplies of gas are likely to decline sharply, perhaps around the turn of the century or a little longer", gas turbine technology was of little significance for the long-term development of the British ESI.[296]

In the early- and mid-1980s the British ESI – and government – remained firmly committed to nuclear power and steam turbine technology for providing all its large-scale power generation, in terms of both present production, and its future investment plans. In the *Institute of Energy* 1986 review of future energy supply and generation technology

---

293 Because of their low load factors (typically under 1%), gas turbine plant remained insignificant in terms of fuel consumed.

294 England, op cit:12

295 N. White, 'The Future for Natural Gas in European Power Generation', I.Mech.E. Seminar, *Combined Cycle Gas Turbines* 12-10-90, pp5-21:7-8

296 Department of Energy, *Energy Technologies for the UK: An Appraisal for Research, Development and Demonstration Planning*, Energy Paper 39, London, HMSO, June 1979:45

(3.4.5), reference was made to the "renewed interest" in combined cycle gas turbine (CCGT) technology.[297] The report argued, however, that the thermal efficiency gains offered by CCGT plant could only be gained at the cost of increased capital costs. This conclusion was based on the extra costs involved in adapting CCGT plant for coal gasification – despite the falling cost of natural gas, the report gave no consideration to natural gas fuelled CCGT plant.[298] Indeed, the report referred to natural gas as "a premium fuel not normally to be used in quantity for electricity generation".[299]

The Sizewell B Public Inquiry, which heard evidence for over two years in the mid-1980s, also gave little consideration to developments in CCGT technology – although all of the evidence to the inquiry was submitted before the collapse in oil and gas prices in 1986.[300] In reviewing potential new generation technologies, the inquiry chairman, Sir Frank Layfield, reported that the CEGB's opinion that, although CCGT plant offered lower construction costs, and "potentially higher" overall efficiency than a comparative coal-fired steam turbine plant, it remained unattractive investment because of the high price of gas.[301] By the time the report was published at the beginning of 1987, gas prices had collapsed.

In early-1987 the Department of Energy / Energy Technology Support Unit published another in their occasional reviews of *Energy Technologies for the UK*.[302] The 1987 review was the first under the Thatcher-led Conservative government's of the 1980s, and it took place in a very different political climate than its predecessors. Whereas similar Department of Energy / ETSU reviews of the 1970s had focused largely on the 'technical' potential of different forms of generation technology the new emphasis, as the introduction to the review stated, was on a more "market view" of technology assessment. By 1987 oil and natural gas prices had fallen dramatically, CCGT technology undergoing rapid development, and the 'cogeneration boom' in the USA was well under way (as discussed in 3.5.3). Nevertheless, natural gas was only briefly mentioned as a potential electricity fuel in the 1987 *Energy Technologies for the UK*. Indeed, in a consideration of deployable large-scale electricity generating technologies, only coal-fired technology was considered as an alternative to nuclear power.

---

297 Institute of Energy, *Energy for the Future* (2nd edition), London, Institute of Energy, 1986

298 The report suggested that falling oil and gas prices in the mid-1980s were a correction to inflated prices in the preceeding decade after the oil-shocks, and that they would subsequently rise along the lines predicted in 1973 (ibid:12).

299 ibid:31

300 Department of Energy, *Sizewell B Public Inquiries*, (Sir Frank Layfield), London, HMSO, 1987

301 ibid: Chapter 60, p3, para60.10

302 Department of Energy, *Energy Technologies for the UK 1986 Appraisal of Research, Development and Demonstration*, Energy Paper 54, February 1987

The supporting background technical papers to the review, written by the AEA's Energy Technology Support Unit (ETSU), were sanguine about the pattern of UK energy research and development investment (3.4.5). In its detailed review of electricity production technologies, ETSU stated that "because of their higher fuel costs, gas turbines have low load factors ... The installed capacity ... is significant at just over 3GW, but there are no RD&D requirements for these mainly aero-engine based, low load factor machines".[303] ETSU made no mention of CCGT technology in its discussion of "electricity production" technologies, but combined cycle plant *was* considered in a later section of the report as an "electricity utilisation technology" – in terms of industrial CHP applications. Here, ETSU emphasised the importance of coal gasification technologies for the exploitation of combined cycle technology in the British ESI. It added that gas turbine CHP required little government support other than the sponsoring of demonstration plant: "CHP technologies ... are generally well-established, and little R&D as such is undertaken".[304] In considering the relative under-investment in CCGT/CHP technology in the Britain as compared to many other European countries and the USA, ETSU argued that investment had been held back by short-termism in the private sector.

The CEGB's Annual Report for 1986/87, published in July 1987, made little mention of CCGT technology.[305] In its discussion of future generation technologies, the report again concentrated largely on coal-fired steam turbines and PWR nuclear power. CCGT technology was discussed solely in terms of its adaption for use with coal gasification or fluidised bed technologies, stating that "design studies of these options are in progress".[306] At a joint Electricity Council/CEGB press conference to announce their annual reports in August 1987, the CEGB Chairman Lord Marshall argued that the prospects for competition in generation after ESI privatisation would be limited by the price and availability of natural gas.[307]

303 Department of Energy/ Energy Technology Support Unit, *Background Papers Relevant to the 1986 Appraisal of UK Energy Research, Development and Demonstration*, ETSU R-43, London, HMSO, February 1987:B91, B93
304 ibid:E96
305 *CEGB Annual Report and Accounts*, London, CEGB, July 1987
306 ibid:28, 31
307 'ESI is Ripe for Privatisation', *Electronics and Power*, August 1987, pp486-487

3.6 Summary and Review

3.6.1 Generation Technology and the Development of the ESI

The early development of British ESI – and the early technical form of electricity generation – whilst it was made possible by scientific advance, appears to have been shaped primarily by local political interests, enshrined in restrictive legislation. Small-scale DC electricity generation technology fitted well into the British tradition of locally-provided public services. As both Hennessey and Self and Watson argued, however, it was the interaction of the industry's early regulatory and organisational framework, with techno-economic changes in generation and transmission, that created problems for the early British ESI (3.2.1).

At the beginning of the twentieth century a dominant technological form for electricity supply emerged, based on coal-fired steam turbine generation and high-voltage AC transmission. The most economically efficient use of these technologies involved large turbine units serving large interconnected supply areas, and, in this way, they rendered archaic much of the early regulatory and organisational framework of the industry. Before 1914, however, the expansion of the technological infrastructure of electricity generation was frustrated by outdated and restrictive legislation. Both Hannah and Landes described the relative backwardness of the early British ESI in terms of a failure to develop a "technocratic tradition" (3.2.1).

The First World War made the case for reorganisation of the ESI a priority for national government. Hughes described the effect of the war as breaking a "conservative crust" that had hitherto frustrated the rationalisation of the industry (3.2.2). In Britain, however, reform was hesitant and ineffective until the mid-1920s. The Weir Report argued that the provision of cheap, abundant, electricity would only be possible with the concentration of generation on a small number of large steam turbine stations (3.2.2). The 1926 Electricity Act introduced the national management of the British ESI under the Central Electricity Board, and also initiated the construction of the national transmission grid. After 1926, municipal authority influence on the industry waned, and generation and transmission technology advanced rapidly in efficiency and scale. A 'virtuous circle' of falling production costs and growing market demand meant that electricity diffused through the economy. At the same time, under predominantly Conservative Government, the private ownership of generation plant was preserved.

The national grid embodied in technical form the case for centralisation and rationalisation of the industry, and it greatly accelerated the wider adoption of advanced generation techniques. As Hughes pointed out, in a conducive political and regulatory context, the ESI during the interwar period could be said to have developed in accordance with the techno-economic potential of generation and transmission technology (3.2.2). Hughes also characterised the changes in this period in terms of the building-up of vested interests, growing momentum, and the co-evolution of institutional and technical forms (3.2.2). Coal-fired steam turbines were the only significant form of electricity generation technology at this time. Within this, technological developments involved the introduction of progressively larger turbine units, and higher steam temperature and pressure. Considerable improvements in the thermal efficiency of plants was achieved.

Postwar nationalisation of the ESI in 1947 was underpinned by a belief – within both the Labour Government and the industry itself – that centralised control under public ownership was the most appropriate organisational form for realising the potential of large-scale generation and transmission technologies. Herbert Morrison referred to ESI nationalisation as an act of "commonsense" (3.3.1). As Hannah identified, it was also a fulfilment of the technocratic tendencies that had built-up in the industry by this time. However, the public ownership of generation plant never commanded universal support, and nationalisation was opposed in parliament by Conservative MPs, who – echoing the views of the 1925 Weir Report – called for the retention of competition in generation (3.3.1).

For many years after nationalisation, the choice of generation technology type and size was determined largely by the pressing concern of government and the BEA simply to meet demand under chronic plant capacity and fuel supply shortages. In the mid-1950s these concerns prompted politically-led diversification into oil-fired steam turbine and nuclear power technology (3.3.1; 3.3.2). Both nuclear and oil-fired plant were a more expensive form of generation than coal-fired plant at the time they were introduced, and both were forced on a reluctant BEA by government.

The structural changes to the ESI introduced in the mid-1950s were a response to the continuing postwar capacity crisis, and the perceived technological backwardness of the BEA. Beyond this, however, debate on the most appropriate organisational structure of the industry was dominated by the perceived need to accommodate a large programme of nuclear power. Parliamentary debate on the proposed reforms to the ESI in 1956-57 took place in the midst of the Suez Crisis, and was overshadowed by fuel supply security fears, and a concomitant desire to build the industry around the nuclear programme (3.3.3).

In such a context, the CEGB was created precisely so as to give a technological lead to the industry, and to rapidly progress the development of nuclear power – as demonstrated by the government's choice of a nuclear scientist, Christopher Hinton, to head it. In rejecting the Herbert Committee's proposals for a powerful supervisory Central Authority, the government had left the CEGB largely unchecked in its ability implementing its preferred strategy for generation technology (3.3.3). Together with the Atomic Energy Authority, the CEGB provided a secure and stable organisational environment for the British nuclear power programme right up to the late-1980s.

From the late-1950s until the late-1980s, the British ESI can be described as *corporatist* – in that institutional and political interests became the dominant influence on the development of generation technology.[308] Within this, the most powerful corporate bodies were the government, CEGB, NCB/NUM and the AEA. The 1963 Select Committee on Nationalised Industries inquiry on the ESI (3.3.4) echoed the concerns of the Herbert Committee concerning the absence of a "technical check" or "adequate professional scrutiny" regarding the CEGB's investment programmes, but in the absence of stringent financial controls, an emphasis on technical quality and refinement, rather than economic criteria such as rates of return, became dominant.

By 1970 the CEGB's Chairman Stanley Brown was in a position to outline with confidence the nuclear power-centred future of the ESI over the next quarter-century (3.4.1). Brown's predictions were based on a number of technical, economic, political and organisational assumptions: the continuity of demand increases, escalating fossil fuel scarcity and prices, reductions in the cost of nuclear technology, and above all, continuity of the institutional power of the CEGB itself. In reality, the industry experienced the progressive breakdown of technical, economic, and political continuity after 1970. The oil-price shocks and the development of North Sea oil and gas meant that the economic environment of the ESI became much more uncertain in the 1970s. For around a decade, however, from the mid-1970s to the mid-1980s, the oil-shocks reinforced corporate decisionmaking in the industry, in a similar fashion to the reaction to the Suez crisis in the mid-1950s (3.4.2).

The energy policy debate of the 1970s was conducted on essentially technocentric terms, and was dominated by the government's attempt to construct a long-term strategy for fuel and technology choice. Policy debate was dominated by discussion of competing

[308] In their analysis of the industry at this time, Jane Roberts *et al.* took Schmitter's definition of corporatism as a "system of interest group intermediation", characterised by powerful 'insider' interests. Applying this to the British ESI, they identified the insider groups as central government, the generating and distribution boards, the coal industry, plant construction industry, nuclear industry, and trades unions. (Jane Roberts, et al., *Privatising Electricity: The Politics of Power*, London, Bellhaven Press, 1991:39.)

technological options – notably the choice of nuclear reactor design – and technological expertise again commanded great authority. The technology-led response to the energy crisis was personified by Walter Marshall, Chief Scientist at the Department of Energy during these years. In the Department's 1976 *Review of Energy R&D*, Marshall asserted that there was no need to consider "non-technological factors" in the analysis of competing technical forms (3.4.2).

The Plowden Committee Report of 1976 advanced a number of technical arguments for the re-integration of the ESI along the lines of the 1947 Act (3.4.4). Like the Herbert report twenty years earlier, the Plowden report proposals were heavily conditioned by the committee's assumption of the central role of nuclear power in the industry's future. The report rejected of any splitting-up of the CEGB on the basis that "the country can no longer afford to try two different approaches to major strategic choices such as a new reactor type", and stressed the importance that "the electricity industry continues to speak with one voice to match the increased concentration in the nuclear design" (3.4.4).

The 1979 General Election marked the end of the political consensus that had supported corporatism since 1945. Thereafter, a long unbroken period in office enabled Conservative government to impose its wider policies of liberalisation and privatisation on the ESI, although its initial efforts were cautious, and failed to overcome entrenched interests in the industry. Even after its statutory supply monopoly was ended by the 1983 Energy Act, the CEGB continued to exert effective monopoly authority in electricity generation. At the same time, large-scale coal-fired and nuclear power generation technology continued to wholly dominate the British ESI (3.4.5).

The Institute of Energy 1986 review of energy policy amounted to a manifesto for a return to a corporatist, technology-led, energy policy (3.4.5). The Institute was highly critical of the Conservative government's aim of introducing market-based decisionmaking into the energy industries. The presupposition of the report's authors – like numerous other similar reports issued in the 1970s and early-1980s – was that investment in electricity generation technologies should be decided by technical experts alone, on the basis of their superior understanding of the "complex technical and commercial factors" involved.

3.6.2 Steam Turbine Technology in the ESI before Privatisation

Coal-fired steam turbine technology emerged as the dominant technical form for electricity generation around the turn of the century; it remained unchallenged as such throughout the twentieth century into the 1980s. Together with high voltage transmission, coal-fired steam turbines were able to provide low-cost electricity in bulk. By doing so, these technologies greatly stimulated demand and the development of new applications for electric power, and made possible the electrification of society in the interwar period. They also transformed the most economically efficient organisational and legislative arrangements for the ESI.

Throughout the twentieth century up to the 1960s, sustained improvements were made in the performance of coal-fired steam turbine technology. Incremental developments in turbine materials and cooling techniques allowed for higher steam temperatures and pressures, and at the same time progressively larger turbine units provided for increased economies of scale. During the interwar period the national grid greatly encouraged the wider adoption of the engineering standards of the most technically advanced plants. After the Second World War, the immediate emphasis was on meeting demand by building small, technically modest plant, but from the mid-1950s onwards, the CEGB adopted very large turbine unit sizes. By the late-1960s, however, the rate of improvement in steam turbine technology was slowing down as limits on material performance were reached (3.4.2).

From the late-1950s onwards the long-term technological interest of the CEGB lay with nuclear power, as reflected, for example, in Stanley Brown's predictions for the future development of the industry in 1970 (3.4.1), and the very similar forecast by John Baker in 1985 (3.4.5). Coal-fired steam turbine technology – although it dominated generation in terms of capacity installed – attracted relatively little R&D effort as compared to nuclear power; it was seen as a mature technology of relevance only in the short and medium term. Nevertheless, protected by powerful vested interests, and in the absence of any serious rivals, fossil fuel-fired steam turbine technology continued to dominate the industry in terms of electricity generated.

During this period the ESI was used by successive governments to provide a protected market for the British coal industry, as the CEGB was required to use indigenous coal. The defeat of the NUM in the 1984/85 miner's strike resulted in the disempowerment of a powerful institutional support for coal-fired generation. Nevertheless, the first two Conservative governments of the 1980s were unwilling to impose radical change on the industry, and indeed, they oversaw the signing of successive Joint Understandings between the CEGB and NCB, which ensured that coal-fired steam technology continued to dominate electricity generation up to the late-1980s (3.4.4).

3.6.3 Nuclear Power Technology in the ESI before Privatisation

Civil nuclear power was essentially an offspring of military nuclear technology, and as such, its institutional, economic, and political context was quite different from fossil-fuel generation technology. From its outset, the British nuclear power programme was driven by political interests over and above economic considerations. In announcing the first nuclear programme in 1955, the Government expressed its faith that "whatever the immediate uncertainties, nuclear energy will in time be capable of producing power economically" (3.3.2). Nuclear power also commanded uniquely strong institutional support, in the form of the Atomic Energy Authority and CEGB. From the mid-1950s, the development of nuclear power technology lay primarily with the AEA, a body which was granted from its creation, as Williams described "a rather special autonomy" (3.3.2). The reorganisation of the ESI in the mid-1950s was conducted largely in terms of the perceived needs of nuclear technology (3.3.3), and the CEGB was purposely created to be a pro-nuclear generator. Both the CEGB and AEA were overtly *technocentric* in outlook – their emphasis was on the solution of technical problems over and above of any economic considerations.[309]

The decision to proceed with the AGR programme in the 1960s was, according to Williams, a consequence of the "technological momentum" that had been built up behind the technology by the AEA. He suggested that, by this time, the British nuclear programme had become institutionally committed to a reactor design conceived in British post-war circumstances – a design that proved impossible to make commercial (3.3.4). By the mid-1960s, however, previously unheard scepticism was emerging from backbench MPs and the CEGB regarding the cost of nuclear power. In the 1970s the momentum behind the nuclear programme was further eroded, as the technical problems involved with the AGR design, and also with the short-lived SGHWR, became increasingly apparent (3.4.3). Nevertheless, both the government and the industry itself remained convinced about the necessity of a large nuclear programme, and their attention was focused largely on issues such as the choice of reactor type.

---

309 In their analysis of technocentrism in the British ESI at this time, Roberts et al. argued that "those holding such a view will tend to look kindly on nuclear power, admiring the scientific and technological achievement it embodies, while believing that the application of further technology will be able to ameliorate its associated problems, such as those of decommissioning and waste management" (Roberts et al., op cit:103).

Despite their declared intention to operate a market-based energy policy, the Conservative governments of the 1980s, from the outset, made special exemptions for nuclear power. Up to the mid-1980s, the CEGB and government justified their support of nuclear power in part on economic grounds. This was evident, for example, in Nigel Lawson's 1982 speech (3.4.4), and also in the CEGB's evidence to the Sizewell B public inquiry, as summarised in John Baker's 1985 speech. Here, Baker claimed that nuclear power was "was by far the cheapest generating cost on the system" (3.4.5). Whilst criticism of the CEGB intensified in the 1980s, in a context of continued government support, there was nothing to seriously challenge the CEGB's proposed programme of investment in PWRs. Elsewhere, however, nuclear power programmes were stalling under increasingly tough legislative demands and more competitive economic conditions. The Institute of Energy argued that these problems were a reflection, not of any inherent technical and economic problems associated with nuclear power technology, but rather political opposition and restrictive legislation (3.4.4). The Institute called for a return to unchallenged technocentric authority in the ESI. Their implicit assumption (shared with many critics of the nuclear programme) was that the British nuclear power programme was *predicated* on a technocentric government-led energy policy framework.

In an analysis of the evolution of electricity generation technologies in the twentieth century, Gordon MacKerron argued that for a period of around thirty years, from the introduction of nuclear power in the mid-1950s, up to the mid-1980s, innovation in generation was driven by *technology-push* rather than *demand-pull*.[310] MacKerron pointed out that the introduction of nuclear power in the 1950s marked a radical change in type for electricity generation technology: by contrast to the primarily economic incentives that had driven forwards the development of coal-fired steam turbine technology in the interwar period, nuclear power was driven by 'technology-push'. Unlike fossil fuel generation technology, nuclear was complex and inflexible, and the normal pattern of falling costs in the course of technological development, associated with learning and economies of scale, were outweighed by design complexities, and progressively more stringent safety criteria. MacKerron also considered the breakdown of technology-push dominance in the 1980s (see also 3.5.3). In the course of the 1980s, he pointed out, many governments became increasingly keen to cut public expenditure, and as fossil fuel prices fell rapidly and reserves increased, long-term energy policymaking

[310] Gordon MacKerron, 'Innovation in Energy Supply: The Case of Electricity'. Unpublished draft prepared for inclusion in *Handbook of Industrial Innovation*, by M. Dodgson and R. Rothwell (eds.), Cheltenham, Elgar, 1994. Assessing the relative contributions of 'demand-pull' and 'technology-push' to technological change has been a recurring theme in technology policy studies since the 1960s. See, for example, R. Coombs, P. Saviotti, and V. Walsh, *Economics and Technological Change*, Basingstoke, MacMillan, 1987:96-103, 206-7

went out of fashion. R&D expenditure was reduced, and became more tightly focused on more incremental, less radical, technologies.

3.6.4 Gas Turbine Technology in the ESI before Privatisation

For most of the twentieth century, gas turbine generation technology was of little interest to electrical plant equipment manufacturers and electricity utilities. Early gas turbine engines, designed along similar lines to steam turbines, were inherently inefficient. A radical change in gas turbine design came about with the invention of the turbojet in the late-1930s (3.5.2). However, whilst turbojet designs progressed rapidly in the postwar period, the massive research efforts of the turbojet manufacturers were ill-suited to the more robust and larger-scale needs of electricity production. During these years the research and development efforts of the electrical manufacturers and utilities were concentrated – with considerable success – on improving steam turbine technology. In the British ESI, the interests of the CEGB and the British plant manufacturers lay firmly with large nuclear and coal-fired plants. Whilst the CEGB installed a number of small aeroderivative gas turbines for peak load and standby use in the early-1960s, as the CEGB Chairman Lord Hinton told the Select Committee on Nationalised Industries, these were a "reluctant" investment, made only in response to pressing capacity shortages (3.5.4). For much of the postwar period, industrial gas turbines remained an under-developed and marginalised technology.

After the mid-1960s, the discovery of large reserves meant that the use of natural gas for electricity generation grew rapidly around the world. Whilst much of this growth involved the use of conventional steam turbine plant, it also included small aeroderivative gas turbines for peak or standby plant, and also some use of small and medium sized CCGT plants. Although CCGT units were under 100MW at this time, they were already more thermally efficient than conventional steam turbine plant – particularly in industrial CHP uses (3.5.2). In the late-1960s and early-1970s the prospects for CCGT technology appeared reasonably good. In 1970 Wood, for example, predicted "continued demand" for CCGT plant, given the chronic problems facing nuclear and coal-fired generation technology (3.5.2). After the discovery of natural gas in the North Sea in the mid-1960s, there is some evidence that the CEGB was considering the installation of medium-sized CCGT plants for mid-merit use – although CCGT technology was not expected to make a major impact on the dominant position of coal-fired and nuclear power plant. In 1970 the then Chairman of the CEGB, Sir Stanley Brown, referred to the "quite promising" prospects for such plant (3.5.4).

In the event, following the first oil shock, the use of natural gas for electricity generation became prohibited by statute, other than in exceptional circumstances. It was also opposed by the powerful 'corporate' bodies in the British ESI, including the CEGB and British Gas. Indeed, there is evidence that the development of natural gas reserves was actively resisted at this time, and the price of gas kept artificially high, so as to protect the market for coal and nuclear power (3.5.4). The Government's 1977 Energy Policy Review, for example, reacted with hostility to the possible expansion of natural gas production and supply – seeing it as a threat to the established technologies of energy provision. In the extensive series of reviews of energy technologies in the 1970s, gas turbine and CCGT plant were scarcely considered, and where they were mentioned, it was only in terms of small industrial CHP applications, or their possible adaption for coal gasification (3.5.4). Throughout this period, up to the late-1980s, gas turbine generation technology remained institutionally marginalised and under-developed in the British ESI.

The mid-1970s *Institution of Mechanical Engineers* conference on the status and prospects of gas turbines reflected the prevalent view that the restrictions on natural gas supply meant that an alternative fuel would have to be developed before gas turbines could gain greater use in power generation. However, the conference also reported the development, by a number of American and European manufacturers, of a new generation of larger industrial gas turbines which incorporated advanced technical features originally developed for aero-engines (5.2.2). One of the engineers involved in the development of these engines, T. E. Thorén of Stal-Laval, argued that modern CCGT plant already offered the cheapest for of generation for peak and intermediate use, and would "play a significant role in the new energy situation" (3.5.2).

The development of turbojet technology continued apace during the 1970s, in part in response to greater pressure for fuel efficiency. In his analysis of the commercial development of gas turbine technology, Jim Watson emphasised the importance of the "technological flexibility" of gas turbines – in terms of their application in both aerospace and industrial markets.[311] The aero-engine market for gas turbines, Watson pointed out – driven largely by military defence contracts – sustained its technological development during long periods in which the industrial market remained small.

The commercialisation of CCGT technology in the 1980s was realised on an international stage in response to factors which were essentially unrelated to events in the British ESI. Much of the important technological developments in the early-1980s took place,

311 Jim Watson, 'The Technology that Drove the Dash for Gas', *Power Engineering Journal*, February 1997, pp11-19:16

ironically, as a response to restrictions on the use of gas imposed by the legislature of the late-1970s. Within a protective legislative and regulatory framework, a significant market developed for small-scale CCGT/CHP plant in the US in the early-1980s (3.5.3).

In response to the increased viability of gas-fired generation after the collapse in gas prices in 1986, a new generation of larger industrial gas turbines were introduced. Before this time, the market for industrial gas turbines had been insufficient to warrant the adaption of established aero-engine technology for use in power generation. By the mid-1980s, however, the improving prospects for gas-fired generation were encouraging the transfer to power turbines of a number of established aero-engine techniques. After 1986 CCGT technology became a central concern of a few major international plant manufacturers, and also gained the interest of a number of more deregulated and flexible utilities and independent power companies. Thereafter, a virtuous circle of growing market sales, and the expansion of dedicated research effort, provided for further rapid improvements in CCGT technology performance and competitiveness.

In the British ESI, however, CCGT technology remained underdeveloped and institutionally marginalised in the mid-1980s. Opinion in the industry displayed a mixture of scepticism and ignorance. Among the vast amount of analysis and opinion submitted to the Public Inquiry on the Sizewell B PWR plant, there was very little attention drawn to gas turbine technology – although, in mitigation, this was all voiced before the 1986 fall in gas prices, and reflected the then dominant presumption that underpinned much energy policymaking, that gas and oil prices would inevitably rise steadily in the future (3.5.4). In their 1986 review of energy technology, the Institute of Energy dismissed any significant role for CCGT in the British ESI on the basis that it was only feasible if adapted for use with coal gasification technology (3.5.4).

In the early- and mid-1980s, when liberalisation of the British ESI was first discussed, CCGT was not a commercial option for electricity generation. In contemporary analyses of the possible impact of greater competition in the ESI, such as one by the present author in 1987, the possible use of CCGT technology for large generating plant was not considered. Rather, it was thought that the adoption of private sector financial criteria by the British ESI would lead to a switch in favoured generation technology from nuclear power to coal-fired steam turbines using imported coal: "the implications of a higher required rate of return ... has been highlighted by the Government's proposed privatisation of the ESI ... [this] would result in a switch from nuclear-based, to imported-coal expansion of the electricity sector".[312]

In their 1987 review of *Energy Technologies for the UK*, neither the Department of Energy nor the Energy Technology Support Unit made any acknowledgement of international developments in natural gas availability and CCGT technology. Indeed, in their supporting technical papers for the review, ETSU expressed their approval of a pattern of R&D spending overwhelmingly dominated by nuclear power technology, and suggested that there were "no RD&D requirements" for gas turbine plant (3.5.4). By classifying CCGT/CHP as an "electricity utilisation" rather than an "electricity production" technology, ETSU was able to rationalise the neglect of gas turbine technology in the British ESI within the wider context of the gross imbalance in investment between electricity *production* and *use* technologies – an imbalance that had characterised energy supply in Britain for decades. In this way, the marginalisation of CCGT technology in Britain could be presumed to be simply a consequence of the different investment conditions of public and private industries. The gulf between public and private sector investment criteria was to have profound consequences for the British ESI in the privatisation process from 1987 onwards.

[312] Mark Winskel, *Theoretical and Practical Aspects of Cash-Flow Discounting: The Case of the British Energy Sector*, unpublished M.Sc. dissertation, Imperial College of Science Technology and Medicine, University of London, October 1987:69-70

CHAPTER 4:

NUCLEAR POWER TECHNOLOGY AND ESI PRIVATISATION

4.1 Introduction

In reviewing the British privatisation programme of the 1980s, Dennis Swann argued that the Government's policies were "substantially inspired by considerations of political ideology".[1] As Roberts et al. pointed out, however, the actual implementation of the British privatisation programme was often dominated by pragmatism and expedience, with an "overriding objective ... to accomplish the sales quickly".[2] In the case of the ESI, these ideological and pragmatic motivations were mixed together – with what proved to be awkward results.

Electricity is an awkward market good. The natural monopoly in the network transmission and distribution infrastructure, non-storability of AC – combined with varying demand patterns, and the high capital cost of plant, mean that free market competitive forces cannot by themselves provide secure supplies, and some regulation and co-ordination by the state is always necessary.[3] Although electricity generation, unlike transmission and supply, is not generally considered to be a natural monopoly, there are considerable technical and economic constraints on its trade. Non-storability means that supply and demand must balance at all times, even though demand varies diurnally and annually, sometimes unpredictably. In addition, generation plant is capital intensive, requires long lead-times, and cannot be switched on and off immediately. In economic terms: "there is no market price mechanism by which demand can match supply on operational timescales."[4]. Vickers and Yarrow express this as a basic mismatch between technical and economic imperatives: "fully decentralised market transactions cannot meet the technological need for continuous market equilibrium".[5] As was described in Chapter 3, the history of the British ESI throughout the twentieth century up into the 1980s is one of progressive centralisation of control, at least in-part in response

1 Dennis Swann, *The Retreat of the State: Deregulation and Privatisation in the UK and the US*, Hemel Hempstead, Harvester Wheatsheaf, 1988:316

2 Jane Roberts, et al., *Privatising Electricity: The Politics of Power*, London, Bellhaven Press, 1991:26. They went on to suggest that the objectives of privatisation were: to free industry from the financial constraints of the public sector, financing the PSBR, promoting popular capitalism, and improving productive and allocative efficiency (ibid:24-26)

3 J Vickers and G Yarrow, 'The British Electricity Experiment', *Economic Policy*, Vol.6, pp187-232, 1991:190

4 Imperial College evidence to the Energy Select Committee, HC 307, 1987-88, Vol II:313

5 Vickers and Yarrow, op cit:190

to these technical imperatives. The construction of a competitive market in electricity was therefore to some extent an attempt by a government ideologically committed to economic liberalisation to impose its policy wishes in the face of technical constraints.

The focus of this chapter is the interaction of nuclear power generation technology with the British ESI privatisation process. At the same time, some consideration is given to more general aspects of privatisation, particularly the Government's measures to restructure the industry so as to introduce greater competition in generation. The chapter is divided into four main sections: Section 4.2 reviews the early debate on ESI privatisation and the Government's 1988 White Paper proposals; Section 4.3 reviews the passage of the Electricity Bill from 1988 to 1991; Section 4.3 considers the changes affecting nuclear power in the period after 1991; Section 4.5 offers a consideration of the interaction of the privatisation process with nuclear power technology research and development (R&D), particularly the fast reactor research programme. Finally, Section 4.6 provides a summary of the chapter, and a more analytical reflection of the issues raised.

4.2 Nuclear Power Technology and the ESI Privatisation Process

4.2.1 Policy Formulation

In June 1987 the Conservative Party was returned for a third successive term, with twin commitments to privatise the ESI, and secure the future of nuclear power.[6] Those utilities already privatised, notably British Telecom and British Gas, had been sold off as unreconstructed neo-monopolies, and were attracting substantial criticism by this time for their perceived profiteering.[7] There was considerable pressure on the Government to introduce competition from the outset in the case of electricity supply privatisation.

In July 1987 the new Energy Secretary, Cecil Parkinson, stated in Parliament that the Government "recognise the need to introduce competition into the electricity supply industry", and he indicated that he was prepared to undertake radical restructuring of the industry.[8] Such restructuring would be essentially unprecedented; *Power in Europe* pointed out that "there is very little competition within the electricity supply industry anywhere in the world ... In Europe the municipal origins of the industry remain very

6 In its 1987 General Election manifesto, the Government stated that it remained committed to "developing abundant low-cost supplies of nuclear electricity" (*The Next Moves Foward*, London, Conservative Party, May 1987).
7 British Gas was referred to the Monopolies and Mergers Commission in 1987.
8 HC Debates, Vol.119, 1987-88, c689

influential on present day practices".[9] In November 1987 Parkinson told Parliament that "a monolithic [ESI] without competition would be a handicap to the country ... I believe that there is plenty of scope for competition in generation, and we are working on proposals that will produce more competition".[10]

In 1987 the CEGB remained exclusively committed to nuclear power and coal-fired steam turbine technology for large generation plant. In January 1987 Sir Frank Layfield's report on the Sizewell B public inquiry recommended approval of the CEGB's planning application, on the basis that the PWR reactor was "likely to be the least cost choice for generation plant".[11] The Government granted planning approval for the plant in March. Shortly later the CEGB submitted an application for a second PWR, Hinkley Point C, and stated that other sites were under investigation for further similar plants. A CEGB pamphlet published in August 1987 declared that "almost the whole requirement for new capacity in the period up to the end of the century will have to be met by some combination of PWR and new coal-fired plant ... The PWR, new coal-fired plant and the AGR represent the main options for meeting capacity shortfalls in the next decade or so".[12]

The joint CEGB/Electricity Council memorandum to the Energy Select Committee's inquiry on ESI privatisation, submitted in early-1988, expressed confidence about the CEGB's proposed investment in coal-fired and nuclear plant; the memo stated that "there are developments in PWR and fast reactor technology, and in clean efficient coal burning systems, which should enhance the advantages of large plant ... economies of scale that can be achieved by large plant remain significant and valuable".[13] Under questioning by the Energy Committee in February 1988, the CEGB Chairman, Lord Marshall, remained confident about the prospects for nuclear power after privatisation; he told the Committee that "the benefits of nuclear power will survive that change".[14] He added that, in his view, nuclear power stations should be run by private companies after privatisation, without any subsidy from government.

Between the 1987 General Election and the publication of the Government's White Paper proposals for privatisation, a wide range of opinion was aired on the future structure of

---

[9] *Power in Europe*, No.11, August 20th 1987

[10] HC Debates, Vol.121, 1987-88, c634

[11] Department of Energy, *Sizewell B Public Inquiries*, (Sir Frank Layfield), London, HMSO, January 1987

[12] Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994:36-37; the document referred to is *Meeting Demand: Options for Future Generating Policy*, London, CEGB, August 1987.

[13] House of Commons Energy Committee, *The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector*, HC 307, 1987-88, Vol II:3

[14] ibid, Vol III:11

the ESI. In general, established interests in the industry argued for little change to its structure, whilst independent companies and analysts called for substantial restructuring. For many observers it was in *generation* in particular – which made up around three-quarters of the final cost of electricity – that the greatest potential benefits of competition were to be found. Proponents of liberalisation focused on two particular changes: firstly, the splitting-up of the CEGB into a number of competing generators, and secondly, the separation of ownership of the transmission grid from the generation plant.

In a paper published in March 1987, Alex Henney, an independent analyst of the industry, and a former member of the London Electricity Board, argued that restructuring of the ESI ahead of flotation was essential.[15] Henney suggested that the fossil-fuel generating plants of the CEGB and SSEB should be distributed between ten competing generating companies.[16] He also stated that in order to give the privatised distribution companies greater bargaining power with the generators, and become a "countervailing force", the grid should be transferred to their mutual ownership.[17] A number of other analysts offered similar proposals for the liberalisation and restructuring of the industry ahead of privatisation. Andrew Holmes et al. warned that without any breaking-up of the CEGB, there would be no changes to the established pattern of generation technology:

> A privatised ESI based on an 'all-in-one' sale will do nothing to make the ESI more commercially minded, or to force it to open up to new technologies like combined heat and power/district heating or combined cycle generation, both of which technologies it views with disdain. A national electricity company will ... almost certainly push ahead with centrally conceived capacity plans based on large power stations.[18]

On the other side of the debate, a number of individuals and organisations argued against any major changes to the industry, and questioned the benefits of any proposed restructuring. John Lyons, president of the Electricity Supply Trades Union Council (ESTUC), argued that ESI privatisation offered "only disadvantages, compared with the arrangements which have served us up to now", and added that "a vital and successful industry is being privatised for purely political reasons".[19] Lyons claimed that the

---

15 Alex Henney, *Privatise Power: Restructuring The Electricity Supply Industry*, Policy Study No. 83 London, Centre for Policy Studies, March 1987. Henney claimed that under the CEGB the choice of generation technology was dictated "not by commercial considerations but by the political interplay of vested interests" (ibid:7).

16 ibid:9

17 ibid:9

18 Andrew Holmes, John Chesshire, and Steve Thomas, *Power on the Market: Strategies for Privatising the UK Electricity Industry*, London, FT Business Information, 1987:7. Similar views were also expressed by Allen Sykes and Colin Robinson, in *Current Choices: Good and Bad Ways to Privatise Electricity*, Policy Study No.87, Centre for Policy Studies, London, October 1987;

19 'John Lyons' CEGB Entity Arguments Dismissed', *Electrical Review*, Vol.220, No.22, 16th-29th September 1987, p9-11; see also John Lyons, 'Privatising Electricity Supply Cannot Be Justified', *Energy Policy*, Vol.17, No.2, pp149-154, April 1989. In 1987-88 Lyons submitted similar arguments to the Department of Energy and also the Energy Select Committee.

integrated ownership of generation and transmission was essential to enable the most efficient use of the nation's generation plant in a 'merit order'. He added that in a competitive structure for electricity generation, without any guaranteed market for new power plant, there was a threat of future capacity shortages: "the most serious impact of breaking up the CEGB will be felt when it comes to the construction of new stations ... capital is not forthcoming in circumstances of insufficient certainty".[20]

The most powerful opponent of any radical restructuring of the industry was the CEGB, particularly its Chairman, Lord Marshall. Marshall had been reappointed CEGB Chairman for a second five year term in 1987. From mid-1987 onwards, a series of (often leaked) reports emerged from the CEGB, arguing that any restructuring of the ESI would threaten the technical and economic benefits offered by the present integration of generation and transmission. These views, closely associated with Lord Marshall himself, were voiced in parliament by Labour's Energy Spokesman, John Prescott. In November 1987 Prescott quoted Marshall's view, taken from a leaked CEGB document, that "breaking up the integrated power system [would] result in the loss of the benefit of economy of scale, seriously prejudice the security of supply, and increase prices".[21]

In evidence to the Energy Select Committee in February 1988, just days ahead of the publication of the White Paper, Marshall argued that the CEGB should be sold off in its present structure, and he gave a number of technical and economic reasons for opposing both the splitting-up of the CEGB, and the separation of ownership of transmission from generation. He told the Committee that "because electricity is not storable, and the grid does not operate as a simple pipeline, then transmission and generation should be integrated".[22] He also claimed that the British grid had been designed from the outset to integrate supply on a national basis, and was therefore ill-suited to a system of regional generators, as was found, for example, in West Germany: "the generating company needs to be integrated in the UK because that is the way the grid developed ... in other countries regional ownership led to regional grid structures".[23] Marshall also argued that the running of power plants in an efficient merit order was dependent on integrated national ownership of generation, and suggested that disintegration carried a threat to security of supply. In an attempt to lend authority to his views, Marshall repeatedly referred to the inside-knowledge of the CEGB, telling the Select Committee, for example, that "those who run the grid know most".[24]

---

20 'John Lyons' CEGB Entity Arguments Dismissed', op cit:9
21 HC Debates, Vol.121, 1987-88, c637
22 HC 307, 1987-88, op cit, Vol III:9
23 ibid:5
24 ibid:2

The CEGB and ESTUC case against ESI restructuring was challenged by other expert opinion. Robert Peddie, for example, a former CEGB member, stated that there were no technical problems with splitting-up generation and transmission, and he added that "continuity of technical expertise does not depend on continuity of ownership".[25] In September 1987, *Electrical Review* published a point-by-point rejection of John Lyons' technical and economic arguments against restructuring of the industry, by an anonymous group of electrical engineers and investment analysts.[26] The Electricity Council – which had been in the shadow of the CEGB ever since its creation in 1957 – was also known to be in favour of ESI liberalisation. In early evidence to the Energy Select Committee, Sir Philip Jones, Chairman of the Electricity Council, stated that "it is essential that the privatised industry be market-driven, and not technology-driven".[27]

The technical arguments over the future structure of the industry were repeatedly raised in parliament. In December 1987 John Prescott echoed Lord Marshall's claims that there were technical reasons why transmission and generation should not be separated. In response, Cecil Parkinson stated that whilst this was the CEGB's view, "there is a strong body of opinion that argues that transmission should be separated from generation if one is to encourage competition in generation".[28] In a later parliamentary question on the same issue, Tam Dalyell suggested that the breaking-up of the CEGB risked the security of power supply, and he asked "why do the Government think they know better than Lord Marshall?" Parkinson replied that "the Government think they know better than Lord Marshall because, although he is a learned a powerful figure in the industry, he is only one voice. There are many other people in the industry who know just as much ... as he does and who do not agree with him".[29]

4.2.2 The White Paper Proposals

In February 1988 the Government published its proposals for the restructuring of the ESI ahead of privatisation in twin White Papers – one for England and Wales, and one for Scotland.[30] The White Paper for England and Wales began by making a number of

---

[25] Robert Peddie, 'Who Should Own the Grid?', *Electrical Review*, Vol.220, No.21, 2-15 September 1987, pp16-17:17
[26] 'John Lyons' CEGB Entity Arguments Dismissed', *Electrical Review*, Vol.220, No.22, 16-29 September 1987, p9-11
[27] HC 307, 1987-88, op cit, Vol II:19
[28] HC Debates, Vol.124, 1987-88, c762
[29] HC Debates, Vol.133, 1987-88, c3, 9th May 1988
[30] Department of Energy, *Privatising Electricity: The Government's Proposals for the Privatisation of the Electricity Supply Industry in England and Wales*, Cmnd 322, February 1988; Industry Department for Scotland, *Privatisation of the Scottish Electricity Industry*, Cmnd 327, February 1988

critical references to the existing structure of the industry. It stated that this gave the CEGB "too much influence in power station investment decisions", and added that there was correspondingly "too little say to the Area Boards whose customers have to meet the costs".[31] It asserted that "there is no reason why there should not be competing power stations, supplying the Area Boards through the grid, and the Government believes it is not in the interests of customers to be supplied by a monopoly producer".[32]

The Government's proposals had the following main features:

- The generation assets of the CEGB were to be divided between two privatised generating companies (known later as *National Power* and *PowerGen*), with respectively 70% and 30% of the Board's generation assets. The larger company was to contain all the CEGB's nuclear plant. The privatised generators were not to be placed under any statutory obligation to supply.

- The 12 Area Distribution Boards of England and Wales were to be privatised as independent distribution and supply companies (known later as *Regional Electricity Companies, or RECs).* These were to be allowed limited rights to generate, up to a capacity limit (set later at around 15% of total demand within their franchise area), in order to prevent them becoming vertically-integrated regional monopolies.[33]

- Ownership of the national transmission grid was to be transferred from the CEGB to a newly-created transmission company (known later as the *National Grid Company*), which was to be jointly-owned by the twelve RECs. Electricity trading through the grid was to take place on a more transparent contractual basis, so as to facilitate access to the grid and distribution lines for independent generators.

- The RECs were to be required to contract for a specified minimum proportion of their electricity supply from non-fossil fuel sources, mainly nuclear power (this became known as the *Non-Fossil Fuel Obligation, or NFFO).*

- The two Scottish electricity boards were to be privatised, without substantial restructuring, as two independent vertically-integrated generation and supply companies, known later as *Scottish Power* and *Scottish Hydro-Electric*. The Scottish nuclear assets were to be jointly-owned by Scottish Power and Scottish Hydro-Electric, under a new holding company.[34]

- A *Director General of Electricity Supply* was to be appointed. The Director General was to have statutory responsibilities for the regulation

---

31 Cmnd 322, 1988, op cit:4

32 ibid:4

33 It was later decided that there was to be a progressive loss of REC local monopoly within their area supply franchises. For the largest electricity users (annual consumption above 1MW), this would apply from April 1990; for medium users (1MW to 100kW p.a.) from April 1994; for small users and the domestic market (under 100KW p.a.) from April 1998. (The decision to liberalise supply in this way was announced on the 29th September 1989.)

34 This less radical plan for Scotland reflected chronic over-capacity in the Scottish ESI, and the high proportion of overall capacity made up by nuclear power plant (over 50%). Given the Government's desire to secure the future of nuclear power, this meant that there was little scope for competition and new entry in generation in Scotland.

of electricity supply, the promotion of competition, and for ensuring fair access to the transmission grid and distribution lines. (The ESI regulatory body was later given the title of the *Office of Electricity Regulation, or OFFER.).*

The White Paper stated that "the Government's proposals will end the effective monopoly in generation and give more influence to the distribution companies and their customers".[35] The Government made clear that they were "determined to remove barriers to full and effective competition", and they claimed that under the new arrangements for the industry, "the distribution companies will have a very strong incentive to contract with the most efficient generating companies. Real competition in generation will develop".[36] The Government anticipated significant changes in generation after privatisation: "the prospect is for a more diverse and competitive electricity industry, with new types of power station, better equipped to meet the demands of customers".[37] It concluded that "decisions about investment in power stations will be driven by the distribution companies and so will reflect the needs of customers".[38] In presenting the White Paper to Parliament, Parkinson reiterated his view that there was "substantial room for competition in the electricity industry".[39]

The White Paper proposals were recognised as a radical break with established organisational and regulatory practices, both in the British ESI and elsewhere. The key features of the proposals were, firstly, the breaking-up of the CEGB, and secondly, the loss of generator ownership of the grid. In announcing these measures, the Government had rejected the CEGB's technical and economic case against restructuring of the industry. Henney stated that after the White Paper was published, "the CEGB was in a trauma of disbelief and shock that it was about to be broken up, and confusion as it was reorganised".[40] In parliamentary debate on the White Paper, Parkinson himself stated that he "did not expect the CEGB to welcome the reorganisation".[41] The transfer of the grid to the RECs represented a significant change in the balance of power in the ESI, as Sir Philip Jones made clear in evidence to the Energy Select Committee shortly after the White Paper was published; Jones stated that the proposals "transferred power from the production side to the retailing side. That is a long overdue and desired structure for the

35 Cmnd 322, 1988, op cit:2-3
36 ibid:14, 10
37 ibid:11
38 ibid:16
39 HC Debates, Vol.128, 1987-88, c456
40 Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, op cit:73
41 HC Debates, Vol.129, 1987-88, c54

industry ... the distribution PLCs have the incentive to go out and get the cheapest source of electricity".[42]

4.2.3 Provisions for Nuclear Power

From the time ESI privatisation was first suggested, it was widely recognised that selling-off the nuclear power stations – with their poor reliability record, and uncertain waste treatment and decommissioning costs – would present particular difficulties. It was also clear that the high capital cost of nuclear power technology meant that the progression of the CEGB's proposed PWR series would be very difficult in a privatised ESI. A number of independent analysts had argued early on that the British nuclear plants were not commercially viable, and should be withheld from privatisation. In May 1987 Andrew Holmes, the editor of *Power Europe* (later known as *Power in Europe*), argued that in the particular circumstances of the British ESI, nuclear power was unsaleable, and he concluded that "the only possible route is to leave the nuclear industry, at least in its present operations, in state hands".[43] Similarly, in a paper published in March 1987, Henney concluded that nuclear power "might well have to remain in public ownership for the present", and that in particular, the age of the oldest (Magnox) stations made them "clearly unsaleable".[44]

Other analysts argued that although nuclear power technology *was* privatisable, the protective measures needed to secure its sale would effectively stifle any possible benefits of privatisation. Colin Robinson and Allen Sykes argued that if it was not to be sufficiently opened up to competition, the entire ESI should remain in public hands; they stated that "privatisation is a necessary part of liberalisation ... but it is by no means sufficient".[45] In the evidence submitted to the Energy Select Committee in early-1988 (before publication of the White Paper), a number independent analysts suggested that for real competition to emerge in generation after privatisation, the CEGB's generating assets should be divided among several competing companies. Robinson and Sykes, for

---

42 HC 307, 1987-88, op cit, Vol III:291 (The Electricity Council was left with no role under the Governments proposals, and was subsequently disbanded.)

43 *Power Europe*, No.1, 28th May 1987, p2. Very similar views were expressed by A. Holmes, J. Chesshire, and S. Thomas in *Power on the Market: Strategies for Privatising the UK Electricity Industry*, FT Business Information, London, 1987. Here, the authors stated that "Britain has the oldest commercial reactor stock in the world; much of it is simply unsaleable" (ibid:7).

44 Alex Henney, *Privatise Power: Restructuring The Electricity Supply Industry*, Policy Study No.83 London, Centre for Policy Studies, March 1987:39

45 HC 307, 1987-88, op cit, Vol.II:230

example, called for "five or six" generators.[46] Similarly, Robert Peddie suggested a five company structure.[47]

In his memorandum to the Committee, Dieter Helm, of the London Business School and Institute for Fiscal Studies, argued that the future of nuclear power in a privatised ESI could only be secured by direct Government intervention:

> The nuclear commitment and its implementation will have a profound effect on the performance of the privatised ESI. Unless the Government is prepared to finance the nuclear investment programme directly – buying the security/diversity of supply in the marketplace – it will prove inconsistent with competition.[48]

The Government itself recognised, from the outset, that selling the nuclear power plants would be problematic, particularly given its parallel commitment to introduce competition in generation. In November 1987, when questioned in Parliament about the difficulties of reconciling privatisation with the continuation of the nuclear power programme, Cecil Parkinson stated that "fitting those two commitments together is one of the problems on which we are working and which we are achieving success".[49]

The White Paper proposals included specific measures aimed at securing the future of nuclear power under private ownership, notably the *Non-Fossil Fuel Obligation* (4.2.2).[50] The Government justified these measures on the basis of the contribution made by nuclear power to diversity and security of supply; the White Paper stated that "too much reliance on fossil fuels would increase the electricity industry's exposure to future price shocks of the kind witnessed in the last 15 years", and maintained that "there remains a vital strategic need for the significant non-fossil-fuelled contribution that can only be made by nuclear power".[51]

As well as necessitating the introduction of specific mechanisms for market protection, however, the Government's desire to secure the future of nuclear power had greatly shaped the chosen structure for the entire generation sector. As Parkinson told the Energy Committee shortly after the White Paper was published, the proposed two-generator structure reflected a decision by Government that the successful privatisation of nuclear plant required that they not make up the majority assets of any one company:

---

46 ibid:231
47 ibid:216
48 ibid:205
49 HC Debates, Vol.121, 1987-88, c637
50 In March 1988 Parkinson stated that the NFFO would be set at a level so as to ensure that the amount of electricity generated from nuclear plant would remain "fairly constant" (HC Debates, Vol.129, c56).
51 Cmnd 322, 1988, op cit:12

> We were advised that from a marketability point of view, if nuclear were too big a component of any company, it might be difficult to market it ... The Government has a very strong commitment to maintaining a nuclear programme ... that commitment ... has had a very substantial impact on the chosen structure ... We came to the conclusion that a more diverse structure would cause more problems than it would create opportunities.[52]

The larger of the two generator companies, National Power, was therefore created to be of such size that it could contain all the CEGB's nuclear plant, whilst still having predominantly fossil fuel plant assets; it was also to inherit responsibility for the CEGB's proposed PWR plant (and the proposed coal-fired plant). National Power was widely seen as the privatised successor to the CEGB, and, indeed, Lord Marshall was appointed its Chairman Designate shortly after the publication of the White Paper..

Even before the publication of the White Paper, Marshall had discussed various options for the structure of generating companies with members of the Energy Select Committee. Whilst he made clear his preference for the retention of a single integrated generation and transmission company, Marshall indicated he was not wholly opposed to the two generator option – indeed, he referred to it as his own idea.[53] In later evidence, after the White Paper was published, Marshall told the select committee that although it was not his preferred structure for the industry, the two generator structure was better than a more divided one, since only a very large company could properly capture the economies of scale offered by nuclear power.[54]

In later evidence to the Energy Committee after the White Paper was published, a number of independent analysts suggested that, whilst they would act to limit competition in generation, the Government's proposals would prove insufficient to guarantee the successful privatisation of nuclear power plant. Andrew Holmes, for example, made clear his view of the inadequacies of the Government's chosen structure:

> The provisions made in the white paper are not enough to offset the disadvantages to ... [National Power] as a saleable company, because nuclear power is always going to be risky ... The fact is that politically, in this country as in so many others, nuclear power's life hangs by a thread. It depends partly on the continuation of Mrs. Thatcher's Government, and I say that meaning Mrs. Thatcher personally, not the Conservative party, because her successor may not have her commitment to nuclear power ... For an investor that represents an unacceptable risk ... I feel that nuclear power will only survive in the public sector ... The only way forward is for

52 HC 307, 1987-88, op cit, Vol III:72
53 ibid:4
54 ibid:272

the Government to back away from the idea of selling the nuclear industry.[55]

Dieter Helm stated that since private investors would not invest in nuclear power, to be successfully privatised, it would have to be "embedded" in regulations, and he added that "one of the problems ahead for the Government is whether or not it can actually sell the CEGB".[56] Alex Henney argued that the "one can sell almost anything provided the terms are made right by taking sufficient risks off the purchasers ... but at the end of the day it's not really worth doing".[57] Similarly, Allen Sykes predicted that since the Government would have to "ring-fence" nuclear power, there was no logic in privatising it.[58] Holmes concluded, prophetically, that "this is the hardest privatisation and the nuclear part is the hardest part to privatise ... if something has to give it has to be nuclear power".[59]

Lord Marshall was questioned by the Energy Committee after the publication of the White Paper about the difficulties facing nuclear power in the private sector. Despite the concerns of independent analysts, Marshall maintained his confidence about the prospects for nuclear power, stating that he saw "excellent opportunities to build the small family of PWRs which have always been a part of the CEGB's programme. I do not see privatisation as a threat to that".[60] In their final report, the select committee expressed "great concern" about the costs of nuclear power, and on the distortions effect of nuclear power on the whole ESI; it commented that "the nuclear tail seems to be wagging the ESI dog".[61]

4.3 The Passage of the Electricity Bill

4.3.1 Debate on the Future of Nuclear Power

After the publication of the White Paper, Department of Energy officials began work on the parliamentary bill which would specify the detailed regulatory and legislative framework of the ESI after privatisation. During this period there was continued speculation about the prospects for nuclear power. At the same time the nuclear industry itself continued to defended its record under nationalisation, and argued the case for its

[55] ibid:186-7
[56] ibid:180
[57] ibid:188
[58] ibid 189
[59] ibid:190
[60] ibid:278
[61] ibid, Vol.I:xxiii

continued expansion after privatisation. In an article published in May 1988, for example, Professor Peter Jones, the AEA's Chief Economic Advisor, argued:

> There have been significant economic gains ... investment in civil nuclear development has fully justified itself ... The economic gains ... stem not only from direct reductions in electricity generating costs but also from reduced environmental damage, reduced costs for fossil fuels, energy supply security and the general stimulus to the economy ... nuclear appears to have more than paid for itself and the costs of its development, and there is promise of more to come.[62]

In early-November 1988 the Energy Secretary Cecil Parkinson indicated that the Government were encountering difficulties with the privatisation of nuclear power plants when he stated in Parliament that "the question of nuclear economics is extremely hard to settle".[63] The Electricity Bill was published later in the same month. It upheld all of the White Paper proposals, and – as was widely anticipated – it contained significant additional concessions to nuclear power, notably the imposition of a *Fossil Fuel Levy.* The levy was a charge to be imposed on all electricity bills, in order, the Government stated, to recoup the extra costs incurred by the RECs in meeting the Non-Fossil Fuel Obligation.[64] The Levy was a tacit recognition by Government of the extra cost of nuclear power as compared to fossil fuel generation.[65] The Bill also announced the authorisation of up to £2.5bn of Government grants and loans to National Power, for nuclear fuel waste management and plant decommissioning costs.[66]

During the second commons reading of the Electricity Bill in December 1988, the Energy Secretary Cecil Parkinson again defended the Government's commitment to nuclear power on diversity grounds. He stated that "the original case for nuclear power remains strong ... No major new alternatives to nuclear power have yet been discovered".[67] He also argued that nuclear power offered an insurance against the likelihood of increased fossil fuel prices, adding that "we can all be reasonably certain that ... [fossil fuel prices] will be a great deal higher than they are now".[68] At the same time, Parkinson made more explicit than before that the diversity offered by nuclear was valued by Government as a safeguard against the threat of the NUM and foreign oil suppliers:

---

62 Professor Peter Jones, 'The Benefits of Nuclear Power', *Atom,* No.379, May 1988, pp12-17:12,17

63 HC Debates, Vol.140, 1987-88, c5

64 Parliamentary Bills, *Electricity Bill,* Bill 4, 1988-89, 30th November 1988. (The levy is introduced in *Clause 31* of the Bill.)

65 David Owen MP recognised the historic break that the introduction of the Levy represented; he stated that "[no-one] believes that we shall in our lifetime again hear nuclear generation justified on economic or commercial grounds" (HC Debates, 1988-89, Vol.143, c813).

66 *Electricity Bill: Explanatory and Financial Memorandum*:iii, viii-ix

67 HC Debates, 1988-89, Vol.143 , c673

68 ibid, c673

> We need a nuclear component in our electricity supply. Security of supplies demand diversity ... If we had not had nuclear power in 1985, Mr Scargill would have won ... If there had been no nuclear power during the oil price explosion, the lights would have gone out ... We believe that maintaining a strong nuclear industry is a vital part of diversity.[69]

Parkinson also defended the introduction of the Fossil Fuel Levy, which was criticised by Labour's Energy Spokesman, Tony Blair, as a "nuclear tax".[70] Parkinson claimed that "the consumer will pay no increased costs", as a result of the imposition of the levy, but rather that it would "simply identify costs which had previously remained hidden"; he added that the Government was "prepared to expose those figures and argue the case for diversity".[71] At the same time, Parkinson made a surprisingly direct attack on the CEGB's record in generation. He stated that "there has been insufficient pressure on costs, efficiency or prices" in the nationalised ESI.[72] He also stated that "had Lord Marshall retained the obligation to supply ... the four PWRs would have been built and ... whatever the cost, the customer would have paid for them".[73]

During the same debate, other long-standing parliamentary supporters of nuclear power, such as Trevor Skeet and Michael Clark, argued that the nuclear plant should be placed in a separate company and retained in public ownership. Clark warned that the "cost-plus" operational basis of the nuclear industry was incompatible with privatisation.[74]

Between January and March of 1989, the Energy Bill passed through its parliamentary Standing Committee stage.[75] In the course of Standing Committee scrutiny, further details about the Non-Fossil Fuel Obligation and the Fossil Fuel Levy emerged: Parkinson stated that the NFFO would be set at a level which would allow the operation of four PWRs[76]. Michael Spicer, Parliamentary Under Secretary of State, stated that the Levy would be set at around 10% of electricity bills in its first year, in order to fund National Power's PWR programme.[77] It was also in Standing Committee that Tony Blair

---

69 ibid, c674

70 At the same time as criticising the Government's proposals, Blair committed a future Labour government to renationalisation of the ESI. He stated that "throughout all [the] decades of restructuring, streamlining, innovation and change – there was one driving impulse that has gone today: the creation of an electricity supply industry where the technology of electricity was harnessed to the needs of the nation" (ibid, c680). In stating this position, Blair was accused of technocentrism by Sir Ian Lloyd, Chairman of the Energy Select Committee; Lloyd argued that Blair was "impressed, as many [MPs] are ... by technology-driven industries ... the whole AGR programme in this country was technology-driven" (ibid, c697).

71 ibid, c678-9

72 ibid, c669

73 ibid, c691

74 ibid, c725-6

75 HC Debates, Electricity Bill, Standing Committee 'E', 10th January 1989 to 16th March 1989

76 ibid, Sixteenth Sitting, 7th February 1989, c775

77 ibid, Eighteenth Sitting, 9th February 1989, c846

exposed, in embarrassing detail, the rationale behind the NFFO and the Levy – the uneconomic status of nuclear power – and also drew attention to the difficulties associated with the Levy should nuclear prices escalate. Nevertheless, the Government majority on the Committee was such that the Bill passed through this stage essentially unchanged.

In late-1988 and 1989 a series of leaks emerged from the CEGB's National Power Division which indicated that National Power was concerned about the competitive disadvantages they would face in the privatised ESI, as a result of their responsibilities for nuclear power. At the beginning of March 1989, *Power in Europe* published the details of a leaked letter from National Power's Chief Executive, John Baker, to the Department of Energy.[78] In the letter, Baker outlined the difficulties National Power was having in agreeing contracts for nuclear fuel waste treatment with British Nuclear Fuels Limited (BNFL) – the British nuclear industry's monopoly fuel handler. Baker also expressed concern about the effect on the competitive position of National Power of the long-term financial provisions required for nuclear power station decommissioning. Baker was reported as stating that "National Power is being sent out into a highly competitive world, and any such restrictions will reduce its ability to compete against PowerGen and the other electricity generators". He concluded:

> The problems of nuclear power are very intractable and something will have to give ... We see a very real risk that ... we ... [will] run out of time trying to find a coherent nuclear package that enables the successful privatisation of National Power to take place.[79]

In April 1989 a series of proposed amendments to the Electricity Bill were considered in the House of Commons. Amongst these was a clause by the pro-nuclear power MP Trevor Skeet, suggesting that the nuclear power stations be retained in public ownership. Skeet suggested that "the flotation of National Power could be jeopardised by the nuclear element unless funds and guarantees are lavished on the company to eliminate risk".[80]

In debate on Skeet's proposed clause, Tony Blair argued that "there is a contradiction written into the Bill between the idea of privatisation and the reality of the special ring-fence to be built around nuclear power"[81], and claimed that under private sector investment criteria, nuclear power was "wildly uncompetitive" with fossil fuel power

[78] *Power in Europe*, No.44, 2nd March 1989, pp1-3
[79] ibid:1-3
[80] HC Debates, Vol.150, 1988-89, c262
[81] ibid, c267

stations.[82] Several other MPs criticised the Government's provisions for nuclear power at this time. Alan W. Williams, for example, stated that "nuclear power is the *Achilles' heel* of the Bill ... There is the danger that National Power ... may be unmarketable".[83]

In response, the Energy Secretary Cecil Parkinson reiterated the Government's position that nuclear power was vital to the diversity and security of electricity supply, and maintained that the Government would carry through its policy commitments; he stated that "we were elected on a promise to privatise and a promise to maintain a nuclear programme. We are determined to honour both those promises".[84] At the same time, Parkinson also made some revealing comments about the Government's attempts to privatise nuclear power plant; he stated that "for the first time, as a result of our proposals, the public is being told what nuclear costs are".[85] He went on to make an outspoken – and unprecedented – attack on the British nuclear power programme under nationalisation:

> [The] cost-plus basis is the basis on which the public has had to pay for nuclear from day one. The nuclear programme has been imposed on the country by successive governments ... In future, it will have to justify its existence ... The history of the British nuclear programme ... is littered with appallingly wrong and bad decisions ... There was a total lack of financial discipline and management.[86]

Parkinson argued that if the British ESI remained under public ownership, "CEGB policy ... to build four PWRs initially, with another five by 2003 ... would have gone through".[87] He stated that, by contrast, privatisation would bring about a transformation in the rationale for investment in generation technology, and for the first time make generators financially accountable for their investment decisions: "in the future the generating companies will be able to build power stations only if they can find a customer for the electricity. In the past, because they had the obligation to supply, they decided on the technology, the site, and the size".[88]

More leaks from the CEGB/National Power – and their financial advisors, Lazard Brothers – followed in May and June 1989. These detailed the poor performance and technical problems associated with AGR nuclear plant, rising cost provisions for waste treatment and decommissioning, and deteriorating relations between the CEGB and

---

82 ibid, c268-9
83 ibid, c300
84 ibid, c276
85 ibid, c276
86 ibid, c277-8
87 ibid, c276
88 ibid, c302

BNFL. Other evidence of the high cost of nuclear power was also emerging by this time. An Energy Select Committee inquiry on BNFL's Annual Report and Accounts revealed that BNFL's assessment of its nuclear plant decommissioning liabilities had risen elevenfold in the past year, from around £440m to over £4.6bn.[89] In June 1989 Lord Marshall stated that the cost of the first phase of decommissioning at Berkeley Magnox power station was now estimated to be £200m, rather than the £30m previously quoted by the CEGB.[90] The increase, Marshall made clear, arose from the inclusion of activities previously ignored in CEGB decommissioning cost estimates.[91]

At the beginning of July 1989, *Power in Europe* suggested that the Treasury considered that the problems of privatising nuclear power could jeopardise the entire sale of the ESI, and reported that it was putting pressure on the Department of Energy to exempt the nuclear stations from privatisation.[92] The report added that "opinion among UK financial analysts and fund managers is more or less unanimous in regarding the government's nuclear proposals as unworkable".[93] By the middle of July, *Power in Europe* was reporting "intense speculation" that the Treasury was increasing its pressure on the Department of Energy to withdraw nuclear plant from privatisation.

4.3.2 The Withdrawal of Nuclear Plant from Privatisation

On the 24th of July 1989, immediately preceding the final Commons reading of the Electricity Bill, Cecil Parkinson announced the withdrawal from privatisation of the Magnox nuclear power stations, the oldest British nuclear plant. Parkinson told the Commons that, because "it has recently become clear that the cost of reprocessing and waste treatment of spent Magnox fuel will be a great deal higher than has been charged in electricity prices and provided for in the accounts of the CEGB and SSEB ... It has been decided that both the assets and liabilities relating to Magnox stations ... should remain under Government control".[94]

Parkinson argued that the Magnox stations had presented special problems for privatisation: they were particularly fuel intensive, and therefore subject to much higher

89 House of Commons Energy Committee, *British Nuclear Fuels plc: Report and Accounts 1987-88*, HC 50, 1988-89:xvii
90 *Atom*, No.380, June 1988
91 *Power in Europe*, No.54, 20th July 1989:9
92 *Power in Europe*, No.53, 6th July 1989:1
93 ibid:1
94 HC Debates, Vol.157, 1988-89, c746. He also stated that the back-end provisions for nuclear power had been increased from £1bn to £2.2bn.

waste management and decommissioning costs than more recent nuclear plant. In addition, they were nearing the end of their working lives, and he stated that it would have been unreasonable to expect the ESI's new private owners to pay for "cleaning up the costs of technology of more than thirty years ago".[95] Parkinson stressed that the Government could not have anticipated the difficulties faced in attempting the privatisation of the Magnox plants since "only when we set about the process of privatisation were [the] facts forced out ... Privatisation does not create the costs; it simply reveals them".[96] He maintained that the other, more modern, nuclear power stations would be sold off as planned:

> The AGR stations will be privatised ... we have good reason to believe that the AGRs will have a long and successful future in the private sector ... the nuclear past should stay where it is and the nuclear future should move into the private sector.[97]

The Labour Party Energy Spokesman, Tony Blair, suggested that since nuclear power had greatly shaped the Government's designs for the privatised ESI, the decision to withdraw the Magnox plants had removed "the entire justification for the form that privatisation has taken".[98] Blair added that the apparent escalation in the cost of nuclear power was a reflection of the changed interests of the CEGB's successor, National Power: "where it used to be in the interests of the electricity board to tell us that nuclear power was cheap, it is now, short-term at least, in its interest to tell us that it is expensive, so that it can get more guarantees and more subsidies from the Government".[99] The Conservative MP Peter Hardy suggested that even after the Magnox plants' withdrawal, "National Power will not be a successful flotation", and that a further concession – the complete withdrawal from privatisation of all nuclear power plants – would be necessary at a later stage.[100] Blair agreed, and suggested that this was not done simply because the Government recognised that such a step would have jeopardised the whole Electricity Bill.[101]

---

95 ibid:c750

96 ibid:c753, 759

97 ibid:c750, 752. The Magnox withdrawal statement was Parkinson's last as Energy Secretary – he was replaced within hours by John Wakeham as part of a Cabinet reshuffle. The Electricity Bill received Royal Assent just a few days later, on the 27th of July 1989.

98 ibid:c748

99 ibid:c771. Similarly, the analyst Andrew Holmes referred to the "political game" being played by National Power at this time, as it sought to secure cast-iron guarantees from government regarding nuclear power generation and plant construction after privatisation; Holmes described this as a "wonderful irony after all the years of propaganda about the cheapness and controllability of nuclear costs" (*Power in Europe*, No.54, 20th July 1989).

100 HC Debates, Vol.157, 1988-89, c779

101 ibid:c772

Even before Parkinson's statement, the suggested withdrawal of the Magnox nuclear plants alone was dismissed as inadequate by independent analysts. Andrew Holmes, editor of *Power in Europe*, argued that given their disastrous economic record, "the idea that AGRs are noticeably more attractive to private investors than Magnoxes is hard to take seriously".[102] Holmes added that "the exclusion of the Magnoxes has done nothing to solve the problems of the AGRs".[103] He concluded that it was remarkable that the Government had not anticipated the difficulties associated with attempting to privatise nuclear power plant, since "the issues ... have been clear enough from the outset to all but those who refused to see them ... Despite Parkinson's oblique remarks about new information, they are the same now as they were on Day One".[104]

Over the following months, as the detailed contractual and legislative terms of privatisation were developed, there was continued speculation about the position of the remaining nuclear plants. By mid-September, the Government was reported to be considering the withdrawal of AGR plants from privatisation.[105] In a speech to nuclear power workers in October 1989, Lord Marshall stated that National Power's accounting provision for the Magnox fuel cycle (waste treatment and decommissioning) had risen from £2.8bn to £6.8bn[106] The bulk of the increase, Marshall made clear, arose from increases in BNFL charges for fuel handling. On the same basis, Andrew Holmes estimated that the total bill for Magnox and AGR station decommissioning was around £15bn – around the same as the estimated total proceeds from ESI privatisation. At the end of October a presentation by Wakeham to the Cabinet was leaked, in which the Energy Secretary stated that the cost of nuclear power in the private sector was at least double that from coal-fired generation.[107]

On the 9th of November 1989 John Wakeham announced the withdrawal from privatisation of the AGR plants, and also Sizewell B PWR. Wakeham stated that despite its continued support for nuclear power, the Government was not prepared to meet the demands of the proposed operators of nuclear plant in the private sector:

> Unprecedented guarantees were being sought. I am not willing to underwrite the private sector in this way ... the Government have concluded that the English Advanced Gas-cooled Reactors and Sizewell B should remain, along with the Magnox stations, in a Government-owned

[102] *Power in Europe*, No.54, 20th July 1989:6
[103] ibid:6
[104] *Power in Europe*, No.55, 24th July 1989
[105] *Power in Europe*, No.58, 14th September 1989
[106] *Power in Europe*, No.61, 26th October 1989:4
[107] *Power in Europe*, No.61a, 31st October 1989

> company. This company will inherit all the nuclear related assets ... [of] the CEGB.[108]

Wakeham also announced that the Non-Fossil Fuel Obligation would be set at a level which could be satisfied without the construction of any new nuclear power stations beyond the completion of Sizewell B – in effect, cancelling the proposed PWR programme. He added that no new nuclear power stations would be sanctioned for construction before a review of nuclear power scheduled for 1994. His statement was immediately followed by a similar one by the Secretary of State for Scotland, Malcolm Rifkind.[109]

Wakeham explained that the decision to withdraw the remaining nuclear plants was forced on Government because the prospect of privatisation had revealed hitherto unknown costs. He stated that "the costs of nuclear power remained hidden throughout nationalisation, and it was only the preparations for privatisation that brought them to light".[110] He also stated that the commercialisation of combined cycle gas turbine technology, by providing an alternative source of diversity of supply, and also an alternative means of reducing pollution, had undermined the strategic importance of nuclear power: "there are already a number of projects based on combined-cycle gas turbine technology, which of course lead to lower carbon dioxide emissions".[111] Wakeham rejected the demands from some MPs that his announcement required the restructuring of the generator companies ahead of flotation, stating that "we have no intention of changing the allocation of assets at this stage ... it would [not] be in the interests of the consumer or of the privatisation".[112]

4.3.3 Analysis of the Withdrawal of Nuclear Power

More details about the events leading up to the Government's decision to withdraw nuclear power from privatisation emerged in evidence to the Energy Select Committee in December 1989.[113] Here, John Wakeham explained that the "unprecedented guarantees" referred to in his November Commons statement were being sought by National Power,

---

108 HC Debates, 1988-89, Vol.159, c1172 The new company was later known as *Nuclear Electric.*

109 Rifkind announced that the nuclear assets of the SSEB were to be transferred to a newly created state-owned company, known later as *Scottish Nuclear.* The company would be the dominant generator in Scotland, providing over half of all electricity.

110 HC Debates, 1988-89, Vol.159, c1177

111 ibid:c1172 The commercialisation of combined cycle gas turbine technology, and its impact on the British ESI, is analysed in the next chapter.

112 ibid, c1174

113 House of Commons Energy Committee, *The Consequences of Electricity Privatisation: Minutes of Evidence,* HC96, 1989-90, December 1989

in response to its own reassessment of the cost of nuclear power. Wakeham stated that the Government's hand had been effectively forced after receipt of a letter on the 11th of October from National Power, which gave – apparently for the first time – a specific price of nuclear electricity in the private sector. He told the Committee the price confirmed that nuclear power was clearly uncompetitive with fossil fuel generation: "[it] was a price which ... [reflected] the City's perception of the financial risks of going into nuclear, as a result of which they wanted very high rates of interest, very short payback terms, and a Government guarantee".[114] He argued that rather than a change in intrinsic costs, "by far the biggest item" in the price increases affecting nuclear power was the changed accounting practices associated with privatisation: "the overwhelming bulk of the increase ... is because a different view was taken ... of the same set of costs".[115] As a result, he added, "there was no one date ... that [nuclear power] changed from being economic to uneconomic", and pointed out that "if the CEGB had gone on for another 25 years ... the whole thing would have gone along happily without any great drama".[116] He concluded that the unattractiveness of nuclear to private investors arose from a combination of "engineering assessment and the accounting treatment".[117]

Wakeham also revealed that, ironically, it was National Power's plans for new PWR plants, inherited from the CEGB, that had prompted the reassessment of the costs of nuclear costs. He stated that "the cost of financing the capital building programme of National Power caused the financial pressures on nuclear and exposed their costs".[118] The Energy Committee suggested that the withdrawal of the nuclear plants meant that the generator companies should now be reorganised ahead of privatisation, by breaking-up the National Power and PowerGen duopoly into more competing companies, so as to increase competition in generation. Wakeham replied that this was now impossible, given the tight time schedule for flotation. At the same time, however, he conceded that the privatised structure for the ESI that was being introduced was less than optimal: "I would readily confess that if I were starting from scratch, I would not have decided to split the CEGB fossil stations into two companies".[119]

Other evidence submitted to the Energy Select Committee at this time confirmed that National Power's reassessment of the price of nuclear electricity was the result a change

---

[114] ibid:6

[115] The most important accounting changes, Wakeham stated, were the use of 'current' rather than 'historic' costs, and the adoption of a higher required rate of return, or 'discount rate'. Both of these changes acted to make nuclear – with its high upfront capital cost – relatively less competitive as compared to fossil fuel generation technology.

[116] ibid:6, 8, 9

[117] ibid:9

[118] ibid:14

[119] ibid:13

from *cost-plus* to *fixed-price* contracts between the CEGB/National Power and BNFL. The cost-plus contractual basis that the ESI had operated on under nationalisation meant that any cost increases could be easily passed on from contractors to the CEGB, and, via the Bulk Supply Tariff, to the Area Boards, and ultimately to the electricity consumer. Under the Government's proposals for liberalisation, RECs would in future be given freedom of choice of generator company. This meant that cost increases could no longer be automatically passed on through the supply chain, and from 1988 onwards the various organisations in the industry renegotiated their dealings on the basis of fixed-price contracts. In order to avoid exposing themselves to risk – at a time when increasingly tough worldwide radiological protection standards were leading to increases in fuel waste management costs – BNFL had massively increased their prices for fuel handling to the CEGB, as they changed to fixed-price contracts. Decommissioning costs – always highly speculative – were also increasing in the face of more stringent standards, and also from early experience at Berkeley Magnox power station, the first nuclear plant to be decommissioned in Britain.[120]

The Government's decisions to remove nuclear power plants from the assets of National Power, and to cancel the proposed PWR series, presented particular difficulties for Lord Marshall, who had been the industry's most prominent proponent of PWR generation technology. In December 1989 Marshall resigned as CEGB Chairman, and Chairman Designate of National Power; in announcing his resignation, he was reported as stating:

> The government asked me to become chairman of National Power because the company was to build and operate nuclear stations. That is no longer the case. The new government policy means that Britain will now be building a single PWR, perhaps the only one of its kind. That is not a nuclear policy I feel able to advocate or defend.[121]

Shortly before his resignation, at the end of November 1989, Marshall gave a fuller reaction to the withdrawal of nuclear power from privatisation in a speech to the *British Nuclear Energy Society*.[122] Here, he argued that, in formulating its proposals for the ESI, the Government had made a clear choice against the long term benefits offered by nuclear power technology:

> The plain fact of the matter is that we are going to have a new electricity industry which is driven by short-term market considerations and fierce competition, and you cannot introduce new nuclear power into that environment, because the benefits of nuclear power, assuming we get the technology right, accumulate over half a century ... It is my belief that the

120 ibid:7-8

121 *Atom*, No.400, February 1990:2

122 'The Future for Nuclear Power', *Atom*, No. 400, pp5-13, February 1990

> government was faced with a stark choice between the long-term benefits of nuclear power and the short-term benefits of privatising the industry in this particular form. They chose privatisation.[123]

Marshall also made critical references to a long history of political interference in the British nuclear power programme. He stated that "I do not like this form of electricity privatisation, but the broad story of nuclear power in this country is the most powerful argument in favour of privatisation that I have ever seen".[124] In the CEGB's last-ever Annual Report, published at the end of 1989, Marshall described the Government's decision to cancel the proposed PWR programme after Sizewell B as "a tragedy for civil nuclear power in the UK and a personal disappointment too large to describe".[125]

In mid-1990 the Energy Select Committee carried out a more detailed report on *The Cost of Nuclear Power*.[126] The inquiry gave the select committee the opportunity to question Lord Marshall about the various technical and economic reasons for the increases in nuclear power costs. In answering the committee's questions, Marshall repeatedly distinguished between Magnox and more recent nuclear technology. He claimed to have conceded as early as 1988 that Magnox plant (which, he pointed out, was developed before his time as CEGB Chairman) was more expensive than coal plant. He maintained that, by contrast, AGRs and PWRs remained cost-competitive, and he defended the CEGB's investment in these technologies. Marshall again argued that the withdrawal of the AGR plants from privatisation, and the cancellation of the PWR programme, was a reflection, not of the economic failure of nuclear technology, but of weaknesses in the Government's privatisation proposals:

> The competitive structure that the Government has set up favours gas turbines, small plant, and disfavours nuclear power and coal plant ... The institutional structure that we are going to have in the future makes it extremely difficult indeed for any generator to build any large plant ... I believe that when the Government chose this structure for the electricity industry ... they were creating an institutional structure which would make it impossible to pursue new nuclear power.[127]

Marshall now claimed to have recognised the threat presented by the Government's proposals soon after publication of the White Paper. In particular, he stated that he recognised that the ending of the generator's obligation to supply "might well lead to the

[123] ibid:7
[124] ibid:13
[125] CEGB, *Annual Report and Accounts 1988/89*, London, CEGB, December 1989
[126] House of Commons Energy Committee, *The Cost of Nuclear Power*, HC 205, 1989-90, June 1990
[127] HC 205, 1989-90, Vol.II:4-6

end of new nuclear power in this country".[128] He added that if the Government had chosen to maintain the generator's obligation to supply after privatisation, the PWR programme could have progressed successfully, alongside investment in combined cycle gas turbine plants.

In the course of its inquiry, the Energy Select Committee uncovered further details of National Power's dramatic reassessment of the cost of nuclear power in 1989. In evidence submitted to the Hinkley Point C public inquiry in 1989, the CEGB's National Power Division had estimated the unit cost of electricity from the proposed PWR plant to be 3p/kWh. By stark contrast, in its letter to the Department of Energy in October 1989, National Power estimated the cost of power from a PWR in a privatised ESI to be 6.2p/kWh.[129] Under questioning by the Energy Select Committee, the Chief Executive of National Power, John Baker, stated that this doubling of cost arose from the different investment criteria under public and private ownership. Unlike Lord Marshall, Baker added that he did not see any institutional arrangements for the privatised ESI under which nuclear plant could compete on cost grounds with combined cycle gas turbine technology:

> If the question is, whether there was any way in which the PWR could have been made price competitive with contemporary combined cycle gas turbine plant, then the answer is no in all circumstances. That would ... also be true for large coal-fired plant in my judgement.[130]

The Energy Committee also questioned senior Department of Energy officials over their failure to anticipate the very different financial conditions between public and private ownership. John Guinness, Deputy Secretary at the Department of Energy's Atomic Energy Division, argued that assessing the cost of nuclear power in a privatised ESI presented a *Catch-22* problem, in that the institutional and regulatory framework of the industry had to be in place before a detailed assessment of the cost of nuclear could be made. Guinness stated that "it was only by going out and having discussions with all their advisors that I think National Power came up with their particular proposals".[131] Like Wakeham, Guinness referred to the importance of the commercialisation of gas turbine technology – in offering an alternative form of supply diversity – in the withdrawal of nuclear plant.[132]

---

128 ibid

129 ibid:9

130 ibid:11 The independent analyst Gordon MacKerron, of Sussex University, told the Committee that even wind power was now marginally more economic than nuclear (ibid:127).

131 ibid:38

132 ibid:38

The Committee also heard evidence from representatives of investment advisors involved in ESI privatisation, who were also widely thought to be implicated in the Government's embarrassing policy reversal. Kleinwort Benson, the Department of Energy's investment analysts, claimed that they had consistently stuck by their initial advice to Government made in 1987, that there was no inherent reason why nuclear could not be privatised. David Clementi of Kleinwort Benson told the Committee that "we believe that our advice was generally accepted by the Government that it was possible to float the companies".[133] He argued that this required that the cost of nuclear power be "quantifiable ... sustainable ... and supportable".[134] Ultimately, Clementi argued, the withdrawal decision was a matter of political choice – the Government had chosen not to "pay the price" for privatising nuclear, by their refusal to meet National Power's demands for market guarantees.[135] Referring to Lord Marshall's comments that nuclear power could have prospered under privatised ownership with a continued generator obligation to supply, Clementi argued that what was really necessary to maintain the nuclear programme – and what the CEGB/National Power were in reality requesting – was the continuation of a monopoly in generation, so that costs could continue to be passed on.[136]

By contrast, Alexander Johnston and Duncan Clegg, of Lazard Brothers, the investment advisors to CEGB/National Power, told the Committee that their advice had always been that privatising nuclear plant would be very problematic, due to the "unlimited liabilities arising from spent fuel management, from decommissioning, and from fuel disposal"; they added that "most of the risks were unquantifiable in our view".[137] Clearly, whilst the Department of Energy had been receiving assurances from Kleinwort Benson that nuclear power technology *was* privatisable, Lazard Brothers' advice to National Power had instead stressed the financial risks involved.

As part of their investigations of nuclear power costs and risks, the Energy Committee also sought independent financial advice from UBS Phillips and Drew. In their submission to the Committee, UBS emphasised the huge differences in accounting practices between the CEGB and private companies. They pointed out that as late as 1989, in evidence to the Hinkley Point C public enquiry, the CEGB was using a 5% discount rate, whilst, in the same year, they adopted a 10% rate in submissions to the

133 ibid:56

134 ibid:47-48

135 ibid:49 In his analysis of the role of the Kleinwort Benson in the attempted privatisation of nuclear power, Henney concluded that they "did not ... appear to think through the implications of what the government was considering in fragmenting the industry and introducing competition". (Henney, op cit:137) He went on to suggest that the privatisation of the AGR plants would have required the writing-down of their book value, the capping of their back-end costs, and allowing National Power to make the kind of high returns it was seeking (op cit:143)

136 ibid:56

137 ibid:60-61

Department of Energy. UBS suggested that, realistically, a rate of around 17-24% was needed to properly reflect the financial risks involved in nuclear power.[138] Another accounting difference they highlighted was in the amortisation period, or asset life, of generating plant. The CEGB adopted a 40 year amortisation period for all power stations in their accounts – the designated working life of CEGB plant. By contrast, private investors used periods of, at most, half of this. National Power only came to adopt a 20 year amortisation period as part of their preparations for privatisation. Under questioning by the select committee, Dr J. Wilson, of UBS Phillips and Drew, argued that "the whole ethos of the CEGB was to build bigger and better stations, they were supporting the coal industry and providing a diversity of supply essentially".[139] Wilson concluded that the CEGB was unable to come to terms with the radical change in financial environment that was being brought about by ESI liberalisation and privatisation; he stated that they "never adopted an approach that was as rigorous as the City demanded".[140]

In reviewing the highly embarrassing withdrawal of nuclear plants from privatisation, a number of analysts have considered why the Government had not foreseen earlier the scale of the difficulties involved with their proposals. Both Henney and Roberts *et al.* suggested that the Government was keen to transfer the nuclear power programme to private ownership because of the vast capital expenditure required to meet a looming capacity shortage.[141] Roberts *et al.* added, however, that this was insufficient on its own to explain why the Government invested so much "political capital" in pursuit of an ultimately lost cause.[142] They argued that this required reference to two additional factors – the powerful vested interests associated with the British nuclear industry, and also the "technocentric world view" exhibited by Government, and especially by Margaret Thatcher herself. They stated that whilst all Prime Ministers in the postwar period could be described as *technocentric* in their support for nuclear power, it was a particularly strong character trait of Mrs Thatcher:

> The first Prime Minister to be a trained scientist, her belief in the beneficence of the onward march of science was as great as her belief in the virtues of the free market. The attempted privatisation of the nuclear power stations was to expose the potential for conflict between these two creeds ... [However] the Prime Minister's dual commitments, to financial liberalisation and to nuclear power were so firmly held by her that ... their mutual incompatibility was not acknowledged.[143]

---

138 ibid:37

139 ibid:110

140 ibid:110

141 Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, op cit:137; Jane Roberts et al., *Privatising Electricity: The Politics of Power*, op cit:68

142 Roberts et al., op cit:100

143 ibid:103-4. As stated earlier, Andrew Holmes also drew attention to the importance of Mrs Thatcher own personal views and authority in his evidence to the Energy Select Committee in 1988, just after publication of the White Paper.

Similarly, Henney suggested that "for Mrs Thatcher support for nuclear power almost became a tenet of being 'one of us'. She regarded ... [it] as a means of combating the industrial power of the miners, and a technology of the future".[144] If anything, Lord Marshall's personal support of nuclear power technology exceeded Mrs Thatcher's; Henney stated that Marshall was "obsessed with building PWRs", which he saw as the answer to the chronic technical difficulties of the British nuclear power programme.[145]

The ESI privatisation process proceeded relatively smoothly after 1989. In February 1990 John Wakeham issued regulatory licences for electricity generation, transmission and supply.[146] The licences specified a price control formula for electricity suppliers, and set the Fossil Fuel Levy at 10.6% in its first year. National Power, Powergen, The National Grid Company, and the Regional Electricity Companies were vested at the end of March 1990. Despite further uncertainty associated with Margaret Thatcher's resignation in November 1990, and the Gulf War in early-1991, the RECs were floated in December 1990, and National Power and Powergen at the end of March 1991.

4.4 Nuclear Power Technology after ESI Privatisation

After their withdrawal from privatisation in 1989, the British nuclear power plant were placed in a protected economic and organisational environment. In England and Wales, the Non-Fossil Fuel Obligation provided Nuclear Electric a guaranteed market until 1998, and the fossil fuel levy provided it with an income of over £1bn p.a. – equivalent to a subsidy of around 3p/kWh subsidy for nuclear power.[147] The *Scottish Nuclear Energy Agreement,* which extends to 2005, allows Scottish Nuclear to sell all its output to Scottish Power and Scottish Hydro Electric on a take-or-pay basis.[148]

Holmes pointed out that, given that a future Government or Prime Minister might not share her views (the Labour Party was still committed to renationalisation of the ESI at this time), this was not a basis for the successful flotation of nuclear power (4.2.3).

144 Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, op cit:148. Henney also reported that even after the withdrawal of the Magnox and AGR plants, Mrs Thatcher was personally in favour of the construction of further PWR plants in the public sector, and was only dissuaded on this issue by John Wakeham's and Nigel Lawson's arguing that this would greatly restrict competition in the privatised part of the ESI (op cit:142)

145 ibid:148

146 *Atom*, No.402, p27, April 1990

147 HC 113, 1991-92, Vol.I:lv. The value of the levy for each year was decided in advance by the Office of Electricity Regulation.

148 HC 48, 1995-96, Vol.I:xi

From 1990 onwards Nuclear Electric's electricity output rose steadily. The availability of the AGR power stations improved dramatically, as outages at existing AGR plants were greatly reduced, and the more recent AGR plant (Heysham II and Torness) proved more reliable than their predecessors. At the same time, Nuclear Electric (NE) adopted much more commercial management and accounting practices than the CEGB, and the company underwent substantial rationalisation. By the mid-1990s, staffing levels at NE were less than half of those at the company's creation in 1989. At the same time, those areas which were the cause of greatest difficulty during the preparations for the privatisation of National Power – notably fuel waste processing and plant decommissioning costs – were given far more engineering and financial scrutiny than hitherto. Fixed-price contracts were established with BNFL, and the closure of three of the oldest Magnox stations enabled NE to gain fuller experience of the decommissioning process.

At the same time as these technical and economic gains were being made, the political context of the British nuclear industry remained highly uncertain, pending the Government review announced by John Wakeham in 1989, and scheduled for 1994 (4.3.2). In May 1994, Tim Eggar, Minister of State for Energy at the Department of Trade and Industry, announced the terms of the Nuclear Review. Eggar also invited the industry to make the commercial case for new nuclear power plant.

Nuclear Electric published its submission to the Minister in June 1994. Here, NE called for the division of its assets into two companies, one of which – holding all the 'privatisable' risks and liabilities – should be sold off. NE also argued the case for the resumption of the PWR plant series, through the construction of a new station, Sizewell C.[149] In their submission to the review, Scottish Nuclear also asked to be privatised, in order to have "the same freedom" as the privatised generators. Scottish Nuclear was also anticipating the construction of a new nuclear plant, Hunterston C.

In the run-up to the review, Nuclear Electric, Scottish Nuclear, the AEA, and the nuclear industry's lobbying groups such as the *British Nuclear Industry Forum*, attempted to re-establish the reputation of nuclear power in Britain, and argued the case for new nuclear plant. This campaign was reflected in industry journals, such as the AEA's *Atom*, and also in a sustained advertising in the national press.[150] In an article published in April 1995, Dr Robert Hawley, Chief Executive of Nuclear Electric, argued that "in just four years Nuclear Electric has improved beyond all belief ... The nuclear assets of the nation have

149 Roger Dettmer, 'A New Deal for Nuclear?', *IEE Review*, September 1994, pp213-216

150 See, for example, Catriona Lyons, 'Pushing for Privatisation, *Atom*, No.435, August/September 1994, pp14-15, and Nuclear Electric's advertisement 'Nuclear Electric Racing Ahead', published widely in mid-1994.

never worked as well as they do today".[151] Hawley estimated that, as a result of improved engineering knowledge economic management, Nuclear Electric decommissioning costs were now as low as £2.7bn.[152] He went on to argue, on strategic and environmental grounds, that the Government "implement a definite future for the industry", by subsidising the construction of a new PWR series.[153] He concluded that "the time has never been better for firm and determined Government action ... to recognise the vital and strategic role that nuclear power needs to play in the future UK energy scene".[154]

The outcome of the Government's review was eventually published in May 1995.[155] The report confirmed that the performance of the nuclear industry had improved dramatically since 1989 – output from all of Nuclear Electric's nuclear stations had increased from 36.9TWh to 54.1TWh, and their market share in England and Wales now stood at a record high of 28% of all electricity produced (see Appendix 1).[156] The review attributed this transformation to a combination of technical and economic factors. Firstly, the reliability and performance of the AGR power stations in particular had greatly improved in the 1990s – total output from Nuclear Electric's AGRs had risen by more than 50%, and from 1989/90 to 1994/95 unit costs had almost halved, from 5.2p/kWh to 2.7p/kWh (according Nuclear Electric figures). Secondly, Sizewell B PWR had been completed on time and to the budget agreed to in 1991, and was commissioned in September 1995.[157] Finally, the waste processing and decommissioning costs of nuclear power generation could be estimated with considerably more certainty than in 1989, and recent experience in Britain (at the three Magnox stations already closed) and overseas indicated that the early stages of nuclear plant decommissioning were less expensive than had previously been thought.[158]

Given the transformation of the nuclear industry since 1989, the review announced the Government's intention to privatise, together in a single company, the seven AGR nuclear power stations belonging to Nuclear Electric and Scottish Nuclear, and also Sizewell PWR.[159] (The new company was known later as *British Energy*). The flotation was

---

151 Dr Robert Hawley, 'The Nuclear Review', *Power Engineering Journal*, April 1995, pp 61-68:62-68

152 ibid:63 In 1993 the National Audit Office had estimated the total decommissioning cost of British nuclear plant to be around £18bn. (*The Cost of Decommissioning Nuclear Facilities*, HC 692, 1992-93)

153 ibid:68

154 ibid:68

155 Department of Trade and Industry, *The Prospects for Nuclear Power: Conclusions of the Government's Nuclear Review*, Cmnd 2860, 1995

156 ibid:12

157 ibid:14 According to Nuclear Electric, Sizewell B would provide electricity at a lifetime cost of 2.9p/kWh, when calculated using a 8% discount rate over 40 years; this rose to 3.7p/kWh with the use of a 15% discount rate (ibid:14).

158 The total cost of decommissioning British Energy's nuclear plants was now estimated to be £8.5bn (ibid:13).

159 The Government justified this structure for privatisation in evidence to the Trade and Industry Committee's 1995 inquiry on *Aspects of the ESI* (HC 481, 1994-95). The DTI stated that they had been advised that a unified company gave the strongest financial profile, and the least exposure to market risk (ibid:Vol.II, p118). By contrast, the Office of

scheduled to take place in mid-1996. The Government accepted that the six Magnox stations still operating remained unsaleable, and they were therefore to remain in public ownership under a new company, known later as *Magnox Electric.* British Energy was to inherit the power contract between Nuclear Electric and the RECs established after 1989, that ran to March 1998. The Government also announced that a 'segregated fund' was to be set-up, in order to meet British Energy's decommissioning costs. The fund was to be made up from contributions by British Energy from their revenue on sales.

The review also announced its intention that the nuclear part of the NFFO and Fossil Fuel Levy would end with privatisation. (Renewable energy technologies were to continue to be subsidised under a greatly reduced NFFO until 1998). The Government argued that they could find "no convincing arguments" in favour of extending the NFFO or the Levy beyond the flotation of British Energy in 1996.[160] However, although it was prepared to grant Nuclear Electric's wish to be privatised, the Government stated that it was *not* prepared to subsidise the construction of new nuclear plant, which it argued was a commercial matter for private generators.

In Parliamentary debate on the review and the planned flotation of British Energy, whilst some MPs complained about the privileged position enjoyed by Nuclear Electric since 1989 – especially as compared to British Coal – there was general agreement that the nuclear power industry had greatly improved its technical and commercial performance.[161]

At the end of 1995, British Energy announced that it would not be proceeding with the early construction of any new PWR plants. BE later claimed that this decision was taken on commercial grounds because of the uncertainty in long-term electricity prices, and also because the Nuclear Review had "made it abundantly clear" that no Government funds would be provided for the construction of new nuclear plant.[162] It was widely believed, however, that this decision was forced on British Energy, because – in an echo of events in 1989 – the prospect of new nuclear plant construction was discouraging private investor interest in nuclear power. The Financial Times reported at the time that, despite the improvements made by Nuclear Electric/British Energy, nuclear power

Electricity Regulation, and a number of independent ESI analysts, argued that the UK's nuclear assets should be divided between two similarly-sized companies, in order to introduce more competition into generation.

160 ibid:64. Indeed, under EU competition rules, the Levy and the NFFO were only permitted as temporary "transitional relief". The Government later announced that the nuclear levy was to continue, in reduced form, until 1998, in order, it was stated, to recover Nuclear Electric arrears from previous unclaimed levy payments.

161 See 'Nuclear Review Debate', HC Debates Vol.259, 1994-95, c 563-578, 9th May 1995, and 'Debate on Nuclear Power Industry Privatisation', HCD Vol.260, 1994-95, c 394-444, 17th May 1995.

162 HC 43, 1995-96, Vol.iii:115

generation remained far more expensive than that using fossil fuel.[163] BE's decision was reported as marking the death-knell of the British nuclear power programme.[164]

In February 1996, a few months before the proposed flotation of British Energy, the Trade and Industry Committee published the results of its own inquiry into *Nuclear Privatisation*.[165] In their memorandum to the Committee, the Government's financial advisors on the privatisation, Barclays de Zoete Wedd, stated that "the overall performance of the nuclear generators is now much better", and added that "investors are also generally more familiar with the ... sector".[166] Under questioning by the committee, Dr Lynda Rose of Barclays de Zoete Wedd confirmed that:

> A number of things have changed [since 1989] ... all the stations are performing better ... and that is really a great change to the management of the company. The other major change is ... the [establishment of the] electricity market ... which we were all struggling to come to terms with in 1990.[167]

Nevertheless, the select committee also found that the prospects for new nuclear plant remained very poor. In his evidence to the committee, John Reynolds, of independent advisors James Capel and Co. told the Committee that in the absence of incentives, such as would be provided by a 'Carbon Tax', "it is not commercially viable to build new nuclear stations in the UK at this time".[168] Reynolds added that nuclear industry waste management costs still presented a considerable risk to private investors. In its report conclusions, the Trade and Industry Committee stated that, whilst it agreed with the Government that nuclear power plant decommissioning costs appeared to be lower than earlier estimates, British Energy's liabilities were still very uncertain. On an undiscounted basis, they were estimated to be £14.6bn. [169] In his evidence to the committee, however, Dr John Robb, Chairman Designate of British Energy, pointed out that even after privatisation, the Government would remain the ultimate guarantor for much of BE's risks and liabilities.[170]

---

163 David Lascelles, 'Plug Pulled on More Nuclear Power', *Financial Times*, 12th December 1995, p9

164 See, for example, Simon Beavis and Ian King, 'Nuclear Dream Turns to Dust', *The Guardian*, 12th December 1995, p18

165 House of Commons Trade and Industry Committee, *Nuclear Privatisation*, HC 48, 1995-96

166 ibid, Vol.III:136

167 ibid, Vol.III:142

168 ibid, Vol.II:128

169 ibid, Vol.I:xiv.

170 Robb stated, for example, that under existing agreements, the Government would remain an "insurer of last resort" for costs arising from civil nuclear accidents over £140m – in effect 'capping' BE's liabilities arising from such accidents (House of Commons Trade and Industry Committee, *Nuclear Privatisation: Minutes of Evidence*, HC795, 1994-95, Voli:13).

In the event, British Energy was successfully floated in mid-1996, but there remained no prospect of any new nuclear plant being developed in the British ESI.

4.5 Fast Reactor Generation Technology and ESI Privatisation

4.5.1 The Fast Reactor Programme in the Nationalised ESI

The great technical advantage of fast reactors over conventional (thermal) nuclear reactors is their ability to 'breed' fuel – that is, to produce more secondary plutonium fuel than the primary plutonium they consume. The primary motivation behind the initial development of fast breeder technology in Britain and elsewhere was perceived worldwide uranium shortages in the late-1940s and early-1950s. A secondary advantage of fast reactors, in the context of the British ESI, was their ability to use the waste plutonium produced by Magnox reactors for their primary fuel [171]

As Margaret Gowing described – even more than was the case for conventional nuclear technology – the emphasis in the early fast reactor research programme was on *technical* rather than *economic* criteria:

> The only point on which there was general agreement ... [was] on the ultimate and overriding importance of breeder reactors ... Enthusiasm for the fast reactor in the early days derived from its inherent scientific promise, and from the shortage of proved reserves of uranium ... There was as yet no point in working out any costs, however provisional, because it was not certain whether such a reactor could be successfully built.[172]

Christopher Hinton, who was later to become inaugural CEGB chairman, was closely involved in the initial work on fast reactors. According to Gowing, Hinton's concern for the adequacy of uranium supplies led him to the opinion that fast breeder research should have first priority in the British nuclear power programme.[173]

In a personal interview conducted in 1994, Alistair Cruickshank, Special Projects Manager at the AEA, reflected on the rationale behind the development of fast reactor technology in Britain:

---

171 Roger Williams, *The Nuclear Power Decisions: British Politics 1953-1978*, London, Croom Helm, 1980:43
172 Margaret Gowing, assisted by Lorna Arnold, *Independence and Deterrence: Britain and Atomic Energy, 1945-52: Volume 2, Policy Execution*, London, Macmillan, 1974:266-267
173 ibid:298

> The economic projections for the mid-1950s, and for a long period after, into the 1970s ... projected an almost exponential increase in demand for electricity, coupled with a demise in the availability of oil, coal and uranium, coincident with a vast increase in uranium prices ... The motivation, therefore, for fast reactors, was to use the 98.3 per cent of uranium which is not really available for fuel in thermal reactors, giving us a guaranteed power supply for thousands of years.[174]

The established view of the British nuclear industry was that, after a transitionary period of twenty-five to thirty years – during which conventional reactors would provide Britain's nuclear electricity – the long term future of nuclear power lay with fast reactor technology. Gowing stated that "fast breeder reactors were, from the outset, the main goal of the nuclear power programme".[175]

After some debate within the AEA, Dounreay airfield on the remote northern coast of Scotland was chosen as the main site for Britain's fast reactor development. The AEA began construction of a small experimental reactor, the *Dounreay Fast Reactor (DFR)* in 1955.[176] The DFR started operation in 1959. It soon encountered problems common to all fast reactors, associated with the very high energy density at the reactor core, requiring the use of 'primary' and 'secondary' liquid sodium coolant circuits (see Appendix 2, Figure 4). As a reactor coolant, liquid sodium becomes irradiated, and as it reacts volatilely with air and water, numerous special engineering provisions are required to ensure it remains isolated. The added engineering demands of fast reactors mean that they are inevitably a more expensive way of generating electricity than conventional nuclear reactors. Although this was quickly appreciated by those closely involved in the British fast reactor programme, research into the technology was sustained by the belief that massive worldwide escalation of nuclear power would deplete uranium reserves and increase prices, so that power from fast reactors would eventually become cheaper than that from thermal reactors.

In his 1970 look-ahead to *The Next 25 Years in the Electricity Supply Industry*, the CEGB Chairman, Sir Stanley Brown stated that "the general consensus of world opinion, from which we do not dissent, is ... that the fast breeder reactor will take over ... The ability of the fast reactor to build more fissile material than it consumes is likely to be a very important factor of fuel economy in the longer term".[177] Brown went on to discuss the

---

174 Personal interview, Dounreay, 17th March 1994

175 Gowing, op cit:270

176 Williams, op cit:43

177 Sir Stanley Brown, *The Next 25 Years in the Electricity Supply Industry*, London, CEGB, November 1970:16,19

"probable evolution of the fast reactor as a commercial proposition for use in the 1980s".[178]

In 1966 the Labour government under Harold Wilson approved construction of a 250MW *Prototype Fast Reactor (PFR)* at Dounreay, as an "essential intermediate step" towards a 1000MW commercial station by 1978.[179] The Dounreay PFR plant was the dominant electricity generation technology research project in the British ESI from the mid-1960s up to the late-1980s. It began operating in 1974, in the midst of the energy crisis, during which energy policy was dominated by renewed fears of fuel supply shortages in the wake of the first oil shock (see 3.4.2) Within this climate, a massive expansion of nuclear power was thought necessary, so that fresh impetus was given to fast reactor development in the UK and elsewhere.[180] The 1976 ETSU survey of *Energy Research and Development in the United Kingdom* report stated that "world supplies of reasonably priced uranium could well be seriously restricted before 1990", and stated as a result, "the fast reactor needs to be proved ... within the next decade".[181]

From the late-1960s the AEA had urged the government to progress with the construction of a commercial fast reactor plant, and developed plans for a 1250MW *Commercial Demonstration Fast Reactor*. The House of Commons Select Committee on Science and Technology reported in favour of the construction of a commercial fast reactor in 1976.[182]

Over the next decade, however, the economic and political context of fast reactor development changed profoundly. The prospect of uranium shortages disappeared, as known reserves increased with further exploration, and at the same time, conventional nuclear power programmes failed to expand on anything like the scale anticipated. Alistair Cruickshank described the changed circumstances affecting the fast reactor programme over these years:

> From the mid-1970s onwards, the economic projections were beginning to look a bit sick, what was projected to happen wasn't happening. The time when fast reactors would be required was moving backwards all the time ... Every single one of ... [the] projections was proved wrong ... The demand increases just haven't happened ... [and] uranium scarcity was not nearly as much as was thought ... The price of uranium rather than going

178 ibid:17

179 House of Commons Energy Committee, *The Fast Breeder Reactor*, HC119, 1989-90, Vol.I:xi

180 As well as the UK, France, West Germany, the USA, USSR and Japan all had substantial fast reactor research programmes by this time.

181 Department of Energy, *Energy Research and Development in the United Kingdom*, Energy Paper 11, 1976:12, 4

182 Select Committee on Science and Technology, *Fast Breeder Reactor*, HC 625, 1975-76

up, is now in real terms around one-fortieth of the price when Dounreay [PFR] was projected.[183]

Nevertheless, political support for the British nuclear power programme remained unbroken under the Thatcher Governments of the 1980s (3.4.5), and debate over whether or not to proceed with a commercial fast reactor also continued. In 1980, for example, Sweet suggested that "because such large resources have been committed to the fast breeder over the last 25 years, there must be a presumption that the decision will be in favour of proceeding".[184] The Energy Select Committee reviewed the fast reactor programme in 1984.[185] It reported that £2.4bn (at 1982/83 prices) had been spent on fast reactor research since 1955, at an annual rate, since 1963, of around £100m, but added that despite this, there was no immediate prospect of a commercial fast reactor. The then Chairman of the AEA told the Committee that another 25 or 30 years of development work, and another £1.3bn, would be needed before commercialisation. In the same year the UK entered a collaborative agreement with France and West Germany to build three commercial fast reactors.[186]

In their background technical papers to the Department of Energy's 1986 *Appraisal of UK Energy Research, Development and Demonstration*, the AEA's Energy Technology Support Unit (ETSU) concluded that "the fast reactor has the potential to become the major supplier of electricity in the UK by 2020-2030".[187] ETSU anticipated that the first commercial fast reactor plants would be commissioned in the first decade of the next century, with "series orders" from 2011 onwards. The cost of development of the first plant was estimated by ETSU to be around £1bn. In the mid-1980s, expenditure on fast reactor research, development, and demonstration continued at around £100m p.a. Whilst it recognised that estimated returns varied over a wide range, according to certain technical and economic assumptions, ETSU described this level of investment as "timely".[188]

183 Personal interview, Dounreay, 17th March 1994

184 Colin Sweet, 'Introduction', in Sweet, C. (ed.), *The Fast Breeder Reactor: Need? Cost? Risk?*, London, MacMillan, 1980, pp1-9:1

185 House of Commons Energy Committee, *Energy Research, Development and Demonstration in the UK*, HC 585, 1983-84

186 John Valentine, *Atomic Crossroads: Before and After Sizewell*, Merlin Press, London:1985:190

187 Department of Energy/ Energy Technology Support Unit, *Background Papers Relevant to the 1986 Appraisal of UK Energy Research, Development and Demonstration*, ETSU R-43, London, HMSO, February 1987:B74 (ibid:B73)

188 ibid:B74

4.5.2 ESI Privatisation and the Fast Reactor Programme

Amongst the wealth of evidence submitted to the Energy Select Committee in late-1987 and early-1988 as part of its inquiry into ESI privatisation, there was little detailed discussion of the future of the fast reactor programme. Under questioning by the select committee, the Chairman of the Electricity Council, Sir Philip Jones, defended the dominance of the fast reactor technology in industry research spending on generation technology, on the basis that "it is important on a national basis to keep abreast of fast-breeder technology ... in other areas you can keep abreast or do the development for smaller amounts of money".[189]

It was clear, however, that the Government's determination to introduce competition into generation after ESI privatisation (4.2.1), would present difficulties for continuation of the fast reactor programme. In his evidence to the Energy Committee in February 1988, a few days before the publication of the White Paper on ESI privatisation, the CEGB Chairman Lord Marshall stated that "a privatised CEGB without the obligation to supply would have no interest in fast reactors".[190] In later evidence to the committee he added that privatisation presented "difficulties with longer term research".[191]

Despite Marshall's concern, the Government would offer no pledges of their continued support for R&D programmes after privatisation – including that of the fast reactor. In March 1988, Michael Spicer, Parliamentary Under-Secretary of State for Energy, in reply to a written question in the Commons, stated that "after privatisation, it will be a matter for the industry to decide how much it should spend on the fast reactor".[192] In May 1988 a review of the fast reactor programme by the Cabinet Office's Advisory Council on Science and Technology suggested that the fast reactor programme – as a *technological* rather than a *scientific* project – should be financed entirely by the ESI, rather than by government.[193]

In July 1988, the Department of Energy announced that it would cease funding the Dounreay PFR plant after 1994, and that fast reactor funding would be reduced to a

---

189 House of Commons Energy Committee, *The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector*, HC 307, 1987-88, Vol.III:304

190 ibid, Vol.III:16. In 1987-88 the CEGB had agreed, for the first time, to contribute £30m to the fast reactor programme, with the rest (£70m) being provided by the Department of Energy, through the AEA.

191 ibid:278. Tellingly, Marshall also described fast reactors here as the "long-term dream of nuclear power".

192 HC Debates, 1987-88, Vol.128, c647(w)

193 David Fishlock, 'Funding is at the Core of a Nuclear Future', *Financial Times*, 6th May 1988, p6. The report referred to is Advisory Council on Science and Technology, *The Industrial Impact of Sizewell B*, London, HMSO, 1988.

"core" programme of £10m p.a., to be concentrated on the development, in collaboration with France and West Germany, of a commercial size *European Fast Reactor* (EFR).[194] In March 1989, *Power in Europe* reported that the fast reactor was suffering "death by market forces", and added that "whilst public opposition can make things very difficult for a technology, rejection in the market place ... can be a much more deadly weapon".[195]

The Government's decision to withdraw funding for the Dounreay Prototype Fast Reactor was investigated by the Energy Select Committee in mid-1990.[196] The committee heard contrasting opinion over the Government's decision – within the ESI, it was referred to as an "unwise reduction in the UK's participation in a promising technology", whilst opponents argued that even the continued funding of the EFR project was a waste of public money.[197] The independent energy analyst Walter Patterson – a well-known critic of the British nuclear industry – referred to the "appalling costs" of the PFR, and spoke of the "obsessive pursuit of the fast reactor in the UK over the past 30 years".[198]

In its memorandum to the committee, National Power argued that the difficulties facing the development of fast reactor technology were a consequence of the Government's removal of the generator's statutory obligation to supply:

> CEGB ... support for [the] development of Fast Reactor technology ... has been driven by strategic considerations of fuel diversity and the long-term economics of electricity generation, flowing from the CEGB's statutory duties ... The successors to the CEGB no longer have the obligation to consider, or plan for long-term diversity or security of primary sources for electricity generation.[199]

National Power added that they would still be prepared to join the rest of the industry in supporting fast reactor technology development – but only on the basis of being able to "pass-through" any costs incurred by doing so.[200]

In his evidence to the select committee, John Collier, Chairman of the AEA, and newly-appointed inaugural Chairman of Nuclear Electric, defended the nuclear industry's spending on fast reactor R&D as "excellent value for money".[201] Nevertheless, Collier conceded that the capital cost of fast reactor plant was 20% higher than conventional

194 HC Debates, 21 July 1988, c1288 The contracts for the EFR project were signed in February 1989.
195 *Power in Europe*, No.44, 2nd March 1989:4-5
196 House of Commons Energy Committee, *The Fast Breeder Reactor*, HC 119, 1989-90
197 ibid, Vol.I:ix
198 ibid, Vol.II:40, 48
199 ibid, Vol.I:24
200 ibid:25
201 ibid, Vol.II:22

nuclear plant.[202] He added that, given the competitive pressures now being imposed on the privatised generators, "it is up to the Government ... to take the major load in terms of .... a funding programme".[203]

In its final report, the Energy Committee concluded that since there was no early prospect for the commercialisation of fast reactors, further substantial research investment could not justified, and that therefore, there was no reason to dissent from the Government's decision to withdraw funding for the Dounreay PFR plant:

> It is clear that because of the very long timescale involved, the newly privatised electricity supply industry is not likely to make a significant contribution until the development of fast reactors is very much more advanced ... An extremely large rise in uranium prices would be necessary to make fast reactors economic with PWRs ... On the Government's own forecasts the need might not arise until 2120 [sic].[204]

The Committee reported that since 1954, the UK had spent over £4bn on fast reactor research, and that even in the late-1980s, it had still accounted for over half of the Department of Energy's total R&D expenditure.[205] The report added that the ending of the main part of this programme without any clear return pointed to general deficiencies in public R&D investment: "the story of the UK's fast reactor programme shows the necessity of keeping all major R&D projects under close and continuous review".[206]

After the decision to withdraw funding for the Dounreay PFR, the European Fast Reactor (EFR) became the mainstay of fast reactor research in Britain. In September 1989, Tony Broomfield, Director of the AEA fast reactor programme, stated that the British research effort was a key part of the collaborative European R&D effort in support of the EFR design.[207] In October 1989 the EFR project was described by two senior British nuclear scientists as "unchallenged as the route by which uranium can be the main contribution to the non renewable energy resources of the world ... The EFR project bridges the remaining gap in bringing the fast reactor system to commercial maturity in Europe".[208]

However, as discussed in Section 4.3 above, the attempted privatisation of conventional nuclear plant in 1989 revealed them to be grossly uncompetitive with fossil fuel plant in a privatised ESI. Given the extra costs of fast reactor generation over and above

---

202 ibid:17
203 ibid:23
204 ibid, Vol.I:x-xxv
205 ibid:ix
206 ibid:xxvi
207 A. M. Broomfield, 'Fast Reactor Development Programme', *Atom*, Vol.395, pp6-9, September 1989:9
208 D. Broadley and A.M. Judd, 'The European Fast Reactor', *Atom*, Vol.396, pp25-31, October 1989

conventional nuclear technology, this clearly meant that there was no foreseeable prospect for the commercialisation of fast reactors. In November 1992 the Government announced that it would cease funding R&D work in support of the EFR. The statement was described as "effectively putting an end to fast reactor R&D in the UK".[209]

4.5.3 The Nuclear Industry Perspective

Interviewed in early-1994, just as the Prototype Fast Reactor plant was being closed down, Alistair Cruickshank, Special Projects Manager at AEA Dounreay, defended the record of the British fast reactor programme. Cruickshank made clear that he saw the PFR as a technical success confounded by changing economic and political circumstances:

> The operation was a success but the patient died. We proved the technology, we proved the materials, we developed high performance steam generating units, we increased the burn-up of fuel ... which is a big economic advantage ... we've done everything we were asked to do, essentially.

Cruickshank traced the demise of the fast reactor programme to the inaccuracy of uranium price forecasts (as quoted in 4.5.1 above). On the basis of similar long-term projections, however, he maintained that fast reactors would eventually prove commercially viable: "at current projections it will be around 2050-2100 before it will be necessary, probably, due to run-down in the alternatives, and greater demand". He identified institutional and political errors for the demise of the PFR, and the wider British nuclear power programme: "we did stupid things, like insisting on a system of tendering for designs instead of going for series manufacture". He claimed that under different political circumstances, nuclear power was economically viable:

> Nuclear power pays in other countries, it depends on social things. We had political reasons in our country why nuclear looked worse than it was. We were doing things for political reasons rather than rational reasons. but I don't think there's any real reason why [nuclear power] can't be popular and cheap.

In common with Lord Marshall (see 4.3.3 above), Cruickshank saw the ending of the fast reactor research programme as evidence, not of the uncompetitiveness of the technology, but rather of the absence of provision for long term R&D in the Government's proposals

---

209 'UK government pulls out of EFR...', *Atom*, Vol.425, p2, November/December 1992

for ESI privatisation, and the absence of an overall framework for energy policy. Political short-termism, he claimed, had resulted in the dominance of economic short-termism:

> Governments tend to take short term views geared to the next General Election ... they don't take a long term view. We've got a bad attitude generally to the development of science and technology – we don't spend nearly as much on R&D as competitor countries do ... I don't think you can leave everything to the free market, because ... [it] doesn't operate in the long term interests of the general population, but in the short and medium term interests of its shareholders.

Cruickshank suggested that the Government's ideological commitment to privatisation was applied in an ill-considered way to the ESI. Whilst conceding that "the power industry was a bit over-fat and needed leaning down", he stated that "we've been privatising beyond logic to some extent ... It's become political dogma rather than common sense". Like other critics of privatisation, he argued that the Government should play a leading role in energy policy and maintaining R&D investment in the sector:

> We ... have no coherent energy policy ... [it has] to be centrally run in some way by Government. I can't see the private energy producers doing it ... there's very little energy R&D going on in this country at the moment. An integrated energy policy would include fossil fuels and nuclear. You can't put all your eggs in one basket, or dissipate your resources too quickly.

Cruickshank argued that "we should have kept our toes in the water with the European Fast Reactor, even if we shut down the PFR". He also stated that the thermal reactor programme should have been continued, in order "to meet the requirements for energy and keep the industry moving ... If you opt out of the technology and you need it in 50 years time you're going to ... have to buy in the technology". Cruickshank maintained that "in the longer term we are going to need fast reactors ... it is essentially now a proven technology ... The day will come when we will require the 98% of uranium that we can't use now ... due to run-down in the alternatives, and greater demand ... it's difficult to see that nuclear power will not be required, given the way we live".

Others involved in the fast reactor programme also to defended its record, and called for its continued funding. Brian Eyre, the Deputy Chairman and Chief Executive of AEA, stated that he remained "convinced that fast reactors are essential to realising the full potential of nuclear power and to meeting the energy needs of the 21st century".[210] Similarly, in a review of the fast reactor research programme in 1994, Tony Broomfield, the Business Director of AEA Technology, stated that "the original *raison d'être* for the

---

210 'UK government pulls out of EFR...', *Atom*, Vol.425, p2, November/December 1992

fast reactor remains ... The nuclear industry ... is convinced that the fast reactor is the system of the future and that the day will come when fast reactors are deployed commercially".[211]

4.6 Summary and Review

4.6.1 Nuclear Power Technology and ESI Privatisation

The ESI privatisation process from 1987 onwards brought about the radical restructuring of the economic and institutional context for electricity generation technology. From the start of the ESI privatisation process after the 1987 General Election, the Energy Secretary Cecil Parkinson made clear the Government's determination to *liberalise* as well as privatise the ESI (4.2.1). Parkinson also made clear early on that he was prepared to confront CEGB's opposition to liberalisation. In early debate on the future form of the industry, the CEGB and ESTUC invoked a number of supposed technical imperatives to defend the integration of generation and transmission and the monopoly ownership of generation plant. In outlining their case, the CEGB repeated many earlier arguments, espoused, for example, by Herbert and Plowden Committees, but with the added *kudos* of insider technical authority (4.2.1). After 1987, however, the CEGB's views were no longer bolstered by Government support, and a range of independent expert opinion came forward to challenge the Board's technical arguments (4.2.1). Parkinson also made clear that the opinion of the CEGB Chairman no longer carried significantly greater weight than other voices (4.2.1).

The Government proposals for ESI privatisation announced in the February 1988 White Paper represented a radical break in established policies towards the ESI, both in the UK and elsewhere (4.2.2). In terms of generation technology, the key proposals for the liberalisation of the industry were the transfer of grid ownership to the RECs, and the splitting-up of the CEGB and the removal of its statutory obligation to supply. At the same time, the proposals for generation included a number of measures designed to secure the privatisation of nuclear power, and the continuity of the nuclear programme in the privatised ESI. The most significant of these was the limited extent of the division of the CEGB, and the retention of a large generator with sufficient market control to drive forward the nuclear programme (4.2.3).

211 Tony Broomfield, 'PFR Builds Firm Foundations for Fast Reactors', Atom, Vol.433,pp22-26, March/April 1994:26

At the beginning of the ESI privatisation process, the Government and the nuclear industry continued to make the case for the nuclear programme on cost grounds. In their 1987 manifesto, the Conservative party stated their commitment to develop "abundant low-cost supplies of nuclear electricity" (4.2.1). As late as May 1988 Professor Peter Jones, the AEA's Chief Economic Advisor, claimed that "investment in civil nuclear development has fully justified itself" (4.3.1). Whilst the 1988 White Paper expressed continued support for the nuclear programme, however, it made no claims for the cost-competitiveness of nuclear electricity, and instead defended the nuclear programme on diversity and security of supply grounds alone (4.2.3). In increasingly difficult circumstances in late-1988 and early-1989, the Government's support for nuclear power – and their exposition of the 'diversity case' – became more overtly politicised. During the second reading of the Bill in December 1988, Cecil Parkinson invoked the historic threats of "Mr Scargill" and "oil price explosion" in this regard. By the late-1980s, however, both the NUM and OPEC were institutionally weak, and largely irrelevant to the ESI's future.

A number of analysts quickly recognised that the Government's provisions for nuclear power unveiled in the White Paper would not prove sufficient to secure its flotation (4.2.4). The proposals meant that, although nuclear electricity would enjoy a protected share of the electricity market (through the NFFO), there was no mechanism by which the extra costs of nuclear power could continue to be passed on without difficulty. The need for such a mechanism became apparent in 1988, resulting in the introduction of the Fossil Fuel Levy in the Electricity Bill in November 1988. Whilst they provided a protected market and continuing subsidy, however, the Non-Fossil Fuel Obligation and the Levy also made embarrassingly transparent the extra costs of nuclear power as compared to fossil-fuel plant. The Levy was a powerful recognition by Government of the extra costs of nuclear electricity, and finally made the economic case for nuclear power untenable.

For a brief period in mid-1988 after the publication of the White Paper, the CEGB/National Power remained publicly committed to its proposed PWR programme (4.3.1). From late-1988 onwards, however, the CEGB's National Power Division was expressing its concern to the Department of Energy about being ultimately financially accountable for nuclear power in a privatised ESI, and a series of leaked reports and letters emerged that suggested that nuclear power would be grossly uncompetitive in a privatised ESI (4.3.2). As Tony Blair pointed out, whereas for decades the CEGB's concern had been to promote the supposed benefits of nuclear power, it had now become in the institutional interests of National Power to emphasise the risks and extra costs of nuclear technology, in order to secure the maximum guarantees and subsidies from the Government (4.3.3). In John Baker, this *volte-face* was personified. Whilst CEGB Managing Director in the early- and mid-1980s, Baker was a prominent proponent of nuclear power. In 1985 he stated that nuclear power "was by far the cheapest generating cost on the system", and claimed that the CEGB's proposed series of PWRs would "reduce the costs of electricity generation" (3.7.2). In 1988 and 1989, however, as the Chief Executive of National Power, Baker's leaked letters to the Department of Energy portrayed a very different picture of the economics of nuclear power. In March 1989 he was reported as describing National Power's responsibility for nuclear power as a "restriction ... [which] will reduce its ability to compete against PowerGen and the other electricity generators", and also that "the problems of nuclear power are very intractable" (4.3.2). Whilst Baker's dramatic change of mind in part reflected the radically different economic environment for nuclear technology in 1989 as compared to 1985, it also reflected the changed institutional interests of National Power as compared to the CEGB.

The suggested withdrawal of nuclear plant from privatisation was extensively debated in Parliament in April 1989, but despite the warnings of MPs from all parties, the Energy Secretary Cecil Parkinson insisted that the Government should press ahead with nuclear privatisation. At the same time, Parkinson acknowledged that nuclear costs were higher than previously thought, and that the public had never been told the true cost of nuclear power. He also made scathing criticisms of the British nuclear power programme (4.3.2). At any earlier time such comments by an Energy Secretary would have been inconceivable, and their statement reflected Parkinson's growing frustration at the unanticipated consequences of ESI liberalisation. Parkinson's widely anticipated Commons announcement, in July 1989, of the withdrawal of Magnox plant was immediately recognised by a number of MPs and industry analysts as an inadequate half-way retreat (4.3.2)

John Wakeham's announcement of the withdrawal of AGR plants from privatisation was again widely anticipated – although the Government's cancellation of the PWR programme after the completion of Sizewell B caused some surprise in the industry. The evidence submitted to Energy Select Committee in 1990 confirmed that the immediate cause of the huge nuclear power cost increases in 1989 were the switch from cost-plus to fixed price contracts between National Power and BNFL (4.3.3). However, Wakeham's (and others') distinction between the underlying *cost* and actual *price* of nuclear electricity was rather spurious, given that, on any terms, nuclear power had been revealed to be grossly uncompetitive compared to fossil fuel generation technologies.

The cancellation of the PWR programme was made easier by the fact that, by mid-1989, it had become clear that gas turbine generation technology was offering an alternative means of supply diversity, as Wakeham indicated in his November statement on the withdrawal of nuclear plant (4.3.3). However, as compared to the private sector's rejection of the liabilities and risks associated with nuclear power, the emergence of CCGT technology probably had only a marginal influence. Indeed, if the cost escalation of nuclear power had not risen to the extent that it was threatening the entire ESI privatisation process, the PWR series would probably have progressed in parallel with the gas turbine plant development, as Lord Marshall had suggested. Rather, the most significant role for CCGT technology in the withdrawal of nuclear plant was probably that of providing an *ex-post* rationale for Government.

In evidence to the Energy Select Committee shortly after the publication of the White Paper, although Lord Marshall argued forcefully for the retention of a monopoly generator with control of the grid after privatisation, he appeared reasonably content with the Government's proposals. Under questioning by the Committee, Marshall stated that he did "not see privatisation as a threat ...[to the] ... excellent opportunities to build the small family of PWRs" (4.2.3). After the withdrawal of nuclear power from privatisation, however, he presented a rather different account of his views. In evidence to the Select Committee in 1990, he claimed that he had quickly recognised the threat presented by the Government's proposals to the PWR programme, stating that he "thought that it might well lead to the end of new nuclear power in this country" (4.3.3).

4.6.2 Nuclear Power Technology after ESI Privatisation

Following its withdrawal from privatisation, the British nuclear power industry developed in a quite different economic, regulatory, and organisational environment to the rest of the ESI. The mechanisms for market protection and subsidy of nuclear power, originally introduced in order to secure the privatisation of the nuclear plants, remained in force after their retention in public ownership, and provided a privileged framework within which the nuclear industry could improve its performance. Nevertheless, even the nuclear industry faced very different demands after 1989 compared to those within which it had developed in under nationalisation. Although it continued to enjoy market guarantees and subsidies, nuclear power was placed under much greater commercial pressures than ever before. The extra cost of nuclear power, which, as Wakeham conceded, had "remained hidden" throughout nationalisation, was now transparent – painfully so for those in the industry. It was also evident that the continued protection of nuclear power was only temporary. In effect, Nuclear Electric was placed on a probationary period pending the Government's Nuclear Review. The Government also made clear that the case for any new nuclear plant after Sizewell B would need to made essentially on economic grounds.

Given these pressures and incentives, Nuclear Electric was able to greatly improve the technical economic performance of the British nuclear power plants. The much greater availability of AGR plant achieved after 1989 was somewhat due to fortuitous timing on the part of Nuclear Electric. A number of AGRs finally became available for commercial operation in 1988 and 1989. Although wholly overshadowed by other events, the CEGB had reported improved performance from its nuclear plants in the late-1980s, and some of the technical gains would have been achieved irrespective of privatisation. At the same time, Nuclear Electric operated the industry on much more commercial basis than at any time under nationalisation (4.4). Under pressure 'by comparison' with the rest of the ESI, the nuclear industry was run on contractual and management terms that reflected those now governing the privatised generators.

Although it was greatly disempowered and marginalised after its withdrawal from privatisation, the nuclear industry remained largely institutionally intact, and it retained some influence, as was confirmed by the re-emergence of the British nuclear industry lobby ahead of the Government's Nuclear Review (4.4). By 1995, assured by the much more commercial running of the industry, the fixed-price contracts now established for waste-processing, and the greater provision for decommissioning costs, the Government was able to propose the privatisation of the AGRs and PWR plants. However, the Government offered no support for the construction of new nuclear plant, and the newly-created British Energy was forced to drop its tentative plans for new nuclear plants before it was successfully sold-off in 1996.

The successful completion of the privatisation of British Energy in 1996 was testament to the changed technical, economic, and organisational conditions of the British nuclear industry in 1996 as compared to 1989. It also confirmed the view that the withdrawal of nuclear power from privatisation in 1989 was a *contingent* rather than an *inevitable* event. Rather than revealing, in a technological (or economic) determinist fashion, the inherent incompatibility of private ownership and nuclear power technology, the changes to nuclear power during this period were an outcome of particular technical, economic, and institutional dynamics, steered by particular political choices on the part of the Government.

4.6.3 The Fast Reactor Programme and ESI Privatisation

More than any other technology, the fast reactor reflected the technocentrism of the powerful corporate institutions of the ESI under nationalisation. The case for fast reactor development was never made on economic grounds – other than highly speculative long-term fuel projections. Rather, the fast reactor research programme was driven from the outset by technical potential – and on this basis became, as Gowing stated "the main goal of the nuclear power programme" (4.5.1).

As late as the mid-1980s, the fast reactor research programme was still by far the biggest research programme in the British ESI. In 1986 the Energy Technology Support Unit defended this dominance, and predicted that "the fast reactor has the potential to become the major supplier of electricity in the UK by 2020-2030" (4.5.2). It was also defended by Sir Philip Jones, Chairman of the Electricity Council, in his early evidence to the Energy Select Committee in 1988, on the overtly technocentric grounds that fast reactor technology *required* greater investment than other areas, in order to "keep abreast of the technology" (4.5.2) .

Nevertheless, it was quickly recognised that without Government intervention, ESI privatisation was likely to bring about the end of the fast reactor programme. Following the Government's withdrawal of funding for the Dounreay PFR in July 1988, the Energy Select Committee's inquiry on the fast reactor reported that, even on Government forecasts, fast reactor technology might not become commercial for around 150 years – several generations beyond the investment horizons of any private investor (4.5.2).

By the mid-1990s, the institutionalised technocentrism that had driven forwards the British nuclear programme, from its postwar inception up to the mid-1980s, remained audible only in the protests of a few disenfranchised voices, such as those of the AEA's Alistair Cruickshank. Cruickshank, like others involved in the fast reactor programme, associated the demise of the British fast reactor programme with economic and political short-termism, and effectively argued for a return to the government-led energy policymaking of the 1970s (4.5.3). However, whilst nuclear engineers still argued the case for nuclear technology on technical grounds, the rest of the ESI was no longer responsive to such arguments. In the new economic, institutional and regulatory framework for electricity generation, the most authoritative voices were private sector investors, who imposed *financial* rather than *technical* criteria on choices in generation technology.

CHAPTER 5:

GAS TURBINE TECHNOLOGY AND ESI PRIVATISATION

5.1 Introduction

This chapter considers the role of combined cycle gas turbine (CCGT) technology in the period during and after privatisation. Although gas turbine technology had no significant role in the British ESI under nationalisation (3.5.4), it proved to be central to the changes affecting the industry during and after privatisation. As will be explored in this chapter, the causes of this transformation were a complex mix of interacting technical, economic, institutional and political forces.

As was discussed in Section 3.5, the development of CCGT technology took place outside of the British ESI, in an institutional and regulatory environment quite different to those determining generation technology choice in Britain. Section 5.2 analyses the continued development of CCGT technology in the late-1980s and early-1990s. Section 5.3 returns to the British ESI, and considers the reasons for the adoption of CCGT technology during and after the privatisation process. Section 5.4 presents particular perspectives on the adoption of CCGT technology in the Britain, based on a small number of personally-conducted interviews. Finally, Section 5.5 is a summary and more analytical consideration of the causes and effects of CCGT technology in this period.

5.2 CCGT Technology in the late-1980s and 1990s

The market prospects of gas turbine/CCGT technology was transformed in the 1980s (3.5.3) – to the extent that by 1988 Williams and Larson reported that "a revolution is under way in electricity generating technology. It may soon radically transform the power industry in both industrial and developing countries".[1] They added that this revolution "involves not an exotic new technology, but rather the upgrading of the familiar but little-used gas turbine".[2]

---

[1] Robert H. Williams and Eric D. Larson, 'Aeroderivative Turbines for Stationary Power', *Annual Review of Energy*, Vol.13, pp429-489, 1988:429

[2] ibid:429 Williams and Larson claimed that, at 1986 gas prices, a modern 200MW CCGT power plant could produce power at 3/5ths of the cost of that from a large coal-fired steam turbine plant (ibid:448).

Between the late-1980s and the early-1990s, the use of gas turbine generation technology expanded rapidly in the US ESI, so that by 1990, it was capturing two-thirds of all power plant orders.[3] In 1989 Smock stated that a new "gas turbine boom" was taking place in the US power industry, as a rush of orders were placed, including a number of larger-sized CCGT/CHP schemes.[4] He added that "gas turbines are expected to be the dominant form of new utility and independent capacity ordered in the 1990s".[5] In the same year, Andrews also stated that plant manufacturers were reporting an increasing number of orders for larger CCGT stations.[6] In 1989, General Electric began installing its larger, more efficient 'Frame F' series industrial turbines, rated at over 200MW.[7] At the same time other plant manufacturers, such as ABB, Siemens and Westinghouse/Mitsubishi, were introducing similarly advanced larger-scale gas turbine units.

The thermal stability of turbine blade materials had, for many years, been the principal limiting factor on gas turbine efficiency.[8] In the late-1980s, a number of established aero-engine turbine blade technologies, such as directional solidification, oxide dispersion, and single crystal bladeing, were adapted for use in industrial gas turbines.[9] Directional solidification, for example, was a 20 year old technology first applied to industrial gas turbines in General Electric's 'F' series engines.[10] Other technologies introduced at this time were the introduction of air-cooling of turbine blades, and thermal barrier coatings.[11] Haywood stated that improved turbine materials and cooling technologies had together produced "very significant improvements in gas turbine performance".[12] By 1990 the newest nickel-based superalloy turbine blades were capable of withstanding temperatures of up to 1300°C, compared to around 900°C twenty years earlier.[13] Horlock stated that "it has been the increase in the gas turbine maximum temperature ... that has enabled the ...

---

3 R. Smock, 'Gas Turbine, Combined Cycle Orders Continue', *Power Engineering*, May 1991, pp17-22:17

4 R. Smock, 'Gas Turbines Dominate New Capacity Ordering', *Power Engineering*, August 1989, pp23-28:23

5 ibid:23

6 David Andrews, 'Joining Forces', *International Power Generation*, March 1988, pp19-22:21. General Electric had recently announced a 190MW CCGT/CHP plant at Big Spring, Texas and Westinghouse had stated they would build two 300MW CCGT/CHP plants for Intercontinental Energy, an independent US power producer.

7 R. Smock, 1989, op cit, pp23-28:27-28

8 Haigh pointed out that "temperature limits have usually been the governing factor on turbine development, and major advances can usually be tied to improvements in blade technology". (I .T. Haigh , 'Lighter fuel: The Gas Turbine Comes of Age', *IEE Review*, Vol.37, No.3, 21 March 1991, pp97-102:100)

9 M. Valenti, 'Combined-Cycle Plants: Burning Cleaner and Saving Fuel', *Mechanical Engineering*, September 1991, pp46-50:50.

10 Smock, 1989, op cit:28. Similarly, single-crystal blades were first used in aero-engines in 1982. (Chris W. Maude and Andrew T. Kirchner, *Gas Turbine Developments*, London, IEA Coal Research, September 1995)

11 Haigh, op cit:100; P. J. Alberry, B. J. Davidson, and M. Corey, 'Advanced Gas Turbine Power Generation', in *Energy for the 21st Century*, I.Mech.E. Seminar 1996-3, London, pp27-30:28

12 R. Haywood, 'New Technologies in Power Generation', *Rolls-Royce Magazine*, No.62, September 1994, pp11-14:11

13 MPS Review, 'Gas expands into European power', unnamed staff report, *Modern Power Systems*, February 1991, pp27-29:27

combined plant to become increasingly competitive with conventional high pressure steam plant".[14]

As well as these 'conventional' improvements in gas turbine technology, by the late-1980s, computer modelling was also allowing for significant additional improvements in the overall design of CCGT plant. Alberry et al., for example, highlighted the reduction in heat recovery losses by the use of three separate steam circuits operating at different pressures, with reheating between high, and intermediate and low pressure stages. They stated that "in the few years since natural gas became available for use in power generation, there have been spectacular improvements both to the gas turbines themselves and to the way in which the gas turbine is integrated with the steam plant in a combined cycle".[15] Together, these improvements provided for an increase in CCGT plant efficiencies from 47% in the mid-1980s to over 55% a decade later – an increase that brought with it significant fuel cost savings.[16]

As Haywood pointed out, "advances in the industrial gas turbine have largely followed developments in the aero-engine business where the intense competition – and massive market – ensures an investment in research and development which is probably unparalleled elsewhere".[17] The transfer of aero-engine technologies to the larger-scale and more robust demands of industrial-engines involved significant additional costs in scaling-up and adaption. Up to the late-1980s, these costs of conversion were prohibitive. Industrial gas turbine R&D did not benefit from the high-turnover and mass-production of turbojets, nor the support of state-funded military sales contracts. Rather, the development of CCGT technology had to be borne by sales on industrial turbines alone. Only after 1986, when natural gas became cheaper and more widely available, did the market for gas-fired generation provide sufficient financial incentive for the conversion of established turbojet technologies. The introduction of these technologies, by providing significant gains in the competitiveness of industrial gas turbines, led in-turn to further growth in sales revenue from the power generation market, and by the early-1990s, all the major international plant manufacturers had substantial research programmes dedicated to the further technological development of CCGT plant for electricity generation.

---

14 J. H. Horlock, *Combined Power Plants: Including Combined Cycle Gas Turbine (CCGT) Plants*, Oxford, Pergamon Press, 1992:269-70. At the same time, Horlock pointed out, the reliability of industrial gas turbines was also substantially improved, from under 80% availability in the mid-1970s, to over 95% availability by the late-1980s (ibid:27).

15 P. J. Alberry, B. J. Davidson, and M. Corey, 'Advanced Gas Turbine Power Generation', in *Energy for the 21st Century*, I.Mech.E. Seminar 1996-3, London, pp27-32:27

16 Haywood, op cit:11-12

17 Haywood, op cit:11

Nevertheless, as Maude and Kirchner emphasised, that the worldwide interest in gas turbines for power generation was still predicated on the availability and affordability of natural gas:

> In the early years the industrial gas turbine was expected to produce cheap energy from low grade fuels ... The widespread availability of natural gas has turned the tide ... The emphasis on the use of gas turbines for utility power generation is very much based on the ready availability of natural gas in many areas of the world.[18]

Many industry observers and power plant industry insiders argued that cheap gas prices could not be maintained beyond the short-term, so that CCGT technology had to be adapted for coal gasification. Smock, for example, stated in 1989 that: "the long term viability of gas turbines depends on the availability of coal as a fuel."[19] Similarly, Johnson predicted that rising gas prices in the second half of the 1990s would lead to a return to coal plant orders.[20] In the event a combination of further discoveries, supply industry deregulation, and the construction of international supply pipelines provided for continued cheap gas prices into the mid-1990s.

Advances to CCGT technology also continued apace in the mid-1990s. These included the incorporation of further techniques from aero-engines, such as steam cooling of turbine blades and the development of transonic compressors, as well as innovations developed purely for industrial gas turbines, such as sequential combustion.[21] In 1995 General Electric unveiled its 'H' series of gas turbine engines, the basis of a 480MW CCGT plant, capable of 60% thermal efficiency. These engines incorporated many aeroderivative technologies and components, such as single crystal and directionally solidified gas turbine blades, and an advanced aeroderivative compressor.[22] Further improvements in the performance of gas turbines were expected to continue during the rest of the 1990s. Horlock concluded that "the competitive advantages of CCGT plants are now widely recognised ... [it] is here to stay as a major producer of electrical power. It may well become the dominant one by the twenty-first century".[23]

---

18 C. W. Maude and A. T. Kirchner, *Gas Turbine Developments*, London, IEA Coal Research, September 1995:72. Similarly Smock stated that "much of the popularity of gas-turbines based capacity stems from the low price of natural gas relative to coal." (1989, op cit:24)

19 Smock, 1989, op cit:27

20 op cit:116

21 Alberry, et al., op cit

22 M. Valenti, 'Breaking the Thermal Efficiency Barrier', *Mechanical Engineering*, July 1995, pp86-89

23 Horlock, op cit:xiii-xiv

5.3 Gas Turbine Technology and ESI Privatisation

5.3.1 Awareness of CCGT Technology ahead of Privatisation

In 1987, as debate on the privatisation of the ESI got under way, the CEGB remained firmly committed to coal-fired and nuclear power technology for all new large-scale generation plant (4.2.1). The CEGB's Annual Report for 1987/88, published in August 1988, concentrated on plans for additional PWR and coal-fired steam turbine plant. However, the Report also stated that "the Board has been in discussion with gas producers and plant manufacturers on the possibilities of generating electricity from combined cycle plant involving both gas and steam turbines".[24] It went on to explain that "this initiative arose because of the prospects of lower gas prices and improved technology in this field, making the economics of this plant more attractive".[25]

Among the vast amount of evidence submitted to the Energy Select Committee inquiry into ESI privatisation in early-1988, there was little discussion of gas turbine technology.[26] Even where they were mentioned, CCGTs were referred to as being of marginal importance, suited only for small and medium-sized plant, or for industrial CHP. The Electricity Council/CEGB memorandum to the Energy Committee claimed that nuclear power and coal-fired plant would continue to be the dominant choices for new generation plant after privatisation (4.2.1). At the same time, the memo also stated that "depending on the future prices ... CCGT has attractive potential", but added that it would probably be of more relevance for RECs interested in small generation/CHP projects.[27]

Under questioning from the Energy Select Committee in February 1988, shortly before publication of the White Paper proposals for privatisation, the Chairman of the Electricity Council, Sir Philip Jones, stated that although the prospects for CCGT plant were improving, they would play only a marginal role in the ESI after privatisation:

> I would certainly think that a combined cycle plant would become increasingly attractive, but again I would not wish to encourage the thought that it is going to make a significant contribution ... Inevitably much of the capacity which would be required will come from the large generating service.[28]

---

24 *Annual Report and Accounts 1987-88*, London, CEGB, August 1988:27

25 ibid:27

26 House of Commons Energy Committee, *The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector*, HC 307, 1987-88

27 ibid, Vol.II:3

28 ibid, Vol III:32 Jones also stressed that the prospects for gas turbine technology were dependent on the availability and price of natural gas.

In his evidence to the Energy Committee in February, the Chairman of the CEGB, Lord Marshall, was questioned by MPs on fuel and technology choice in generation after privatisation. In his replies, Marshall stressed the continued importance of nuclear power and coal-fired generation technology, and mentioned gas turbine technology only in terms of its use for cogeneration. Even here, Marshall emphasised, the prospects for CCGT investment were highly dependent on the availability of cheap gas.[29] Towards the end of its inquiry, the Energy Select Committee heard some evidence that the prospects for CCGT technology were improving. In June, John Baker, Managing Director of the CEGB, stated that the CEGB was now "looking actively at combined cycle gas turbines ... watch this space".[30]

The Area Board's also tended to downplay any significant role for gas turbines after privatisation. In their memorandum to the Select Committee, for example, Southern Electric stated that they did "not believe that there are any future known [technological] developments of sufficient weight as to affect the optimum structure of the ESI ... [including] CHP, combined cycles, and small generation projects".[31] Other Boards expressed some interest in CCGT technology, notably Eastern Electricity, the largest Area Board. In their memorandum to the select committee in early 1988, Eastern stated that "there are several locations where we might accommodate [CCGT] plants of up to 360MW". They added, however, that "for large conventional power stations, pulverised [coal] fuel technology should continue to dominate in the medium term".[32]

Similarly, under select committee questioning, Wynford Evans, Chairman of the South West Electricity Board, stated that he was "sure we are going to find some significant opportunities for natural gas generation".[33] However, Evans also made it clear that he thought that natural gas would continue to play a marginal role as an electricity fuel after privatisation, and added that he "would expect coal to be the dominant factor".[34] In their memorandum to the Committee, Yorkshire Electricity suggested that CCGT technology *could* make a significant impact on the ESI after privatisation, provided that liberalisation of the industry went far enough:

> There are a number of recent developments in generation which, given the right environment, could develop to considerable advantage, including combined cycle and single shaft gas turbine plant ... In order for these and

[29] ibid, Vol.III:11
[30] ibid, Vol.III:276
[31] ibid, Vol.II:67
[32] ibid, Vol II:23-24
[33] ibid, Vol III:60
[34] ibid, Vol.III:60

CHP power systems to develop there is a need for a real competitive environment for generation.[35]

ESI insiders were not alone in their views that CCGT technology would make little impact after privatisation. Among the evidence presented by independent analysts to the Energy Select Committee in 1988, and in wider discussion on the industry, there was little attention drawn to the potential of CCGT technology. In general, industry observers saw little prospect for a move away from nuclear and coal plant. In April 1988, for example, *Power in Europe* stated that such were the advantages of the CEGB's established large plant, that there were no prospects for significant competition to National Power and PowerGen for at least the first five years after privatisation.[36] In the same month, the *Financial Times* reported growing interest in independent power projects using CCGT technology, but stated that "the bulk of Britain's electricity will still come from the present stations".[37]

There were some exceptions to the general downplaying of the potential impact of CCGT plant. In his recommendations for the future structure of the ESI published in March 1987, Alex Henney referred to the greater diversity and willingness to develop new types of generation technology in more competitive systems – notably in the US.[38] At a Electricity Consumers Council conference on *Privatising Electricity* in October 1987, Nigel Evans suggested that a decentralised ESI would favour the quicker returns on investment offered by CCGT technology above other generation options.[39] At the Financial Times *World Electricity Conference* in November 1987, Mans Lonnroth strikingly compared the ESIs in many countries to the pre-Reformation Catholic church – too "hung-up" on cathedrals, and ripe for radical change. He added that CCGT technology was a likely catalyst for such change.[40]

In an article published in March 1988, David Andrews of the Association of Independent Electricity Producers suggested that the reluctance of the CEGB to exploit the potential of CCGT/CHP plant had led to the building-up of a latent demand for such technology in Britain – a demand which could be unleashed by privatisation.[41] Andrews argued that "in

---

35 ibid, Vol II:75

36 *Power in Europe*, April 1988

37 Maurice Samuelson, 'Private Players Plan for the Power Game', *Financial Times*, 29th April 1988, p10

38 Alex Henney, *Privatise Power: Restructuring The Electricity Supply Industry*, Policy Study No. 83 London, Centre for Policy Studies, March 1987:8

39 *Privatising Electricity – A Chance for Change?*, London, Electricity Consumers Council, 5th October 1987. Reported in *Energy Policy*, Vol.16, No.1, February 1988, p88 (Evans also argued that unless the CEGB was sold off as a monopoly, nuclear would be incompatible with privatisation.)

40 Conference report on the Financial Times World Electricity conference, London, 16-17th November 1987, by Francis McGowan, *Energy Policy*, Vol.16, No.2, April 1988:198

41 Andrews, David 'Joining Forces', *International Power Generation*, March 1988, pp19-22

the UK progress on the use of combined cycle plant has been slow because of the attitude of the CEGB. This was based on a commitment to the 'big is beautiful' electricity-only condensing steam cycle power station".[42] He concluded that if privatisation provided sufficient liberalisation of the industry, a major change in the choice of generation technology may be about to take place:

> It looks as though a breakthrough in the development of combined cycle plants in the UK may be about to occur ... The advantages of combined cycle plants using gas turbine engines seems to be irresistible. The outstanding question is whether the combination of low capital cost and high efficiency offered by relatively small combined cycle plants carry sufficient weight to overcome the inevitable inertia of those with vested interests in conventional 'big' power generation ... If privatisation really does enable competition to occur in power generation, then the growth of combined cycle plants may prove to be unstoppable.[43]

Early parliamentary debate on privatisation reflected the consensus view that there would be few opportunities for challenging the dominant institutions – and technologies – of generation in the post-privatised period. At the same time, however, there were a small number of MPs who argued that CCGT technology could have a significant impact on the industry. Most notable amongst these was Peter Rost, a member of the Energy Select Committee, and a longstanding supporter of independent generation. As early as December 1987, Rost stated that Area Board Chairmen were claiming that they could self-generate more cheaply than taking their power from the CEGB.[44] In March 1988, during parliamentary debate on the White Paper, Rost stated that "competition is already happening", and reported that offers from private generators to the Area Boards were coming forward. He added that plant manufacturers were "waiting to market its CCGT in this country, but the CEGB was not interested.[45] In an article published in October 1988, Rost argued that "new technologies have been neglected" in the nationalised ESI.[46] He was highly critical of the development of the industry after nationalisation, and claimed that a more competitive ESI would have provided "greater diversity and security of supply, as well as lower cost power, from using more gas turbine generation".[47] He predicted that after privatisation, "new independent producers will want to prove more efficient generation such as combined cycle gas turbines".[48]

---

42 ibid:22

43 ibid:22

44 HC Debates, 1987-88, Vol.124, c758

45 HC Debates, 1987-88, Vol.129, c107-8. At the same time John Hannam, another prominent supporter of ESI liberalisation, was critical of the CEGB's commitment to established generation technology, and their neglect of CCGTs (ibid, c72-3).

46 Peter Rost, 'Towards a Competitive Market-Related Energy Policy', *Energy Policy*, Vol.16, No.5, pp450-452, October 1988

47 ibid:451

48 ibid:452

During the second commons reading of the Electricity Bill in December 1988, Labour's Energy Spokesman, Tony Blair, argued that there would be very little scope for independent generation in the privatised ESI.[49] Blair's dismissal of the possible impact of independent generation was rejected by Peter Rost at this time; Rost estimated 10GW of new capacity could develop in the following five years, "from new independent producers putting up power stations that the CEGB has preferred to ignore".[50] Rost stated that a number of schemes were already active, but that commercial sensitivity restricted details of these. Similarly, John Hannam predicted that CCGT plant "will flourish in the new arena".[51] The Energy Secretary Cecil Parkinson stated that around 20 major independent power projects were now "in the pipeline".[52]

The evidence submitted to the Hinkley Point C public inquiry in 1989 also provided an expression of CEGB opinion towards generation technology options in the run-up to privatisation.[53] The inquiry inspector, Michael Barnes, requested that the CEGB provide evidence of cost comparisons of the proposed PWR with alternative generation technologies. The CEGB presented comparative figures for PWR, coal-fired steam turbine, and small gas turbine plants – but did not include a CCGT plant in their analysis.[54] Whilst it recognised that there was "considerable interest" in CCGT plant, the CEGB justified its omission from their cost comparisons on a number of grounds: uncertainty in gas prices, the complex contractual details involved with gas-fired plant, and on the much shorter working lives of CCGT plant as compared to nuclear plant. Despite this, on the basis of independent information on CCGT costs, Michael Barnes concluded that "it appears likely that combined cycle gas turbines would enjoy an economic advantage over both PWRs and coal-fired plant, certainly using discount rates of 7% and above".[55]

At the same time as preparations were being made for ESI privatisation, the gas supply industry was undergoing significant liberalisation. By the late 1980s British Gas, which had been privatised without restructuring in 1986, was coming under increasing criticism concerning its perceived monopolistic behaviour. In 1987 the Director General of Fair Trading referred British Gas to the Monopolies and Mergers Commission. The MMC

[49] HC Debates Vol.143 1988-89, c682. Blair reported the views of the Association of Independent Electricity Producers that 4GW of independent power plant was "the upper range" of possible entry after privatisation – just 6-7% of total system capacity.
[50] ibid, c721
[51] ibid, c716
[52] ibid, c672
[53] Department of Energy, *Hinkley Point C Public Inquiries*, (Michael Barnes QC) London, HMSO, 1990
[54] ibid, Ch29, p786, pg29.15
[55] ibid, Ch29, p856, pg29.138

report, published in October 1988, found "extensive discrimination" by British Gas in gas pricing and supply, and stated that it operated "against the public interest by deterring new entry".[56] In March 1990 the Director General of Fair Trading agreed terms with British Gas for the liberalisation of the industry, involving the offering by BG of reasonable charges for the use of the transmission pipeline, and the separation of BG's supply and transportation businesses. In November 1989 British Gas published, for the first time, a price schedule for gas supplies to industrial users.[57]

5.3.2 The Introduction of CCGT Technology during Privatisation

Growing concern about environmental pollution in the late-1980s, especially acid rain and global warming, meant that pollution abatement legislation became an urgent political issue in Europe. In June 1988, after several years of discussion, the EC issued the *Large Combustion Plants Directive* (*LCP Directive*), which committed all EC member countries to progressive reductions in their sulphur dioxide (SO_2) emissions.[58] Coal-fired electricity generation was a major cause of SO_2 emissions, and for the UK ESI, the Directive required reductions in SO_2 emission levels of 11% by 1993, 40% by 1998, and 60% by 2000 (relative to 1990 levels).[59]

The established means of reducing ESI emissions of sulphur dioxide was the retrofitting of flue-gas desulphurisation (FGD) equipment to existing coal-fired plant.[60] For the British ESI it was initially thought that meeting the LCP Directive targets would require the fitting of FGD equipment to around 12GW of coal-fired power plant capacity.[61] It was quickly appreciated, however, that burning natural gas – a much cleaner fuel than coal – offered an alternative means of meeting the LCP Directive emission levels. The prospects for CCGT technology in the British ESI developed rapidly in the second half of 1988, after the passing of the LCP Directive.

After the publication of the White Paper on ESI privatisation made clear the Government's intention of liberalising the ESI (4.2.2), a number schemes for independent power stations were developed. In May 1988 Cecil Parkinson gave approval to the first

---

[56] Monopolies and Mergers Commission, *Gas*, Cmnd 500, October 1988

[57] Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994:221

[58] 88/609/EEC. The LCP Directive also restricted nitrogen oxides and dust particulate emissions.

[59] House of Commons Energy Committee, *The Flue Gas Desulphurisation Programme*, HC 371, 1989-90:ix

[60] The German ESI, for example, confronted with public and political pressure regarding acid rain several years before the UK, had installed FGD to 90% of its coal-fired power stations.

[61] HC 371, 1989-90, op cit:x

gas-fired plant scheme, a 1000MW CCGT plant proposed for Barking Reach in Essex by a consortium of plant manufacturers and civil engineers known as *Thames Power*.[62] Initially, however, most of the independent power plant schemes were based on the recommissioning of former CEGB power stations as coal-fired steam turbine plant.[63] One of the first of these schemes was based on a former CEGB coal-fired steam turbine power station at Roosecote, near Barrow-in-Furness, in Cumbria. Roosecote was bought by *Cumbria* (later *Lakeland*) *Power*, a small consortium led by Neil Bryson, with the intention of recommissioning it using coal from Bryson's own private mines.

The LCP Directive requirement that all recommissioned coal-fired plant had to be fitted with desulphurisation equipment added significantly to the capital and running costs of such plant. It also affected the relative cost of independent versus National Power/PowerGen generation. The Directive targets meant that National Power and PowerGen were only required to fit desulphurisation technology to a small number of their plant – and were given several years in which to do so. By contrast, all new or recommissioned coal-fired power plants were required to install FGD equipment before starting operation. After the LCP Directive was passed the competitiveness of Roosecote and similar independent schemes – already marginal given National Power/PowerGen's scale economies and continued market strength – became very questionable. Lakeland Power subsequently developed alternative proposals for Roosecote based on CCGT technology, using natural gas supplied by British Gas from their nearby Morecambe Bay field. A number of other independent CCGT plant proposals were developed at the same time. East Midlands Electricity, whose Chairman, John Harris, was known to be keen to enter generation as a counter to the market strength of the CEGB/National Power, developed plans for a 350MW CCGT power station at Corby in Northamptonshire. At the end of 1988 *Enron Corporation*, an independent US gas company, developed proposals for the construction of a large CCGT/CHP plant on ICI land at Teeside.[64]

In August 1988 the CEGB announced that they were investigating four sites for the construction of 300MW CCGT plants.[65] At the beginning of 1989 National Power and PowerGen began operating as two separate companies; both quickly developed expanded

---

62 Maurice Samuelson, 'Gas Power Station Approved', *Financial Times*, 11th May 1988, p8. Although the EEC Directive restricting the use of natural gas in electricity generation was still in force in the late-1980s, the British government, as part of its efforts to promote competition in generation, was attempting to secure its revocation. In the meantime, the Government stressed the flexibility of the Directive – it permitted national government's to permit construction of gas-fired power stations where there were "strong technical or economic reasons" for doing so. The Directive was finally revoked in October 1990. (*Power in Europe*, No.44, 2nd March 1989:10-11)

63 In an attempt to avoid being broken-up upon privatisation, the CEGB had sold a number of its old coal-fired steam turbine plant in 1987, so as to encourage a limited degree of independent generation to develop. (*Power in Europe*, No.61, 26th October 1989:8)

64 The development of the Roosecote and Teeside plants is discussed in more detail in Section 5.4.

65 *Power in Europe*, No.32, 1st September 1988:3

plans for CCGT plant. In April 1989 National Power applied to the Secretary of State for consent to build two CCGT power stations, at Killingholme (1020MW) and Little Barford (680MW); in May, PowerGen applied for consent to build two CCGT plants at Killingholme (c1000MW) and Rye House (680MW).[66] Both were also said to be investigating other possible sites for further plants.[67] The last-ever CEGB Annual Report, for 1988-89, reported that National Power had PowerGen's plans for developing CCGT plant had arisen because of the "current preference for smaller-sized units with short lead times and the lowest capital costs".[68]

At the beginning of September 1988, *Power in Europe* suggested that "the lowly gas-turbine appears poised for take-off", and reported that "CCGT plants have suddenly become flavour of the month", with plant proposals now emerging "from all sides of the industry".[69] Karl Schneider reported that, by February 1989, British Gas had received enquiries for around 8GW of gas-fired plant capacity from independent companies.[70] Schneider argued that CCGT technology enjoyed great economic advantages: "with industrial interest rates at about 15 per cent, the lower capital cost and short pay-back period make gas-fired stations almost irresistible".[71] He concluded that "if market forces have their way, [CCGT] stations could dominate new generation capacity for the foreseeable future".[72] In March 1989 *Power in Europe* referred to an "increasing number of paper power stations", but it expressed scepticism about the likelihood of many of the proposed plants being built.[73] The article quoted a City investment analyst as stating that he "did not expect generation to form a significant part of the public electricity supply business in the immediate post privatisation period. Such activities will take several years to develop".[74]

By the end of 1989 plans for a total of around 20 gas turbine generation projects had been submitted. A survey of new generating plant carried out by *Power in Europe* in May 1990 there were at least ten CCGT power stations that were likely to go ahead, with numerous other more speculative proposals.[75] In April 1990 the *Financial Times* reported that "gas is making a dramatic comeback as the favoured fuel for electricity generation",

---

66 CEGB, *Annual Report and Accounts 1988/89*, London, CEGB, December 1989:15
67 ibid:15
68 ibid:3
69 *Power in Europe*, No. 32, 1st September 1988:2-4
70 Karl Schneider, 'The Heat of the Moment', *Electrical Review*, Vol.222, No.4, 22nd February - 7th March 1989, pp31-32
71 ibid:31
72 ibid:31
73 *Power in Europe*, No.45, 16th March 1989:4-5
74 ibid:12. Concerns about the early "paper power stations" centred on the problems of securing a guaranteed long-term market for the output from the proposed plants, which was essential to raise the necessary capital for construction.
75 ibid, No.73, 10th May 1990

and reported that 10GW of CCGT plant schemes were now proposed for the British ESI.[76] Nevertheless, in September 1990, it also reported that "many in the industry view this tumult of activity sceptically".[77]

At an *Institution of Mechanical Engineers* conference in October 1990, Mr N. White of A. D. Little Ltd., stated that an unprecedented "dash-for-gas" was now under way in Britain.[78] White argued that even without environmental concerns prompted by the LCP Directive, there would have been an increase in the use of CCGT technology in the British ESI after privatisation, because of the low capital cost and short lead time of such plant. He concluded that the dash-for-gas was being driven by a "combination of technological developments and lower energy prices, coupled with a recognition that the resource base is very substantial, and recent concerns over pollution".[79]

In March 1991, Ian T. Haigh of Ewbank Preece Ltd. stated that "some profound changes are overcoming the technology of electricity generation ... and the traditional dominance of the venerable steam turbine is now under serious threat".[80] Haigh also emphasised the importance in this of the availability of cheap gas, but he concluded that the ESI's sudden preference for CCGT technology was an outcome of a "combination of environmental, economic and technical factors".[81] The first full Annual Report from the Office of Electricity Regulation, published in May 1991, stated that four generation licenses had been issued to independent generators in 1990, with another "dozen or so" applications under discussion.[82]

5.3.3 Select Committee Analysis of the *Dash-for-Gas*

In June 1990, as vesting of the new ESI companies was taking place, the Energy Select Committee published a report on *The Flue Gas Desulphurisation Programme.*[83] The Committee's investigations revealed that CCGT technology was now enjoying a clear cost advantage for new generating plant, and that it was also considered cost competitive with *existing* coal-fired plant, taking into account the extra costs of fitting and running

---

76 Maurice Samuelson, 'A Dramatic Comeback', *Financial Times*, 20th April 1990, FT Survey of the Gas Industry, p9

77 David Thomas, 'Pioneers Under Siege', *Financial Times*, 6th September 1990, p25

78 N. White, 'The Future for Natural Gas in European Power Generation', paper presented to IMechE, pp5-21, 12th December 1990, p5

79 ibid:8

80 Ian T. Haigh, 'Lighter fuel: The Gas Turbine Comes of Age', *IEE Review*, Vol.37, No.3, pp97-102, 21nd March 1991:97

81 ibid:97

82 Office of Electricity Regulation, *Annual Report 1990*, HC 355, 1990-91, May 1991, p5

83 House of Commons Energy Committee, *The Flue Gas Desulphurisation Programme*, HC 371, 1989-90

desulphurisation equipment. For new CCGT versus new coal-fired plant, the cost difference was overwhelming – both National Power and PowerGen told the select committee that natural gas prices would have to double before the cost of electricity from new CCGT plant reached levels similar to that from new coal plant with desulphurisation fitted. Mr. P. Chester, the Technical Executive Director of National Power, told the Select Committee that National Power had "looked at all the technical options", and were "quite clear that combined cycle gas turbines are the most economic".[84]

At the same time, National Power and PowerGen both also suggested that new CCGT plant provided cheaper electricity than that from their *existing* coal-fired plant, when the extra costs of desulphurisation were added-on. Since natural gas produces no sulphur dioxide, this meant that the LCP Directive limits on sulphur dioxide emissions could be met more cheaply by building new CCGT plant, rather than retrofitting desulphurisation equipment to existing coal plant. In his evidence to the Energy Committee, Dr. Jim Skea of Sussex University agreed that the extra cost desulphurisation placed on coal-fired plant was "sufficient to tip the balance in favour of building CCGT ahead of capacity need".[85]

Under questioning by the select committee, both National Power and PowerGen attempted to downplay the radical nature of their change in preference for new generation technology, and suggested that it was a part of the natural progression of the ESI that would have occurred irrespective of privatisation. The Chief Executive of PowerGen, Ed Wallis, claimed that the 4-5GW of CCGT plant which PowerGen was now estimated to be planning to build was, in large part, replacement for old steam turbine plant which would have closed and needed replacing anyway. Wallis stated that PowerGen were not "burning gas as a consequence of being private companies", but that "the CEGB would have burned it when it became available anyway. It did not because it was not available".[86] He also spoke of PowerGen's pursuit of "a balanced strategy" of plant investment, and that PowerGen did "not wish to be overexposed in terms of price, reliability or quality to any one of three strategic fuels" – coal, oil, and natural gas.[87]

Other evidence to the Energy Committee at this time suggested a more radical turnaround in the industry's generation technology preferences. Mr C. Wilcock of the Department of

[84] ibid, Vol.II:5 In the course of the Energy Committee's inquiry on *The Cost of Nuclear Power*, also published in June 1990, the independent analyst Gordon MacKerron of Sussex University stated that "any private investor would certainly wish to go for combined cycle gas in preference to coal". (House of Commons Energy Committee, *The Cost of Nuclear Power*, HC 205, 1989-90, Vol.II:127)

[85] HC 371, 1989-90, Vol.II:55-56. Dr Skea estimated that the unit cost of electricity from existing coal-fired plant was 2.0p/kWh, which increased to 2.6p/kWh with desulphurisation equipment fitted, compared to an estimated unit cost from new CCGT plant of 2.2p/kWh.

[86] ibid:18

[87] ibid:14

Energy recognised that "over the last few months with increasing acceleration ... it has become evident that combined cycle gas turbine plants ... are the choice of both National Power and PowerGen, as well as of the independent generators".[88] Wilcock rejected the suggestion from a member of the Energy Committee that the government should intervene in this – stating that as far as possible, fuel choice should be a commercial matter for the generators.

In February 1991, British Gas imposed a 35% rise in natural gas prices for new 'interruptable' industrial contracts – the fuel contract used by most of the independent CCGT projects. In announcing the increase, BG stated that was concerned that it would be unable to meet the rapidly escalating demand for gas for CCGT schemes. In mid-1991, shortly after the flotation of National Power and PowerGen, the Energy Select Committee undertook an inquiry into *Clean Coal Technology and the Coal Market after 1993*.[89] The evidence presented to the select committee during its inquiry suggested that CCGT technology was still clearly the cheapest option for *new* generation plant, but that following the gas price increase, its competitiveness with *existing* coal plant was now questionable.[90] The select committee stated that National Power's Commercial Director had indicated that the higher price of gas meant that it was now no longer economic to replace existing coal-fired plant with new CCGT plant, unless the coal-fired plant was required to have desulphurisation equipment fitted.[91]

There were eight CCGT power plants firmly committed by this time. All were based on imported gas turbines, manufactured by General Electric, ABB, Westinghouse and Siemens. Four were being built by National Power and PowerGen, the others by independent consortia involving a number of RECs. PowerGen had just awarded the contract for their second CCGT power station, at Rye House, to Siemens. In his evidence to the select committee, PowerGen's Commercial Director, Dr. Alf Roberts, stated that "as far as combined cycle plant is concerned, British manufacturers have unfortunately not been able so far to play a role in competing for it".[92] Those British manufacturers that were able to provide CCGT plant did so under licence from foreign manufacturers – John Brown Engineering, for example, was a licensee of General Electric gas turbines.

The dash-for-gas was attracting growing opposition by this time, particularly, as would be expected, from the coal industry, but also from some independent observers of the

88 ibid:24
89 HC 208, 1990-91, published in July 1991.
90
91 ibid, Vol I:xxxvi
92 ibid, Vol.II:154

ESI. In his submission to the inquiry, the energy analyst Walt Patterson argued that the enthusiasm for gas-fired generation in England and Wales – and the absence elsewhere of a dash for gas on a similar scale – was an indication of particular distortions within the British ESI. Patterson concluded that the British dash-for-gas was "something of an anomaly", and was the result of "short-term thinking".[93] Similarly, Mr B. Parkin, the Assistant Head of Research at the NUM, argued that the dash-for-gas was a consequence of short-term opportunism on the part of the privatised generators. Parkin stated that the introduction of CCGT technology into the British ESI should not be seen as "some kind of technical evidence of a brave new world of power generation and the liberalisation of energy markets", but rather, "as an expedient, as an alternative to flue gas desulphurisation".[94]

In its report conclusions, the Energy Committee expressed concern, especially in a context of higher gas prices, that almost all of the independent CCGT plant being built was intended to be used continuously – i.e. to meet baseload demand.[95] In their evidence to the Committee, the coal industry consultants, Gerard McCloskey and Guy Doyle, suggested that the marginal cost of existing coal-fired plant may be lower than for new CCGT plant, and that existing plant should therefore be used as baseload plant ahead of gas-fired plant.[96] McCloskey and Doyle also argued that the economics of CCGT plant were very sensitive to fuel price escalation.

The Energy Committee concluded that the dash-for-gas was being driven by a combination of ESI restructuring associated with privatisation – which had proven to be a stimulant for investment in new generating plant – together with essentially unconnected changes in the availability and price of natural gas. The Committee stated that "what has changed is not just privatisation, but the increasing availability of gas, abolition of the EC Directive, reduced gas production and transportation costs, and a progressive saturation of the higher value outlets for gas".[97]

Despite the higher price of gas, the dash-for-gas continued throughout 1991. In the year as a whole, the Office of Electricity Regulation issued nine generation licences to independent consortia, for the construction of over 5GW of CCGT plant.[98] By the time the Energy Select Committee's report on the *Consequences of Electricity Privatisation*

[93] ibid:43
[94] ibid:139-40
[95] The economic profile of gas-fired plant – low capital cost but high running (fuel) cost – meant that it was considered unsuitable for baseload use.
[96] ibid:107
[97] ibid, Vol I:xxi
[98] Office of Electricity Regulation, *OFFER 1991 Annual Report*, HC 289, 1991-92

was published in February 1992, the scale of the dash-for-gas was clear.[99] The select committee found that, including National Power and PowerGen schemes as well as those of the independents, contracts had now been signed for over 17GW of new power plant based on CCGT technology.[100]

In his evidence to the Energy Committee at this time, Professor Colin Robinson commended the dash-for-gas as a demonstration of the technological and economic liberalisation of the industry, compared to the "technological backwardness" of the nationalised ESI.[101] Robinson stated that the dash-for-gas "could have occurred under continued state ownership, but it would almost certainly not have happened at such speed".[102] However, he pointed out that the introduction of CCGT technology arose not from a conscious act of Government, but rather from the coincidence of British ESI privatisation with international developments in the availability of natural gas and gas turbine technology, which together greatly reduced the barriers to entry in generation. Without this, he claimed, the post-privatised character of the ESI would have been very different: "it is a sobering thought that if improved CCGT technology had not been available ... there might have been no new entrants whatsoever to power generation in Britain".[103] Furthermore, Robinson pointed out, in a context of international reductions in fossil fuel prices and advances in generation technology, it was unclear to what extent privatisation itself was responsible for the generation cost reductions that had been achieved in Britain.

The inquiry made evident that there was now a substantial body of opinion – from inside the ESI as well as among independent analysts – that the increases in the price of natural gas had made electricity from new CCGTs more expensive than from existing coal plant. For example, John Harris, Chairman of East Midlands Electricity – one of the pioneers of the dash-for-gas – stated that gas prices were now such that "virtually no project can stand the test of economic purchasing", and he concluded that "the move in gas prices puts a question mark against any future combined cycle gas project within the UK".[104] This view was also expressed by the large generators; in their memorandum to the Energy Committee, PowerGen stated that "even with FGD and dearer British coal, existing plant are competitive with new CCGTs".[105] Similarly, the Chief Executive of National Power,

99 HC 113, 1991-92
100 ibid, Vol I:xxi
101 ibid, Vol.III:49
102 ibid:49
103 ibid:51 Robinson added that the relatively benign environmental impact of gas turbines turned out to be a crucial factor.
104 ibid, Vol.III:123
105 ibid, Vol.I:xxv

John Baker, argued that "the early combined cycle gas turbines at gas prices then prevailing were competitive with marginal [coal-fired] plant on the system, and validated the closure of plant to make way for them. At current gas prices that is no longer the case".[106]

In their submission to the select committee, British Coal argued that although CCGT technology undoubtedly offered the lowest-cost option for new baseload plant, it was more expensive than existing large coal-fired steam turbine plant.[107] BC argued that the dash-for-gas was now being driven by what they referred to as "structural" factors on the part of the RECs and large generators. For the RECs, BC suggested, CCGT plant offered a quick means of reducing their dependence on National Power and PowerGen. BC claimed that, since the RECs continued to hold a partial supply monopoly within their 'home' regions until 1998, they were able to pass on the extra cost of gas-fired generation. BC concluded that "this is the driving force behind unnecessary new capacity. The REC is paying a premium ... but it is a premium which can be passed on in full to the final consumer".[108] John Baker, Chief Executive of National Power, also claimed that the RECs' interest in lessening their dependence on the big generators, allied with their continued local monopoly, was encouraging them to build "uneconomic" CCGT plant.[109]

In their evidence to the select committee, the RECs indicated that they saw investment in generation plant as a means of diversifying their business away from the more heavily regulated areas of distribution and supply. For example, John Harris, Chairman of East Midlands Electricity, stated that CCGT plant provided a way for RECs to "get equity into non-regulated businesses".[110] Under questioning by the select committee, the Secretary of State for Energy, John Wakeham, accepted that it was possible for the RECs to pass on their costs, but he argued that they would be inhibited from doing so in practice because it would be in clear contravention of their obligation in their supply licence to purchase power on an economic basis.[111]

British Coal argued that the big generators had a different institutional interest in investing in CCGT plant. For National Power and PowerGen, BC suggested, CCGT technology presented a threat to their market position, since it offered the generator's

106 ibid, Vol.III:92

107 ibid:36 British Coal estimated the cost of electricity from new CCGT plant to be 2.9p/kWh, compared to 2.7p/kWh from existing coal plant with FGD added on.

108 ibid:37. Under the 1991 Electricity Act, REC franchises continued for medium size customers until 1994, and for domestic customers until 1998.

109 ibid:92

110 ibid:123

111 ibid:100

main customers – the RECs and large industrial users – a relatively quick way to capture some of the market for generation. BC argued that National Power and PowerGen's investment in CCGTs was therefore essentially defensive: they had the advantages of large revenue-earning plants, and pre-existing power station sites which were already connected to the grid and did not need planning permission for the construction of new plant. BC stated that National Power and PowerGen realised that there was limited demand for new plant in the British ESI, so that by building CCGT power stations before the independent consortia – even if they produced electricity more expensively than their existing coal-fired power stations – they aimed to pre-empt the market, and maintain their market dominance in generation.[112] Given these motivations on the part of the large generators and the RECs, British Coal argued that around half of all CCGT plant expected to be built in the next few years would provide electricity more expensively than the coal-fired steam turbine plant it was replacing.

In their report conclusions, the Energy Select Committee concluded that the dash-for-gas was being driven, in-part at least, by non-economic institutional interests, in contravention of the generation and supply licences. The Committee stated that "there is no doubt that the RECs' interest in CCGTs results not just from potentially lower costs, but from the wish to reduce their dependence on the two main generators", and concluded that "some CCGT projects are economically justified as replacements for existing plant and others are not".[113] The Committee added that the dash-for-gas was a reflection of the inadequacy of competition in generation in the privatised ESI, and called for the forced divestment of some plant belonging to National Power and PowerGen, or, pending a referral to the Monopolies and Mergers Commission, a break-up of the assets of the two generators.[114]

In the course of the select committee's inquiry, the financial and contractual details behind independent CCGT plants were outlined in some detail by the *Thames Power* consortium formed to develop a 1000MW CCGT plant at Barking Reach in Essex. The partners in the consortium included three RECs – Southern Electric, Eastern Electricity, and London Electricity – pooling their generation capacity limits imposed under the 1991 Electricity Act. Thames Power was a typical example of the consortia that were formed to develop independent CCGT plant in the late-1980s and 1990s. Like all independent CCGT power stations, Barking was financed on a non-recourse loan, secured on revenue from future electricity sales. In all such schemes, the same RECs involved in the independent power producer (IPP) consortium also undertook to buy the electricity

[112] ibid:38
[113] ibid, Vol.I:xxvii
[114] ibid,Vol.I:xxvii

produced under long-term contracts (known as Power Purchase Agreements, or PPAs), typically lasting 15 years. The same REC therefore acted as both equity partners and customers for the IPP scheme. Contracts for gas supplies were also arranged over the same period as the PPA, on a price based on the market price for electricity at any given time (the 'pool' price) with a 'contracts for differences' adjustment between the fuel suppliers and the IPP. This meant that all independent CCGT schemes were financed on the security provided by long term back-to-back contracts for fuel and electricity sales. In addition, because gas was supplied on a 'take-or-pay' basis, independent CCGT power plants were required to run continuously – the financial arrangements for such plant were predicated on their use as baseload plant.

Thames Power also revealed that independent gas producers were reluctant to expose themselves to the risk of selling their gas on a non-recourse basis, so that IPPs were forced to contract with British Gas for their gas supplies. National Power and PowerGen, with strong cashflow from their existing plant, had no need to need to resort to non-recourse funding, and were able to contract with independent gas suppliers.[115] This meant that unlike the large generators, IPPs were vulnerable to price escalation by British Gas, at a period in which, although the independent gas supply market was growing, BG retained a powerful market influence.[116]

5.3.4 Industry Analysis of the *Dash-for-Gas*

Amongst the evidence of independent analysts to the Energy Committee in 1992, there was some discussion of the relative importance of different influences on the dash-for-gas. In their evidence to the select committee, for example, the Watt Committee on Energy argued that it arose "mainly because gas was allowed to enter the electricity generation market rather than because of privatisation".[117] In his evidence, Eric Jeffs, the European editor of *Turbomachinery International, stressed* the coincidence of privatisation with other developments. Jeffs stated that the privatisation of the British ESI "occurred as the combined cycle became a proven generating system of high reliability and efficiency. At the same time, restrictions on the use of gas for generating electricity were relaxed across Europe".[118] He added that with these conditions established, and with the RECs keen to encourage independent generation, then "the way was open for the construction of new power plants which would challenge a system dominated by coal".

115 ibid, Vol.III:65
116 After 1990 BG was required to make 10% of new gas field supplies available to independent suppliers.
117 HC 113, 1991-92, op cit, Vol II:37
118 HC 113, 1991-92, Vol.II:73

Jeffs concluded that "what we are seeing is a transformation of the electricity supply system by introduction of the combined cycle with its high efficiency and remarkable operating flexibility".[119]

In a 1993 analysis of the dash-for-gas, Gordon MacKerron of Sussex University emphasised that CCGT plant represented a significant and sudden "technological discontinuity" for the British ESI.[120] MacKerron identified six reasons for the British dash-for-gas: the development of CCGT technology, the availability of cheap natural gas from the North Sea, the requirements of private investors for higher interest rates and shorter payback periods, the desire of RECs to gain entry to generation and challenge National Power and PowerGen, a regulatory framework encouraging to new generation, and last, *and least*, in his opinion, the need for environmental compliance on the part of the existing generators.[121] MacKerron argued that "environmental issues played only a minor supporting role" in the dash for gas: the RECs, he suggested, had no direct environmental incentive to go for gas, and National Power and PowerGen only a limited incentive, in the form of an easier task in complying with the Large Combustion Plant Directive".[122] He stated that institutional rivalry had made a greater contribution to the dash-for-gas, and that "without the spur of the IPPs, it is doubtful whether the incumbent generators would have embarked on as much CCGT construction as in practice they have".[123]

MacKerron went on to consider the likelihood of a repeat of the British dash-for-gas elsewhere in Europe. He pointed out that whilst some of the factors involved in the dash-for-gas were international or European in scale, others were particular to the British ESI. Therefore, he concluded that although CCGT use was "almost certain to grow strongly in power systems across Europe ... the rapidity of the British dash-for-gas will not be repeated".[124] Rather than a *dash*, he suggested, it was likely that other European countries would experience "a sustained canter" towards the greater use of CCGT plant. In another paper written in the same year, MacKerron argued that the dash-for-gas in Britain was primarily a response to the creation, ahead of privatisation, of a radically different economic environment for investment in generation plant, rather than the development of CCGT technology itself:

---

119 ibid:74

120 Gordon MacKerron, *The Role of Gas in the Future of European Electricity Generation*, unpublished draft prepared for conference on 'Gas-Powered Electricity Generation', London, February 24th-25th 1993:3-4

121 ibid:4

122 ibid:7

123 ibid:7

124 ibid:11

The reason ... [CCGT] has become dominant as a new technology ... owes less to major technical improvements than to radical changes in the economic environment in which the electricity supply industry operates ... The dominant change ... has been the move away from electricity supply as a long term, public service industry with relatively low profitability towards a liberalised industry exposed to normal commercial objectives and pressures ... Where mistakes in technology choices which lead to higher costs can no longer be passed through to consumers, utilities are much more averse to technological and commercial risk. In such a context CCGTs fit ideally ... the primacy of CCGTs owes much more to radical changes in economic environment than technological change as such.[125]

Other analysts and industry insiders have offered a variety of explanations of the dash-for-gas. In a personal interview conducted in 1994, Roger Semmens, a Development Engineer at PowerGen's Ratcliffe Power Technology Centre, Nottingham, stated that "the growth of combined cycle gas turbines was not to do with privatisation at all – the main reason was the availability of natural gas".[126] Nevertheless, Semmens also conceded that what he referred to as "the politics" of privatisation had perhaps made some difference, at least to the *pace* of technological change in the post-privatised ESI, in that if the industry had remained a public monopoly, it might have been prevented from "going all out for gas in the way that we have".

In an article published in 1994, Ron Haywood, Director of Engineering at Rolls-Royce Industrial Power Group, identified "at least four factors" contributing to the dash-for-gas: improvements in the performance of CCGT technology, regulatory reforms (both in encouraging the US market for cogeneration, and also the liberalisation and privatisation of the ESI in Britain), tightening environmental emission standards, and finally, the increasing availability and reduced price of natural gas against other fuels.[127]

In a personal interview carried out in December 1994, Haywood reflected further on the dash-for-gas. He conceded that the level of awareness of gas turbine technology among the British plant manufacturers under nationalisation was low, and stated that "in the UK, its true to say no-one saw the dash-for-gas coming ... the views seemed so foreign and revolutionary at that time. Now it seems so logical". He described the established thinking towards gas-fired plant in the nationalised ESI: "gas turbines were only used in a

125 Gordon MacKerron, 'Innovation in Energy Supply: The Case of Electricity' unpublished draft prepared for inclusion in Dodgson, M., and Rothwell, R., (eds.), *Handbook of Industrial Innovation*, Cheltenham, Elgar, 1994

126 Personally-conducted telephone interview, June 1994. Semmens added that the capital cost of CCGT plant was around half that of coal-fired steam turbine plant. He estimated that the capital cost of PowerGen's Killingholme CCGT plant was £320/kW, compared to between £600-700/kW for a coal-fired steam turbine plant He stated that there was "unlikely to be any other competing generating plant in the foreseeable future".

127 Ron Haywood, 'New Technologies in Power Generation', *Rolls-Royce Magazine*, No.62, September 1994, pp11-14:14. Haywood also stated that the improved economics of natural gas as a electricity fuel were not only a response to greater reserves, but also improved access through the construction of new transmission and distribution systems.

standby role, and peak lopping. Gas at that time was not cheap ... [it] was also seen as a prime fuel". He stated that this position began changing only in the mid-1980s:

> I remember before privatisation, in the mid-1980s, doing basic calculations about CCGT plant and it was obviously competitive. People were gobsmacked with the efficiency. The CEGB were very keen just before privatisation; attitudes changed very quickly.

Haywood argued that lower gas prices and increased availability was the major cause of the dash-for-gas: "when the dash for gas started gas [prices] were at a twenty year low ... at the end of the day it was the price of gas which won the day ... gas was being discovered all over the world ... [once] the directive on the use of gas for base load power generation was rescinded ... nothing was going to stand in the way of CCGT". However, he also recognised that changes in the British ESI associated with privatisation had a significant effect on the rate of change in the industry: "without privatisation there would have been a slower switch to gas; in practice what we have seen is a revolution".

Roger Smith of PowerGen, and Michael Sharpe of Siemens, who were both personally involved in the construction of a CCGT plant for PowerGen at Rye House in Hertfordshire, also reflected on the causes of the dash-for-gas, in a paper published in 1995.[128] They pointed out that whilst other forms of generation technology were limited in various ways – politically (nuclear), geographically (hydro), environmentally (coal and oil), or economically (solar and wind) – CCGT technology was "the one form of electricity generation that offers many advantages: technical, economic, political and environmental".[129]

In their 1996 analysis of developments in the ESI since privatisation, the independent analysts Guy Doyle and Dominic MacLaine argued that it was the failure, of the Government, to introduce a fully-competitive market for generation that had driven much of the dash-for-gas. They stated that "the Electricity Act cleared the way for new entrants in generation, but it was the Government's creation of a strong duopoly in fossil fuel generation that provided the strongest incentive for the RECs to seek alternative generation sources".[130] They added that "few within the industry anticipated the emergence of CCGT as the plant of preferred choice".[131] In his analysis of ESI

---

128 Roger Smith and Michael Sharpe, 'Rye House - A Further Step in the Use of Gas for Power Generation', *Power Engineering Journal*, Vol.9, No.1, pp33-40, February 1995

129 ibid:33. They went on to describe the Rye House project in some detail; it had a lead time of 3 years – much shorter than conventional plant, and stage-by-stage commissioning allowed it to earn revenue in even less time. The plant components were built in semi-standard modules by Siemens.

130 Guy Doyle and Dominic MacLaine, *Power as a Commodity: The Future of the UK Electricity Supply Industry*, London, Pearson/ Financial Times Energy Publishing, 1996:62

131 ibid:1

privatisation, Alex Henney also suggested that British Coal, the Government and the major generators were all taken by surprise by the dash-for-gas and the determination of the RECs to support independent power projects.[132]

In a recent article, Jim Watson of Sussex University argued that it was mistaken to see the dash-for-gas as merely the product of economic factors, such as changed market circumstances and cheap natural gas. Rather, he emphasised, "many political and technological factors have had a part to play".[133] Watson identified three different aspects to the 'success' of CCGT technology. Firstly, *technological attributes*, in particular its versatility of application – military and commercial – which allowed its development to continue even through periods when its commercial market was small; secondly, the role of the *major manufacturers*, whose size and diversity enabled them to subsidise CCGT development, retain expertise in the technology, and take a long-term view even when there was little demand for the technology; and thirdly, *government involvement*, both by the direct sponsoring of military jet engine development, and also by implementing regulation to foster CCGT/CHP technology and promote ESI liberalisation. Watson concluded that the dash-for-gas arose not simply from changed economic circumstances, but that it could only be explained "by reference to a complex web of factors", many of which, he pointed out, "have not been directly concerned with the CCGT at all".[134]

5.3.5 CCGT Technology and the ESI in the mid-1990s

In late-1992 and early-1993 the ESI entered a period of uncertainty associated with the *coal crisis* (6.3.2). The intention at privatisation was for stringent regulation by the Office of Electricity Regulation (OFFER) of the transmission, distribution, and supply parts of the ESI – which were seen to varying degrees as natural monopolies – but to allow essentially unregulated competition in generation. The coal crisis provoked a wide-ranging debate on the development of the ESI since privatisation – particularly the market distortions in generation which were perceived to be causing, at least in part, the dash-for-gas – and forced a reappraisal of the 'hands-off' approach to generation by the Regulator. Two particular features of the industry were the subject of particular attention by the Regulator at this time: firstly, REC involvement as both financial partners and power

---

132 Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994:299

133 Jim Watson, "The Technology that Drove the 'Dash for Gas'", *Power Engineering Journal*, February 1997, pp11-19:11 (The rather deterministic title of Watson's article belies his emphasis on the interdependency of influences.)

134 ibid:19 Watson also observed that recent technological change in the ESI has had little correlation with direct R&D spending on generation technologies.

purchasers in IPP CCGT schemes; and secondly, the manipulation of the electricity trading 'pool' by National Power and PowerGen.

Concern for REC involvement in CCGT schemes centred on their ability to 'pass-on' any extra costs of CCGT plant, made possible by their retention of franchise monopolies for medium users until 1994 and domestic users until 1998. At the beginning of the coal crisis, OFFER decided to bring forward an inquiry it was planning into the RECs behaviour in this area.[135] The resulting OFFER report concluded that the RECs had not breached their obligation, as *Public Electricity Supply* licence holders, to secure their power purchases at the "best effective price ... reasonably obtainable", and it therefore stated that no action on REC involvement in CCGT plant was necessary (6.3.2). In OFFER's 1992 Annual Report, Littlechild stated that he found that the IPP contracts signed by the RECs for CCGT plant "compared well with other contracts then available ... and provided greater diversity of supply".[136] He concluded that in entering consortia to build CCGT plant, and also in signing up to long term power purchase agreements, "the RECs had sought to facilitate new entry into generation ... to provide protection against the major generators, ... [rather] than to profit, via their equity stakes, from higher electricity prices".[137]

Although National Power and PowerGen gradually lost market share in baseload generation to independent power producers and Nuclear Electric after privatisation, they had little competition in the intermittent or 'mid-merit' market – which, under the workings of the 'pool', set the market price for electricity. In later evidence to the Trade and Industry Select Committee, it was reported that 95% of non-baseload plant was owned by NP or PG, mostly coal plant.[138] Professor Littlechild admitted to the select committee that the electricity *System Marginal Price* was being set overwhelmingly by the CEGB successor companies. Following an investigation by OFFER, the Director General announced in mid-1993 that he would cap pool prices for two years, and also stated that he would be requesting the divestment of some power plant belonging to National Power and PowerGen before 1995.[139] He added that he would consider a reference to the Monopolies and Mergers Commission if the plant divestment was not completed on time. According to Dieter Helm, this action by OFFER "extended regulation well beyond that intended at privatisation."[140] Following the announcement, it was estimated that around 6GW of proposed CCGT plant was either deferred or

135 Office of Electricity Regulation, *Review of Economic Purchasing*, December 1992
136 Office of Electricity Regulation, *Annual Report 1992*, HC 646, 1992-93, May 1993:9
137 ibid:10
138 HC 481, 1994-95, Vol.II:114 (Memorandum by Professor Colin Robinson).
139 Office of Electricity Regulation, *Pool Price Statement*, OFFER, Birmingham, July 1993
140 HC 481, 1994-95, Vol.II:87

cancelled.[141] In February 1994, Littlechild announced that he had established undertakings from National Power and PowerGen on the divestment of 6GW of coal-fired plant – 4GW of National Power plant and 2GW of PowerGen plant.[142] The plant divestments were finally completed in 1996 with the long-term lease of the whole of the 6GW to Eastern Electricity, with the intention of creating a 'third force' in mid-merit plant.[143]

In May 1994 the Department of Trade and Industry published the latest of the occasional appraisals of *Energy Technologies for the UK*.[144] The report stated that since the last such survey – published before ESI privatisation in 1987 (which had made almost no mention of CCGT plant, 5.3.1) – "a number of significant structural, political, economic and technical changes have occurred", including "the commercialisation of cheap and efficient CCGTs", which had "revolutionised the available future pattern of generation".[145] The appraisal forecasted that CCGT technology would make a major contribution to electricity supply in Britain to at least 2025. In April 1995 the Office of Science and Technology published the results of another survey of electricity generation technologies, carried out as part of the Government's *(Technology)Foresight Programme*.[146] The survey, which concentrated on the future market potential of various technologies, concluded that "the gas turbine will play an increasingly important role across the whole power range of duties".[147] It also stated that the drive for even more efficient gas turbines would continue, and that these will be achieved through "cycle variations and higher temperatures with enhanced component performance".[148]

In mid-1995 the Trade and Industry Select Committee carried out an inquiry into *Aspects of the Electricity Supply Industry*.[149] The inquiry adopted a less political tone than earlier such enquiries, and was less a general review of the ESI, rather than an attempt to investigate particular regulatory issues, such as the adequacy of competition in generation, and the consequences of the progressive loss of REC franchises. Nevertheless, the select committee heard some discussion of the changes to the industry

---

141 ibid, Vol II:35 (Norweb memorandum)

142 Office of Electricity Regulation, *1993 Annual Report*, HC 352, 1993-94, May 1994

143 Office of Electricity Regulation, *1996 Annual Report*, HC 16, 1997-98, June 1997. In February 1997, Eastern Electricity, which had been bought by the Hanson group in 1995, was demerged to form the fourth largest generator in Britain, known as *The Energy Group*. (Centre for the Study of Regulated Industries, *CRI Review of Electricity Services, Costs, and Financial Results 1995/96*, London, Chartered Institute of Public Finance Accounting, June 1997:xix)

144 Department of Trade and Industry, *Energy Technologies for the UK: An Appraisal of UK Energy Research, Development, Demonstration and Dissemination*, Energy Paper 61, May 1994

145 ibid:3-4

146 Office of Science and Technology, *Progress Through Partnership: No.13 Energy*, London, HMSO, April 1995

147 ibid:29

148 ibid:31

149 HC 481, 1994-95, July 1995

since privatisation. The DTI memorandum to the Committee stated that there were now ten independent CCGT plants operating in the UK (generating around 6GW of power), with a further two under construction (of 1.7GW output), and eight more with signed transmission agreements (which would provide another 6GW of power).[150] At the same time, it was reported that National Power and PowerGen were operating or constructing 6.3GW of CCGT plant of their own.[151] The DTI referred positively to new CCGT plant as contributing to the "increasingly diverse and efficient portfolios" of generators.[152]

Changes in the supply and generation sides of the industry were increasingly interrelated by this time, and as the Trade and Industry Committee described, the ending of REC franchises for domestic users in 1998 carried with it some implications for generation. The Committee stated that "liberalisation of supply in 1998 will be a vast enterprise without precedent anywhere in the world ... the effect of opening-up competition in supply is to place a much more acute pressure on competition in generation ... [because it requires] all suppliers to buy more economically than they would otherwise have done".[153] It was clear that greater competition between the RECs would further restrict the passing-on of generation costs through the ESI supply chain. The Manchester-based REC, Norweb, in their memorandum to the select committee, stated that the loss of domestic franchise after 1998 was already making them less interested in new generation schemes.[154] Increasingly the trend was for RECs to only enter contracts with generators for a limited part of their existing franchise market – that which they thought would continue to be their 'natural franchise' after deregulation.[155]

The inquiry made some further investigation of the dash-for-gas.[156] The Director General for Electricity Supply was criticised by the Select Committee for his lenient handling of the RECs. He was repeatedly questioned over the RECs investment in CCGT in the context of the 'economic purchasing' licence condition. For PowerGen, Ed Wallis restated his view that only the early independent CCGT power plants were economic compared to existing steam turbine plant.[157] The Electricity Supply Trades Union Council (ESTUC) argued that the dash-for-gas had done little to further competition in generation, since the

150 ibid, Vol.II:2

151 ibid, Vol.II:111 (Professor Colin Robinson)

152 ibid:2

153 ibid:x

154 ibid, Vol II:14

155 ibid:xi As Professor Stephen Littlechild, the Director General of Electricity Supply told the select committee, technical and economic barriers to competition in the domestic market were thought to be such that there was some 'natural franchise' for the local REC, so that they were "likely to remain dominant suppliers in their areas for some time after the end of the franchise". Deregulation was therefore expected to be felt as evolutionary rather than revolutionary change.

156 HC 481, 1994-95

157 ibid, Vol.III:42

contractual arrangements for independent CCGTs divorced them from the market for electricity; the ESTUC memorandum stated that "none of the ... CCGT capacity built by the independent producers can be said to be competitive when it is indifferent to pool prices for a full 15 years, out of a design life of not much more than 15 years".[158] The ESTUC also suggested that, as old nuclear and coal stations were closed, new CCGTs were likely to be built in a "second dash for gas" – with increasingly negative effects on fuel supply diversity. The ESTUC claimed that "if there is no change in direction, 80% of all electricity will be generated from gas by the year 2020".[159]

In his evidence to the Select Committee, Professor Colin Robinson stated that the vigour of the dash-for-gas stemmed from a pent-up demand for natural gas as a generation fuel within the British ESI, created by the protection of coal and nuclear power stations under nationalisation.[160] Nigel Evans of the DTI's *Energy Advisory Panel* (an independent body set up by Government after the coal crisis), was questioned by the select committee about the extent of the dependency on gas-fired generation technology now being built into the British ESI. Evans referred to the suggestion that natural gas would be meeting 85% of the ESI's needs by 2005 as "entirely plausible"; he added that he was unsure if this growing dependency was cause for concern.[161]

The Department of Trade and Industry's 1995 White Paper on the *Prospects for Nuclear Power*,[162] published two months before the *Aspects of the ESI* report, also contained some comments on fuel diversity in the ESI. Here, the Government stated that market forces were the best means of ensuring diversity of fuel supplies. Central planning, they argued, had demonstrably failed in the ESI, whereas privatisation had so far brought about greater fuel diversity. The Government rejected any suggestion that some action on their part was now needed to secure fuel diversity, and instead argued that market forces would provide the necessary level of diversity, through price signals that reflected the risk of loss of supply, or customer aversion to over-exposure to any single fuel.[163] The White Paper concluded that there were no reasons "why the electricity market should not of its own accord provide for an appropriate level of diversity".[164]

In the mid-1990s, as political uncertainties associated with the coal crisis receded, the dash-for-gas gained renewed momentum. In their 1996 review of *Generation in the*

158 ibid, Vol.II:63
159 ibid, Vol.II:64
160 ibid, Vol.II:113
161 ibid, Vol.III:69 He forecast that by 2000, there would be over 16GW of CCGT capacity.
162 Cmnd 2860, 1995
163 ibid:37
164 ibid:4

1990s, Michelle Aveline et al. confirmed that a "second dash-for-gas" was under way in the British ESI.[165] In another recent consideration of the future of the ESI, Guy Doyle and Dominic MacLaine listed five large CCGT plants under construction (all over 700MW capacity). National Power and PowerGen were both reported to be completing construction of huge CCGT plants, each over 1.3GW.[166] Doyle and MacLaine stated that continuing technical advances in CCGT technology and fierce competition between the equipment manufacturers had greatly reduced the capital cost of the latest CCGT plants compared to the earlier ones.

The 1996 edition of the DTI's annual *Energy Report* reported a collapse in wholesale gas prices, as excess supply led to a "gas bubble" in the UK.[167] It also stated that competition in the gas supply industry was accelerating, with the proposed demerger of British Gas, and with independent supply companies now capturing over three-quarters of new industrial contracts. On electricity generation technologies, the report concluded that "further efficiency improvements are expected from new vintages of CCGT technology as it matures".[168] The 1997 National Grid Company *Seven Year Statement* revealed that there would be over 14GW of CCGT installed capacity by the end of 1997, with proposals for this to rise to over 27GW by 2000-01, exceeding the total level of coal-fired capacity[169]; (see Appendix 1, Figs. 4, 5, 7).

5.4 Industry Perspectives on the *Dash-for-Gas*

5.4.1 Norweb

Norweb (the former North West Electricity Board) was heavily involved in the construction of CCGT plants in the ESI during and after privatisation. In 1989 it became the first REC to contract for electricity from an independent plant when it agreed to take the entire output from Roosecote, the first completed CCGT plant in Britain, for a period of 15 years. Norweb also became an equity partner in *Lakeland Power*, the consortium behind the financing of Roosecote. Plant construction commenced at the beginning of 1990, and the plant became fully operational in November 1991. Roosecote is a 220MW

165 Michelle Aveline, Martin Brough and Daniel Sgori, *Generation in the 1990s: Electricity Capacity and New Power Projects: The 1996 Edition*, Oxford, OXERA Press, 1996

166 Guy Doyle and Dominic MacLaine, *Power as a Commodity: The Future of the UK Electricity Supply Industry*, London, Pearson/ Financial Times Energy Publishing, 1996

167 Department of Trade and Industry, *The Energy Report Vol.1: Change and Opportunity*, London, HMSO, May 1996

168 ibid:52

169 Roland Gribben, 'New threat to coal as dash for gas gathers pace', *Daily Telegraph*, 19th May 1997

CCGT plant based on a ABB *13E* 165MW gas turbine, and a 60MW steam turbine.[170] In 1992, Norweb set up a 50/50 joint venture company with Scottish Hydro-Electric, to develop a 680MW CCGT power station, at Keadby in South Humberside. (The Keadby plant is discussed further in 5.4.2 below).

In an interview carried out in August 1994, Graham Wilman, Major Projects Manager for *Norweb Generation*, Manchester (a subsidiary set up by Norweb to manage its investment in generation technology), described the motivations behind Norweb's involvement in electricity generation in the ESI after privatisation:

> [For Norweb] generation was a logical step, an extension of the existing electricity supply business ... [which] upon privatisation became a heavily regulated activity ... The regulator essentially holds the power to make Norweb's main business – that is, distribution and supply – profitable or unprofitable ... Because of the potential for regulation tightening the profitability of the main business, we looked at diversifying into non-regulated business ... and generation is one of those.

In addition, Wilman also made clear that Norweb's interest in generation was also a response to the market power of National Power and PowerGen in the new structure of the industry:

> As a duopoly its very easy for them to watch over each others shoulders, and exploit the 'pool'. This is very tough for RECs, we have to buy electricity from a duopoly, and sell into a competitive marketplace, in which the duopoly is competing as well ... we're left with a duopoly which can rig the market ... RECs are interested in generation in order to break the power of National Power and PowerGen.

Before privatisation, as an Area Distribution Board, Norweb was statutorily forbidden to become involved in generation, other than in exceptional circumstances. Wilman stated that this meant that they had no expertise in generation technology: "Pre-privatisation we were not allowed to own any generation assets, so there was no choice to make of one technology over another ... we had no real interest in fuel sources and fuel mix – we couldn't make those strategic decisions". He then explained how the decision was made to develop Roosecote using CCGT technology. It is clear from his account that the extra burden placed on independent generators by the *Large Combustion Plants Directive* (see 5.3.2) was critical in the change from coal-fired steam turbines – as was initially proposed for Roosecote – towards CCGT technology:

---

170 Sources: *Roosecote: Britain's First Combined Cycle Power Station*, Manchester, Norweb, September 1991, plus other corporate publications by Norweb Generation, Manchester. Also Michelle Aveline, *European Utilities Yearbook 1993*, Oxford, Oxford Economic Research Associates, 1993:290

> [After] Norweb established a generation business we looked at all forms of generation. Pre-privatisation gas-fired generation was almost completely excluded ... around the time of privatisation the UK Government began granting 'gas-burn consents' ... gas-fired power stations became possible. There were also significantly tightening emission standards coming out of the EEC ... The coal generators were given quite some time to bring their plants in line with EEC requirements, whereas any new plant would have to immediately meet them ... We looked at building new coal plant using low cost British coal, in the northern coast of Cumbria, where there is a lot of cheap open-cast coal, and we looked at clean coal technology to do it. The capital cost of that was so high to meet the existing standards that it could not compete economically with existing, less clean, larger coal plants. The CEGB had driven to a very large size ... so their economies of scale were massive. The size we were looking at was around 150-200MW – one tenth of a CEGB plant, so we didn't get the economies of scale, we had to meet higher emission standards – our output cost could not compete. When Roosecote was first planned, it ... was going to be repowered as coal-fired ... The cost comparison said repowering with gas would be the best way ... gas sulphur emissions are practically zero [and] nitrogen oxides control facilities are available.

In addition to its superior environmental performance, Wilman also emphasised that CCGT technology was far better suited than established generation technologies to the changed investment environment established for the ESI after privatisation:

> The change from nationalised to privatised investment criteria meant the cost and lead time advantages of CCGTs were very significant. Pre-privatisation the nationalised industries typically used a 5% discount rate, so their interest was not in capital cost, but fuel cost ... The old industry could accommodate high capital, low running cost technology, the best example of which is nuclear. Pre-privatisation, CCGT would have always lost out because of the investment appraisal used. A private investor uses a discount rate of 15-20%, depending on the technology and risk, [so that] the economics swing from fuel cost to capital cost being important. CCGT plants are essentially modular, [and they] can be built quickly. Ten years – the time needed to build an old CEGB plant – is a lifetime in the capital markets ... We've built Roosecote in 24 months.

On the causes of the dash-for-gas, Wilman concluded that "the things that made gas [-fired plant] more attractive than coal were economic, regulatory or legal, and the need to exist in a private structure".

He then turned to a consideration of the interaction between the ESI privatisation process and the development of CCGT technology. He argued that they were two essentially separate processes – whilst British ESI privatisation was unparalleled elsewhere, CCGT developments were a response to international changes in the availability and use of natural gas:

> I don't think the changes in the UK were driving technological development, they were ongoing. Roosecote was ordered in 1989, at

which time it was the most efficient plant in the world, at 48%. Keadby ... was ordered in 1992-93, at which time it was the most efficient plant in the world, at 53%. ABB are now talking ... of combined cycle efficiencies of around 58-59%, so the technology is moving very quickly, but they are ... the results of pressures from other countries as well. America has a massive gas programme, Holland as well, France are developing some, Japan and China too ... it was coincidental with changes in the UK.

Although Norweb developed a sizeable generation business after privatisation – as well as Roosecote and Keadby, they also built a number of smaller CHP, landfill gas and renewables plants – they relied entirely on turnkey contracts for large plant construction. As Wilman made clear, they did not see the need to engage in their own research and development efforts:

We don't do any R&D. We are profit driven, and therefore don't see ourselves as demonstration facilities. We are much more comfortable with proven technology. The R&D is generally being done by the people who sell the kit, and they will publicise their work widely – we don't have to be very proactive in monitoring technological advancements; R&D is not being funded by us.

Finally, Wilman considered likely future developments in generation technology. Although he stated that continuing improvements in gas turbine technology would ensure that it would continue to be important, like many others in the industry, he argued that there would be a turn to clean coal technology in the British ESI. He stated that Norweb were "always looking at clean coal technology – when this becomes economic it will be a good investment for us ... I think coal technology must come back, as the clean technology capital costs come down ... I think we will see a resurgence of coal". He added that these predictions applied only to the UK, since much of the future development of generation technology in different countries still depended on local political conditions: "the cultures are so different it's difficult to predict – there's so many different vested interests".

5.4.2 Scottish Hydro-Electric

The experience of the ESI in Scotland after privatisation was very different to that in England in Wales. Following the commissioning of Torness AGR plant in 1988, the Scottish ESI was characterised by dominance by nuclear power and gross over-capacity. With the withdrawal of nuclear plant from privatisation in 1989, the nuclear plant of the former South of Scotland Electricity Board were kept in public ownership under Scottish Nuclear, and their output was given market protection to 2005 under the Scottish Nuclear Energy Agreement. For the privatised Scottish electricity companies, Scottish Power (the former SSEB) and Scottish Hydro-Electric (the former North of Scotland Hydro-Electric Board), there was therefore little opportunity to expand their generation businesses in Scotland.

Nevertheless, for Scottish Hydro-Electric in particular, the dash-for-gas in England and Wales was seized upon as a means of business growth and diversification. In late-1991 Hydro-Electric set up Keadby Power Ltd (KPL), a 50/50 joint venture with Norweb to develop Keadby power station, Humberside, built on the site of a former CEGB steam turbine plant. Keadby is a 680MW CCGT plant based on two General Electric *Frame 9F* gas turbines, each having an output of 212MW. The gas turbines were built in the US by GE and installed by John Brown Engineering of Clydebank. Keadby was financed mainly by a $544m loan from a number of international banks, as well as over $100m equity each from Hydro-Electric and Norweb. Together, Hydro-Electric and Norweb also contracted for the entire output from Keadby for 15 years under a Power Purchase Agreement with KPL.[171] After a delay caused by technical problems with the gas turbines (which had to be returned to the US for reworking) Keadby was eventually commissioned in 1996.

In the early-1990s, Hydro-Electric also investigated a number of other proposed CCGT plants which did not proceed. In 1994 it signed a 15 year contract for 400MW p.a. from the Intergen CCGT plant at Rocksavage (see 5.4.4 below). In 1995 Hydro-Electric formed a 50/50 joint venture with British Gas, *Seabank Power*, to develop a 755MW CCGT plant at Avonmouth near Bristol. The Seabank plant is being built on a turnkey contract by Siemens; construction began in August 1996. Fuel for the plant is being supplied by British Gas; Hydro-Electric have contracted to take the entire plant output for 10.5 years.[172]

Although Hydro-Electric did not share the English and Welsh RECs motivation to develop generation projects in order to counter the threat of National Power and PowerGen, they have a powerful institutional rivalry of their own, with Scottish Power. In an interview conducted in June 1994, Phil Inskipp, Project Manager for Business Development at Scottish Hydro-Electric, Perth, outlined the reasons for Hydro-Electric's involvement in the dash-for-gas:

---

171 Sources: various corporate publications provided by Scottish Hydro-Electric, Perth; also MPS Review, 'IPP at Keadby will use Frame 9F Technology', *Modern Power Systems*, June 1992, pp19-22

172 Sources: various corporate publications provided by Scottish Hydro-Electric, Perth; also Guy Doyle and Dominic MacLaine, *Power as a Commodity: The Future of the UK Electricity Supply Industry*, London, Pearson/ Financial Times Energy Publishing, 1996:69

> We were always keen to expand our markets south of the border – because obviously we can't do anything north ... we're a net exporter ... Investment in CCGT was a means of business diversification ... There were always people waiting in the wings waiting to do something. We wanted to make a stand and show we could do things on our own ... We were ... trying to get our feet under the table. It was really just to be in there with all the rest of them.

Inskipp was closely involved with the Keadby CCGT plant from inception to financial closure. He described the problems involved in securing finance for the Keadby project – one of the first CCGT plants in the UK to use General Electric *Frame 9F* gas turbines: "On Keadby the banks who lent us the cash were very nervous that we were taking on new technology. We had to go through various presentations, bringing General Electric people over. Its all been tried and tested in aerospace ... but the banks were still nervous, they don't like anything new". Inskipp also explained that John Brown Engineering was chosen as turnkey contractor for the Keadby project because they had already developed a detailed specification for a similar CCGT plant with National Power, and could therefore offer a "fast-track" negotiated tender route for construction.

In the nationalised ESI, the CEGB – with its *technical* rather than *economic* orientation – was often accused of 'over-engineering' or 'gold-plating' their power plants. As Inskipp described, the engineering standards involved with the CCGT plants built after ESI privatisation were very different to those adopted by the CEGB. He stated that "in today's economic climate, we can't afford to build power station like we used to do. The old places would easily do 40 years plus ... but I wouldn't imagine Keadby lasting that long; nobody engineers them like you used to – if you did, it would cost double the amount of Keadby". Indeed, Inskipp made clear that the investment horizon for the Keadby project was 15 years – the length of the bank loan, the fuel supply contracts, and the Power Purchase Agreement. He stated that "after 15 years the plant is still available, but there's no gas contract, and no PPA – but the thing's made its money". He also indicated that this time horizon, and other aspects of the project, were largely dictated by the terms of loan imposed by the banks: "Keadby, and all the other [IPP] plants at the same time were basically forced by the banks to sign up to deals for 15 years, and by and large these deals were [only] available with the RECs".

Like Graham Wilman of Norweb (5.4.1, above), Inskipp argued that the development of CCGT technology was essentially unconnected with the British ESI privatisation process:

> [CCGT] technology wasn't available beforehand, and you could argue that whoever was developing it would have been trying to develop it anyway for the American market which was already privatised, so I don't think the UK privatisation had any effect on the manufacturers. I think they were

> already trying to get these things improved ... that was more or less coincidental with privatisation coming on.

Inskipp argued that the significant developments in CCGT technology in recent years – improvements in materials allowing for increases in the gas turbine firing temperatures – were essentially a spin-off from aerospace innovations: "it's all really a spin off from aerospace technology ... as they try to get [gas turbines] to be more environmentally friendly and use less fuel. If the engines weren't being manufactured for the aerospace industry, then the industrial engines would be left behind".

He then speculated on the extent to which CCGT technology would have been adopted within the British ESI in the late-1980s and early-1990s if the industry had not been restructured and privatised. He suggested that the pressure of environmental compliance – which had a very immediate effect on the industry's choice of new generation technology during and after privatisation – would have exerted a more gradual influence on an unrestructured British ESI: "If privatisation hadn't come along, would the CEGB have invested [in CCGT technology]? ... That's a very difficult question to answer ... on the emission front, the answer would have been yes. Whether the restrictions on emissions ... would have come through at the same rate if ... [the industry] hadn't been privatised, is difficult to say".

As the ESI moved towards complete liberalisation of supply in 1998, the economic conditions that had allowed for the early dash-for-gas, based on long term power purchase agreements offered by the RECs, were changing, and such contracts were becoming less available. Inskipp suggested that the loss of REC franchise could have a very damaging effect on the independent CCGT plants: "whilst you can get a long term gas contract, you can't get a long term electricity sales contract ... Come 1998 when the [franchise] market disappears altogether, it will be fascinating to see how that develops ... I wouldn't be surprised if all the independents went to the wall". He also suggested that greater competition in the supply-side of the industry meant that there would be little investment in other forms of generation technology – in particular clean coal technology – for the foreseeable future: "clean coal technology ... is big money, and it's new technology risk, and you're back to the banks again. To finance ... [clean coal projects] they'll want 15 year sales contracts, and they just aren't available".

Finally, Inskipp considered the wider impact of the dash-for-gas on the British ESI. Although he was intimately involved in the dash-for-gas, he concluded that it was ultimately an unwelcome phenomenon – driven by narrow self-interests on the parts of the various organisations involved, with damaging consequences for the industry as a whole:

> [Was] the dash-for-gas was a good idea or not? I think I'd have to say on balance that it wasn't ... [we have] all this coal plant ... which we've already invested in. National Power claim that its just as cheap as gas once you've cleaned it up ... [but] who knows what the true cost is ... Looking back, everybody thought that [CCGT] was a great idea, and [said] 'I've got to have some of that'.

5.4.3 ICI

Imperial Chemical Industries is the UK's largest electricity user. It has longstanding experience of running coal- and oil-fired steam turbine power stations on a number of its production sites. For a number of ICI's activities, notably chlorine manufacture, electricity is a major contribution to total production costs. In the nationalised ESI, large industrial users such as ICI were offered special power purchase terms from the CEGB. This special treatment ended shortly after privatisation, reinforcing ICI's determination to gain greater independence in electricity supply.

At the beginning of 1989, *Enron Corporation* of the USA approached ICI with proposals for the construction of a CCGT/CHP plant on ICI land at their Wilton chemical plant on Teeside. (The CCGT scheme was subsequently known as the *Teeside Power Plant.*) Enron had already participated in similar (although much smaller) such projects with chemical companies in the USA. As well as ICI and Enron, the initial proposals for the Teeside Power Plant involved National Power as a potential power purchaser.

In addition to ICI (who contracted for only a small proportion of the proposed plants total output, and chose not to become equity partners in the *Teeside Power* consortium), Enron eventually secured *Power Purchase Agreements* for the proposed plant with four RECs, rather than National Power. Following the signing of letters of intent in January 1990, PPA contracts were agreed in September 1990 with Midlands Electricity, Northern Electric, South Wales Electricity and South Western Electricity – each of whom also became equity partners with Enron in the Teeside Power consortium. The plant was financed by a 15 year £800m loan syndicated to over thirty international banks. At the same time, 15 year gas supply contacts were signed with a consortium of gas supply companies led by Amoco. The gas for the plant was provided from newly-developed North Sea reserves, via a purposely-built pipeline constructed by the gas supply consortium at a cost of £1bn.

At the time it was built, the 1875MW Teeside Power Plant was the world's largest CCGT/CHP power station. Plant construction began in November 1990, commissioning started in October 1992, and full commercial operation was achieved in April 1993. The design of the plant was based on eight 150MW gas turbines, and two 300MW steam turbines, all built by Westinghouse and imported from the US. Fully operational, the plant has a total staff complement of just 66, compared to over 300 for a similarly sized coal-fired steam turbine plant.[173]

In 1994, another US electricity power company, *Intergen*, announced the construction of a further large CCGT plant on ICI land, a 750MW plant at Rocksavage, near Runcorn in Cheshire, to be built on a turnkey contract by Bechtel at a cost of over £300m. The output from the Rocksavage plant was contracted for by ICI and Scottish Hydro-Electric under 15 year PPAs. The gas for the plant is to be provided by BP Gas from North Sea reserves, again under a 15 year contract. The Rocksavage plant is due to commence commercial operation in early-1998.[174]

In an interview carried out in August 1994, Phil Smith, Projects and Services Manager of the Research and Technology Department at ICI Chemicals and Polymers, Wilton, described the problems facing ICI and other large electricity users in trying to develop independent gas-fired power projects in the British ESI before privatisation. In particular, he reported, neither British Gas nor the Area Boards offered the kind of long term fuel supply and power purchase contracts necessary to finance such large capital investment:

> Just before privatisation ... [ICI] was looking at a number of schemes in the ESI with the CEGB and local area boards, but we weren't getting very far. We had done quite a bit of work in-house thinking what we needed, but we'd never made any of them into a project ... There were a number of problems ... to do with contracts and prices ... fuel supplies ... electricity prices and so on ... Some of the key things we needed were a long term gas supply, which was independent of the then silly approach of British Gas, [and] the potential to contract for sales for electricity on more than the short term basis that was then available from local area boards ... [BG] offered six months contracts; for a plant financed over ten years, six months is no good at all. We couldn't get a price that held for more than six months. In the same way, you couldn't get a price for electricity sales to the local REC under the 1983 Energy Act that held for more than a year. You can't build a long term project on that basis.

---

173 Sources: various published and non-published papers provided by *Teeside Power* and *Enron Power Operations Ltd.*, Stockton-on-Tees. Also: M.J.S. Gibbons, 'Lessons from the Teeside Power Project', *Gas Power '91* conference, 22nd March 1990; P. A. Stokes, 'Developments in Combined Cycle Power Technology', *Energy for the 21st Century*, I.Mech.E. Seminar 1996-3, London, pp19-23; Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994:222-223; *Power in Europe*, No.61, 26th October 1989; Maurice Samuelson, 'ICI Plans Gas-Fired Power Stations', *Financial Times*, 19th October 1989, p9

174 Sources: *ICI C&P News*, 27th September 1996, BP Press Notice, 1st August 1996; Doyle and MacLaine, op cit:69

Smith stated that he first became interested in gas turbine generation technology in the mid-1980s: "at that time I was heavily involved in converting Wilton Power Station to coal [from oil] ... We were looking for the next stage ... I noticed in 1985 one of our competitors in the US, Dow, had repowered one of its large sites with three or four large 80MW gas turbines. After I did the calculations and modelling, this seemed to be a very good fit for us". He explained that ICI's interest in CCGT technology for use in CHP arose less from improvements in gas turbine efficiency, but rather from the capital cost savings such plant offered, and the ratio of process steam to power that it provided:

> We weren't too worried about gas turbine improvement, but what was important was the way capital costs were coming down – quite dramatically – and the way the market was building up, giving competition and choice. Gas turbines were coming of age ... Thirty years ago CCGTs didn't compete, their efficiency was too low, and the fuel price too high ... We've seen efficiency increase from 20% to 35%, maybe 40%. Combined cycle efficiencies have increased from 30%, which didn't compete with 36% on a coal-fired boiler plant – up to 50-55%, which does compete, and more than wipes out any fuel price differential. Also the capital cost of the CCGT is half to two-thirds that for same size coal fired plant. They compete in small unit sizes - a 150MW CCGT will compete with a 2000MW coal plant. You don't need to build big to achieve the efficiency gains, and you can spread your expenditure profile to match demand.

Smith explained that although they were keen to lessen their dependence on the public electricity supply system after privatisation (see 5.4.3 above), ICI were restricted by their limited experience in the management of independent power plant projects:

> The ability to build and operate the plant to a high level of efficiency ... was not within the ICI area of expertise. We have a different cost-to-reliability relation, we tend to spend a lot more on the original machine to get the reliability, and that would make it uneconomic in this case. The final thing was finance. We're a chemical company - it's not core to our business to put millions of pounds into a utilities plant.

Smith made clear that the involvement of Enron at this point was critical for the realisation of ICI's desire to promote independent generation:

> We were aware of the potential [of CCGT technology]... but finding it difficult to put together a commercially attractive project ... Enron decided there would be a good window for them just after privatisation ... They came along at just that time, when we were sensitive to what we were trying to put in place and looking for ways to make it happen ... There was an awful lot of persuasion going on. Enron had previous experience of building smaller stations, and they had a few years performance data. But they also had Westinghouse underwrite the gas turbine/steam turbine package. New technology ... [meant] the banks weren't keen, but Enron managed to make it happen.

Like Wilman and Inskipp, Smith pointed out that the improvements in CCGT technology were being driven by the turbojet market: "it was all to do with aero developments ... The aeroderivative companies have turned aero technology, which is high performance, short life technology, into high performance long life industrial technology". In addition, Smith also emphasised the importance of the liberalisation of the gas supply industry in enabling the dash-for-gas to take place, by encouraging the development of new gas reserves. He stated that before gas industry liberalisation, "there was a lot of gas in the North Sea not being brought ashore, because there was no market for it, nothing to justify investment in pipelines".

Finally, Smith considered the extent to which the British dash-for-gas was a response to rivalry among the organisations involved in the ESI, rather than the relative economics of gas versus coal plant. He suggested that if the CEGB had been broken up into a greater number of competing generators, there would have been less desire on the part of the Area Boards and large users to participate in the CCGT schemes: "with more competition in generation there would have been less of a dash-for-gas ... with 8 or 10 generators there would have been scope for private deals". Nevertheless, he argued that some CCGT plant would have been introduced in any structure for the industry, as a response to tightening pollution standards. He concluded that in this respect, "what the dash-for-gas is really doing is saving a massive investment in sulphur removal – shutting plants down and replacing them rather than retrofitting them. It only costs you 2-3 times as much to replace as retrofit on existing stations".

5.4.4 Enron

The project to build the Teeside Power Plant (see 5.4.3 above) was characterised by a high risk proactive strategy on the part of Enron Corporation – the largest gas pipeline and supply company in the USA. Enron's urgency to get the Teeside CCGT plant built quickly reflected their perception that there was market opportunity in the immediate post-privatised period, which was associated with historically low gas prices. Enron awarded plant construction contracts before having power purchase letters of intent from the RECs, and construction commenced before the final contracts were signed by the RECs.[175] In reviewing the Teeside Power project, Henney stated that Enron had "bet a significant proportion of the company – and won".[176] Phil Smith of ICI also emphasised

175 Doyle and MacLaine, op cit:63
176 Henney, op cit:224

that the initiative shown by of Enron was critical to the realisation of the Teeside Power Plant (5.4.3, above).

In another personal interview carried out in August 1994, Stuart Ffoulkes, of *Enron Power Operations*, Teeside, described the background to the financial arrangements for the Teeside Power plant. He suggested that the unanimous choice of CCGT technology for new plant construction in the British ESI after privatisation reflected the fact that finance was only available from the international banks for the most competitive projects; he observed that, "one of the reasons people build CCGT plants is because they can do it". In Ffoulkes' account of the putting-together of the Teeside plant project, it became clear that the terms of lending imposed by the syndicate of international banks played a great part in determining the contractual arrangements established by Enron:

> All the contractual arrangements are based on the fact that we have a large 15 year bank loan, and the banks require repayment over that period ... the banks require guarantees that we have 15 years of gas ... [they also] want to be sure we have customers for that period – so we have Power Purchase Agreements ... That sets the financial basis ... for the first 15 years, much of what Teeside Power does is keeping the banks happy.

The Teeside CCGT plant was built on an unprecedented scale. As Ffoulkes described, this meant that the banks were initially hesitant about the project: "we had to show them everything was built from standard components. Although the configuration is unique, every bit has been proven elsewhere". Ffoulkes also indicated that the long term power purchase contracts offered by the RECs in the early years after privatisation, based on their continued supply franchise, was vital in enabling independent CCGT projects to go ahead: "there's no way a plant of this size could be built if its customers were independent large users – it would mean thirty or so customers, which would be a nightmare with the banks. Its much easier for PowerGen or National Power as they're financing [CCGT plant] from their own capital".

As one of the first CCGT schemes in the privatised ESI, the Teeside Power Plant was able to take advantage of the low gas price contracts available in 1990. As was discussed in 5.3.3, the growth of the dash-for-gas prompted an increase in gas prices, notably the 35% increase in British Gas prices imposed in March 1991. Ffoulkes stated that "when the [gas] price was increased quite dramatically, quite a lot of proposed plants were quietly mothballed – the economic case was no longer there". Although, as Ffoulkes stated, this led to a slowing down in orders for CCGT plant, it was offset by continued improvements in gas turbine efficiency. He added that "without the technological improvements it would be much more difficult to invest in CCGTs, because of the increase in gas prices".

Before joining Enron in 1992, Ffoulkes worked for the National Grid Company, and was involved in the setting-up of the development of the mechanism for electricity trading after privatisation – the so-called electricity 'pool'. Whilst he conceded there was a deficiency of competition in generation under the Government's privatisation proposals, he suggested that there would have also been other problems – such as greater instability – under more competitive arrangements. He concluded that "this wasn't the best way of privatising the industry – but I'm also sure it wasn't the worst".

Ffoulkes also argued that rivalry between the RECs and generators meant that there would have been substantial investment in new plant after privatisation – and in particular CCGT technology – irrespective of the number of competing generators set-up after privatisation: "the RECs were very keen to get involved in independent power projects because of their lack of control in the market. At the same time they didn't want to spend money, so they looked at projects in which they could achieve payback in 10 or 15 years, and that wasn't feasible with coal". He concluded that "the dash-for-gas almost certainly would have happened whatever ... whilst the RECs concern was magnified by the duopoly, I don't think it would have disappeared without it".

5.5 Summary and Review

At the beginning of 1988 the CEGB remained solely committed to nuclear power and coal-fired steam turbine plant for large scale electricity generation. At the same time, most of the generating plans of independent power producers were based on recommissioning of old CEGB power stations as coal-fired steam turbine plant. Across the British ESI, despite the looming liberalisation of the industry, gas-fired generation technology continued to be marginalised. Nevertheless, there is some evidence that there was a growing awareness of the competitiveness of CCGT technology after 1987. Between its 1986/87 and 1987/88 Annual Reports, published in July 1987 and August 1988 respectively, the CEGB shifted from "design studies" concerning the adaption of CCGT plant for clean coal combustion, to discussions with gas producers and plant manufacturers about the construction of gas-fired CCGT plant, prompted by "the prospects of lower gas prices and improved technology" (5.3.1). At the same time, however, the CEGB made clear its continued commitment to new PWR and steam turbine plants for the bulk of its new plant.

Although international natural gas prices had fallen substantially by the time the preparations for ESI privatisation in Britain got under way, established interests in the industry invoked the history of rapid fluctuations in oil and gas prices to urge caution in considering the introduction in gas-fired plant. Such reasoning, for example, was relied on by the CEGB to justify its omission of CCGT from the comparison of generation technology options in evidence to the Hinkley Point C public inquiry (5.3.1). (The same argument was also used repeatedly by the Government to argue the diversity case for nuclear power – as demonstrated, for example, by Cecil Parkinson's comments during the Second Reading of the Electricity Bill in December 1988, 4.3.1.)

The evidence submitted to the Energy Select Committee's inquiry on ESI privatisation in early-1988 suggested that gas turbine technology would play only a marginal role in the post-privatised industry. The CEGB/Electricity Council joint memorandum to the select committee stressed that the technical and economic advantages of large plant, and stated that CCGT plant would probably be of more use in "small generation" applications such as industrial CHP and self-generation by the area boards. The Chairman of the Electricity Council, Sir Philip Jones, told the Committee that he would "not wish to encourage" the thought that CCGT technology was going to make a big impact on the ESI after privatisation, and added that much of the new plant needed would "inevitably" come from large established technologies (5.3.1).

Area Board evidence to the select committee was more positive, and there were some expressions of interest in constructing medium-sized CCGT plants. Even this evidence, however, came with the proviso that gas turbine technology would remain of marginal significance as compared to nuclear and coal-fired plant (5.3.1). It is impossible to know how much of the Area Board evidence to the select committee at this time, downplaying the impact of CCGT technology, was a reflection of their commercial interests. The retrospective evidence from personal interviews suggests that the awareness and interest of the Area Boards/RECs in CCGT developed rapidly – from a very low level – during 1988. Graham Wilman, for example, stated that Norweb had very little interest in, or knowledge about, generation technology before privatisation (5.4.1). For the plant manufacturers, Ron Haywood of Rolls Royce, conceded that there was little awareness of CCGT technology in the British ESI before privatisation. Haywood's comments illustrated the radical departure with established thinking on generation technology options that was made in Britain in 1988 and 1989. He stated that in mid-1988 gas turbine technology "seemed so foreign and revolutionary", but added that "attitudes changed very quickly" (5.3.4).

Unlike the changes affecting nuclear power technology – whose difficulties were anticipated by many independent analysts (as discussed in Section 4.6) – there was very little prediction of the dash-for-gas among independent analysts; even those analysts who foresaw the introduction of CCGT plant in Britain tended to underestimate the scale of interest. As Doyle and MacLaine argued, "few within the industry anticipated the emergence of CCGT as the plant of preferred choice" (5.3.4). The widespread ignorance of CCGT technology in the British ESI ahead of privatisation is confirmed by the absence of discussion of the possible extent of its adoption in the evidence submitted by independent industry analysts to the Energy Select Committee in 1988 (5.3.1).

In debate on the future development of the industry after the Government's White Paper proposals were published, the consensus of independent opinion was that there had been insufficient break-up of the CEGB's assets to provide significant scope for competition in generation (5.3.1). In criticising the Government's proposals, for example, Allen Sykes told the select committee that "it is hard to see how any genuine competition can emerge" (4.2.4). Nevertheless, a number of observers suggested there went a pent-up demand for gas turbine plant in the Britain, and that CCGT technology was set to make a major impact on the industry. Significantly, these views were held by long-time proponents of independent generation, and especially CHP technology, such as David Andrews, of the Association of Independent Electricity Producers, and the MPs Peter Rost and David Hannam (5.3.1).

From mid-1988 onwards, plans for a number of CCGT plants emerged, and despite the continued scepticism of many observers, the number of proposed CCGT schemes, developed rapidly in 1989 and 1990 (5.3.2). A number of distinctive economic, legislative and organisational causal factors are identifiable in the switch to CCGT technology in the British ESI in 1988 onwards. An immediate stimulus to change was the need for compliance with the EC Large Combustion Plants Directive, issued in June 1988. The LCP Directive, by requiring the fitting of desulphurisation equipment to recommissioned plant, proved critical in the relative cost of *new independent* coal-fired plant versus *existing CEGB* coal-fired plant. Graham Wilman of Norweb, for example, made explicit reference to the importance of "significantly tightening emission standards", and the fact that European legislation required independent generators "to meet higher emission standards" (5.4.1). Wilman indicated that its was only after the LCP Directive was issued that the relevant cost comparison for independent/REC companies – recommissioned coal-fired plant plus desulphurisation equipment, compared to new CCGT plant – went in favour of the more radical option.

There is also evidence that the LCP Directive played a critical part in the investment plans of the established generators in the late-1980s. At the time the LCP Directive was issued – and for sometime afterwards – CEGB interest in CCGT technology was restricted to proposals for a small number of medium-sized (300MW) plants. As indicated in the Board's 1987/88 Annual Report, these proposals were not seen as interfering with the Board's the large coal-fired and nuclear plant programme (5.3.1). In early-1989, after the operational splitting-up of the CEGB, National Power and PowerGen interest in CCGT plants developed rapidly, and their established plant programmes were cancelled. In the spring of 1989 both National Power and PowerGen announced proposals for an expanded CCGT programme based on larger plant units (5.3.2). In evidence to the Energy Select Committee's inquiry on the Flue Gas Desulphurisation Programme in 1990, both suggested that building new CCGT plant offered a cheaper means of generating than retrofitting existing coal-fired plant with desulphurisation equipment (5.3.3). This was also the view of the independent analyst Dr Jim Skea, in his evidence to the select committee. The LCP Directive gave both independent and established generators an economic motivation to switch to CCGT technology.

At the same time, there is considerable evidence that institutional rivalry was also an important cause of the early dash-for-gas. The Area Boards/RECs certainly had more than one institutional reason to invest in generation technology. They were undoubtedly keen to enter generation so as to reduce their dependency on the CEGB's successors, particularly after the February 1988 White Paper made clear their continued market power. This was explicitly referred to by those involved in IPP consortia. Graham Wilman of Norweb stated that the "RECs are interested in generation in order to break the power of National Power and PowerGen" (5.4.1). Phil Inskipp referred to NP/PG as a "duopoly which can rig the market" (5.4.2). Stuart Ffoulkes of Enron confirmed that "the RECs were very keen to get involved in independent power projects because of their lack of control in the market". At the same time, Ffoulkes pointed out that a dash-for-gas of some size would have happened under any organisational structure for the privatised ESI (5.4.4).

The RECs' interest in generation was increased after the 1988 White Paper and Electricity Bill made clear the Government's intention to allow essentially unregulated activity in fossil fuel generation – as compared to the strict regulatory regime that was being constructed for distribution and supply. John Harris, Chairman of East Midlands Electricity, in evidence to the Energy Select Committee in 1992, stated that investment in power plant allowed the RECs to "get equity into non-regulated businesses" (5.3.4). This was also identified as a reason for Norweb's interest in generation by Graham Wilman (5.4.1). Phil Inskipp suggested that Scottish Hydro-Electric's interest in generation was a secondary response to the investment of others (5.4.2). The large industrial electricity users had similarly powerful institutional reasons to enter generation, given greater liberalisation of the industry. As made clear by Phil Smith of ICI, they had been frustrated in their efforts to develop independent schemes under the terms of the 1983 Energy Act (5.4.3). At the same time, it became clear that the discount prices for electricity that the CEGB's largest customers had enjoyed under nationalisation were to end with privatisation.

The involvement of the RECs and large users drove forwards the initially speculative schemes of independent power producers. Independent analysts expressed considerable scepticism concerning the feasibility of independent plant proposals in the early stages of privatisation. REC involvement was crucial to the realisation of the IPP schemes. They provided equity, but more importantly, they were in a unique position to offer a guaranteed market for new plant. The signing of long-term Power Purchase Agreements was critical to the securing of finance for IPP schemes. Whilst the RECs' motivations to become involved in generation were a product of institutional and legislative pressures, the expression of this desire depended on a technical and economic factors – in particular, the much-reduced barriers to entry into generation made possible by the development of CCGT technology. Another important factor here was the ongoing liberalisation of the British gas supply industry, which made gas supply contracts available for the first time in the late-1980s (5.3.1). Without the development of CCGT technology, and the availability of competitive gas supply contracts, the desire for new generation in the industry would not have been realised on anything like the same scale, particularly given the disadvantages of independent generators under the terms of the LCP Directive.

The unanticipated realisation of IPP schemes provided the major generators with their own institutional motivations to expand their investment in CCGT plant. As was argued by British Coal in evidence to the Energy Select Committee in 1992, this appears to have been an essentially *defensive* reaction (5.3.4). In their own evidence to the select committee at this time, National Power and PowerGen concentrated on criticising the "uneconomic" investments of the RECs – and had earlier stated to the select committee they were burning gas now simply because it was now available (5.3.3). However, the timing of the large generators' increased interest in CCGT plant suggests a primarily reactionary motivation. Only in April and May 1989 did National Power and PowerGen announce they were greatly expanding the CEGB's plans for CCGT investment – almost a year after the issuing of the LCP Directive. By this time it was clear that independent generator interest in CCGT technology was progressing on a significant scale, and it seems this – rather than the economic implications of the LCP Directive itself – exercised greatest influence on the plans of National Power and PowerGen to scale-up their involvement in CCGT schemes. Even with the LCP Directive in place, it is highly probable that CCGT technology would have been introduced much more slowly into the British ESI if left to the CEGB's successors alone. It was only after it had become apparent that CCGT technology was enabling a much greater and more immediate threat to their markets than had been anticipated, that National Power's and PowerGen's own interest in an immediate large-scale CCGT programme developed.

As well as legislative and institutional factors, economic considerations were clearly a powerful influence on investment in new generation technology in the British ESI after privatisation. CCGT technology was uniquely well-suited to the demands of private sector investors for quick returns on investment, minimum capital outlay, and least exposure to risk. Graham Wilman of Norweb stated that the high rates of return for privately-financed IPP projects meant that "the economics swing from fuel cost to capital cost being important" (5.4.1). The terms of loan set down by international banks exerted a powerful influence on the form and scale of independent investment in generation technology in the British ESI after privatisation. This was the background to the establishment by the IPP consortia of secure long term back-to-back contracts for fuel purchases and electricity sales. Phil Inskipp of Scottish Hydro-Electric stated that IPP plants "were basically forced by the banks to sign up to deals for 15 years" (5.4.2). The concerns of financiers were also a powerful influence in the adoption by the IPP consortia of proven CCGT plant components imported from overseas. Phil Inskip described the problems this presented to the Keadby CCGT plant consortium, and concluded that "the banks were still nervous, they don't like anything new" (5.4.2). The prescribing influence of the conditions of loan by international banks was also clear in the accounts of the Teeside Power Project. ICI's Phil Smith highlighted the need for Enron and Westinghouse to reassure banks about the reliability of CCGT technology (5.4.3). Stuart Ffoulkes of Enron stated that obtaining loans for CCGT plant construction depended on assurances of a guaranteed market that could only be provided by REC involvement; he added that "for the first 15 years, much of what Teeside Power does is keeping the banks happy" (5.4.4).

After the substantial increases in natural gas prices for industrial customers imposed by British Gas at the beginning of 1991 (5.3.3), there is considerable evidence that new CCGT plant became a more expensive form of generation than existing coal-fired plant, even with desulphurisation equipment fitted. This was indicated, for example, by the comments of representatives from both the large generators and the RECs in evidence to the Energy Select Committee's 1992 inquiry on the *Consequences of Electricity Privatisation* (5.3.4). The continuation of the dash-for-gas during 1991 and 1992 confirms the view that much of the desire by the large generators and RECs to invest in new plant arose from institutional rivalry rather than solely economic considerations.

The 1992/93 coal crisis provoked a period of uncertainty in the industry, during which there was considerable pressure on the Director General to restrict the size of any further expansion of the dash-for-gas (5.3.5). Whilst he eventually acted in a much less interventionist way than many of his critics demanded, the Director General's two year capping of pool prices, and his demand for plant divestment on the part of National Power and PowerGen, marked a significant re-ordering of the financial and institutional context for generation. The immediate effect of the uncertainty associated with the coal crisis was the cancellation or deferment of a significant amount of proposed CCGT plant – demonstrating that such investment was predicated on a stable and accommodating institutional and regulatory framework.

By the mid-1990s the ESI was entering a new period of uncertainty associated with the complete liberalisation of supply in 1998. In 1995 Norweb stated that this was making them less interested in new generation schemes (5.3.5). Similarly, Phil Inskipp of Hydro-Electric argued that supply deregulation meant that long-term power purchase contracts with the RECs were harder to obtain, and added that he "wouldn't be surprised if all the independents went to the wall after 1998" (5.4.2). By 1997, however, there was little prospect of this – indeed, such were the extent of further investment plans in CCGT technology, that analysts were reporting that a "second dash-for-gas" was under way (5.3.6).

Amongst the extensive debate on the changes to the ESI since privatisation, some attempts were made at identifying the most important influences of the dash-for-gas. Much of this discussion focused on the relative importance of *local* institutional and legislative and regulatory changes to the British ESI that accompanied privatisation, as compared to *international* technological and economic changes in the price and availability of natural gas, and also the cost and performance of CCGT technology. For example, in evidence to the Energy Committee in 1992, the Watt Committee argued that deregulation of gas-fired generation technology was a more important factor than the restructuring of the industry associated with privatisation (5.3.4). In the same way, Roger Semmens of PowerGen argued that the dash-for-gas was a result of the availability of natural gas, and was "not to do with privatisation at all" (5.3.4). Similar views were expressed by Ron Haywood, who stated that "it was the price which won the day". However both Semmens and Haywood went on to concede that the pace – if not the direction – of change in generation technology was influenced by ESI restructuring.

A close examination of the dash-for-gas makes the case for the primacy of fuel prices and availability, over ESI restructuring, hard to sustain. Despite cheaper gas prices, at the beginning of 1988 the CEGB remained committed to the construction of large nuclear and coal fired plant, and they anticipated only a secondary role for CCGT technology at this time. Furthermore, the accounts of those involved in independent CCGT schemes highlighted not only gas price and availability, but also to other factors such as institutional rivalry and environmental legislation (5.4). Doyle and MacClaine argued that it was the Government's creation of a strong duopoly in generation that provided the liberalised RECs with their strongest incentive to enter the dash-for-gas (5.3.5). Whilst the availability of cheap gas was undoubtedly a critical factor in the development of CCGT technology in the British ESI, it cannot be isolated as the only crucial factor, or even the most important one.

In the same way, it is misleading to give fuel prices primacy in terms of setting the *direction* of change, with non-economic factors having influence on only the *pace* of developments. In the nationalised ESI, economic factors were never the primary influence on generation technology, and it is unlikely that cheaper gas prices alone would have significantly disturbed an unrestructured CEGB's plans for new coal-fired and nuclear plant for the 1990s. Rather, as both Cecil Parkinson and John Wakeham argued, the Board's plans would have probably progressed without comment in the absence of industry restructuring (4.3.1, 4.3.3), with the result that there would have been much less need in capacity (or environmental) terms for any subsequent CCGT plant. As Pacey, Hård and others pointed out, the CEGB's hesitancy to adopt CCGT technology conforms to a pattern: monopoly bodies are characteristically associated with conservative and incremental innovation, and are reluctant to engage in radical technological change. As discussed above, there is evidence that National Power and PowerGen inherited the CEGB's conservatism in this regard, and only expanded their interest in CCGT plant after the scale of threat from IPP schemes became apparent.

Other analysts have discussed the dash-for-gas in terms of the relative importance of *technical* versus *economic* influences. For example, Gordon MacKerron argued that the British dash-for-gas owed "less to major technical improvements than to radical changes in the economic environment in which the electricity supply industry operates" (5.3.5). Although this conclusion is valid in terms of the immediate changes affecting the industry in the late-1980s, from a longer term perspective it is more questionable. The evidence provided by the accounts of those involved in the dash-for-gas would suggest that the steady improvement in CCGT technology since the 1960s was crucial to its introduction in the privatisation period. For example, in his account of the Teeside Power project, ICI's Phil Smith, as well as referring to the economic and institutional factors behind the choice of CCGT plant, referred to the importance of the progressive efficiency gains made by gas turbine technology (5.3.4). Graham Wilman of Norweb pointed to the importance of the additional efficiency gains in CCGT technology since the start of the dash-for-gas (5.4.1). Doyle and MacLaine also reiterated the continuing market implications of increases in CCGT performance (5.3.5).

In another paper, MacKerron argued that environmental factors – specifically the need to comply with the LCP Directive – had "played only a minor supporting role" in the dash-for-gas, particularly for the RECs and independent generators. Instead, he stressed the importance of institutional rivalry (5.3.4). As discussed earlier in the present section, whilst institutional rivalry between the RECs, large users and CEGB successors was undoubtedly a source of much of the desire for new capacity within the industry, there is considerable evidence that the issuing of the LCP Directive was highly influential in the choice of CCGT technology as the technical form in which this desire would be expressed. Until independent power producers were placed under a greater relative burden by the LCP Directive, they were intending to base much of their entry into generation on the recommissioning of coal-fired steam turbine plant. In the period since privatisation, as progressively more stringent restrictions on pollution levels have been introduced, environmental compliance has remained an important factor in the industry's preference for gas-fired generation.

As other analysts, such as Eric Jeffs (5.3.4), and Jim Watson (5.3.5) stressed, the radical switch in technological preference that occurred in the British ESI in 1988 and 1989, and continued thereafter, can only be understood by reference to a number of coinciding technical, economic, institutional, regulatory and political factors – the absence of any one of which would have limited the pace and direction of change. Some of these factors were local, in that they were peculiar to the British ESI privatisation process, whereas others reflected global/international changes in generation technology and fuel prices. At a local level, the partial liberalisation of the industry ahead of privatisation gave release – and because of its limited extent, catalysed and accelerated – the desire for entry into generation on the part of RECs and others. However, the manifestation of this desire in terms of a particular technological form was a reflection of more international forces – particularly those involving CCGT technology and the availability of cheap natural gas – which were essentially unconnected with the privatisation process itself. As such, the introduction of CCGT technology in Britain was an unpredictable and contingent process.

CHAPTER 6:

COAL-FIRED STEAM TURBINE TECHNOLOGY AND ESI PRIVATISATION

6.1 Introduction

This chapter considers the interaction between coal-fired steam turbine technology – always the dominant technical form of generation – with the British ESI privatisation process. The commercial risks and uncertainties associated with steam turbine technology were much less than those of nuclear power, and the selling-off of coal-fired plant presented none of the immediate problems encountered with nuclear plant. As was described in Section 4.2, the structure for electricity generation after privatisation was shaped primarily by the Government's desire to secure the future of nuclear power. By comparison, fossil fuel plant received only secondary attention in the privatisation process. Consequently, rather than an examination of the influence of steam turbine technology on privatisation, this chapter is concerned rathermore with the effects of ESI privatisation of on steam turbine technology.

The chapter is divided into four main sections. Section 6.2 reviews the changes affecting steam turbine technology before and during ESI privatisation, focusing particularly on the views of industry insiders and observers. Section 6.3 considers the fortunes of coal-fired generation after privatisation, including the *coal crisis* of the early-1990s. Section 6.4 provides an industry perspective on changes to the dominant form of generation technology, based on an interview with a senior figure in the British electrical plant manufacturing industry. Section 6.5 considers the impact of privatisation on fossil fuel generation technology R&D, particularly the development of clean coal technology. Finally, Section 6.6 is a summary and review of the chapter.

6.2 Steam Turbine Technology during the Privatisation Process

6.2.1 Industry Perceptions ahead of Privatisation

In the run-up to ESI privatisation there were no new power stations under construction in Britain other than the Sizewell B PWR, and the CEGB was expressing fears of a potential capacity shortage by the late-1990s. The last order for fossil fuel plant had been placed in 1977 (three 660MW turbines, built for Drax B). In February 1988 the CEGB applied for planning consent for two 1800MW coal-fired stations, West Burton B and Fawley B.[1] The plants were to be based on newly-developed 900MW steam turbines, incorporating improved steam conditions and advanced steel alloy turbine blades, which had been developed jointly by the CEGB and GEC. The turbines were described by R. N. Burbridge, the Director of the CEGB's Generation Development and Construction Division, as a "modest extrapolation on the present 660MW sets, with features already established by experience or component development".[2] Burbridge added that "it is clear ... that the nation faces a shortage of generating capacity in the mid-1990s and this is to be averted by the dual policy of a small family of PWR stations and new coal-fired stations using the 900MW units".[3]

As the ESI privatisation process got under way in 1987 and early-1988, concern for British Coal was overwhelmingly centred on the threat of cheap coal imports, and on the urgent need to establish new long term contracts between BC and the CEGB's successors, given the overwhelming market dependence of sales to the CEGB that had built up in the years after nationalisation. Since the early-1980s, over three-quarters of BC sales had been to the CEGB and SSEB, and under the Joint Understandings, BC had provided 95% of coal supplied to the CEGB.[4] Privatisation coincided with the ending, in March 1990, of the revised Joint Understanding, under which the CEGB was obliged to take 75mt p.a. of BC coal. Freeing-up the fuel choice of the electricity generators presented a clear threat to BC, and some analysts argued that because of this, the coal industry should be privatised ahead of, or at the same time as the ESI.[5]

---

1 CEGB, *Annual Report and Accounts 1988-89*, London, July 1989:7

2 R. N.. Burbridge, 'Development of 900MW Coal-Fired Generating Units', *Power Engineering Journal*, May 1988, pp147-154:148-149

3 ibid:154

4 ESTUC evidence to the Energy Select Committee inquiry, *The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector*, HC 307, 1987-88, Vol II:159

5 See for example, Colin Robinson and Eileen Marshall, *Can Coal Be Saved?*, Hobart Paper No. 105, London, Institute of Economic Affairs, 1985; also Peter Rost, 'Towards a Competitive Market-Related Energy Policy', *Energy Policy*, Vol.16, No.5, pp450-452, October 1988:451

However, alongside the considerable concern for British Coal, there was very little attention devoted to the possible threat privatisation might present to the dominance of coal-fired steam turbine technology. As discussed in 5.3.1, the Energy Select Committee heard little evidence on the potential impact of CCGT technology in the course of their 1988 inquiry on ESI privatisation.[6]

In their memorandum to the Select Committee, British Coal stated that they regarded the setting-up of long term fuel contracts with the generators as "essential for both industries", and expressed "great concern" about the threat of cheap coal imports.[7] One of the CEGB's proposed new coal-fired plants, at Fawley, was well-located to receive imported coal, and it was known that the CEGB was proposing to build additional bulk importing facilities at this time. Under questioning by the Select Committee, the Chairman of the British Coal Corporation, Sir Robert Haslam, emphasised that BC's future prospects depended on reaching agreement on 10 year contracts with the generators. Nevertheless, Haslam also maintained that "we still believe we can establish ourselves as a supplier of choice to the electricity industry", and he dismissed the forecast of a recent Coalfield Communities report that BC would be reduced to 48 collieries by 1992, as "going too far".[8]

In stark contrast to its handling of nuclear power, the Government made clear that it was not prepared to make any special provisions for the British coal industry in its plans for ESI privatisation. In particular, the Department of Energy was unwilling to broker the kind of long-term fuel contract with the generators that BC was asking for. The Energy Secretary Cecil Parkinson told the Energy Committee that after ESI privatisation, "there will be no statutory obligation on the generators to buy British coal".[9] The Government's public comments on the impact of privatisation on fossil fuel choice at this time were restricted to an expression of its confidence that – provided BC continued to make rapid improvements in productivity (the industry had undergone substantial rationalisation since the 1984/5 miners' strike) – it would be able to compete successfully with foreign coal suppliers. Under questioning by the Select Committee on this issue, Parkinson stated that "local produced electricity is going to be overwhelmingly the main source of electricity supply in this country ... Seventy to seventy-five per cent of all our future electricity is going to come from coal".[10]

---

6 *The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector*, HC 307, 1987-88
7 ibid, Vol II:120
8 ibid, Vol III:256
9 ibid:72
10 ibid:83

In Parliament, Parkinson was repeatedly questioned about the consequences of ESI privatisation for British Coal. In March 1988, shortly after the publication of the White Paper on privatisation, he was asked about the threat presented by the Government's proposals to the CEGB's plans for new coal-fired steam turbine plant. He replied that "we expect these orders to be pursued. We believe there is an important future for coal and that well into the foreseeable future coal will continue to be the major source of our electricity".[11] Sir Anthony Meyer suggested that the "form of privatisation" that Parkinson had chosen would "unleash competitive forces that will lead finally to the virtual closure of the British deep-mine coal industry".[12] Parkinson stated that this was "pessimistic nonsense", and he added that "there will be a need for 75 million tonnes of coal a year, and I refuse to believe that the British coal industry ... cannot meet the challenge of supplying most of that need".[13] He argued that no protection for BC was necessary – given the established dominance of coal-fired steam turbine technology in Britain's electricity generation infrastructure, and the practical restrictions on coal imports, British Coal would inevitably continue to be the dominant electricity fuel supplier – and steam turbine the dominant generation technology – for some time after privatisation. In the debate on the White Paper, he stated that "three quarters of our electricity will come from coal-fired power stations, way into the future".[14]

The CEGB was reluctant to make any statement of its plans for coal imports in the run-up to privatisation, but under questioning by the Energy Committee, the CEGB Chairman, Lord Marshall, recognised the threat to British coal from cheaper imports. Marshall stated that "the major issues will be about the use of coal and whether coal is imported or we use British coal"; he indicated that he saw no prospect of any other major change in choice of fuel or generation technology.[15]

The general weight of opinion of independent energy analysts at this time was that, although BC would inevitably lose some of its share of the generation market after ESI privatisation, it would nevertheless continue to be the dominant fuel supplier to the industry. Robert Peddie, for example, (a former member of the CEGB) told the Energy Committee that "whilst there would be an increase in imports, a slimmed-down United

[11] HC Debates, 1987-88, Vol.129, c3
[12] ibid, c3
[13] ibid, c3
[14] ibid, c56. Whilst they were frustrated in their efforts to gain long-term contracts, British Coal itself appeared to take some solace from the Government's assurances. Henney argued that it was only in late-1989 that BC began to appreciate the scale of likely investment in CCGT plant, and that even afterwards, up to the 1992 General Election, it hoped for a "political solution" to its problems, with the return of a more supportive Labour Government. (Alex Henney, *A Study of the Privatisation of the Electricity Supply Industry in England and Wales*, London, EEE Ltd, 1994:288)
[15] HC 307, 1987-88, op cit, Vol.III:11

Kingdom coal industry would be capable of retaining the bulk of the power stations market".[16]

6.2.2 Steam Turbine Technology during the Privatisation Process

The limits on sulphur dioxide emissions in the EC *Large Combustion Plants Directive*, agreed to in June 1988, required the fitting of desulphurisation technology to all new, and some existing, coal-fired plant. As discussed in section 5.3.2, the LCP Directive proved critical in the relative cost of electricity from coal-fired steam turbine versus CCGT plant, and from mid-1988 onwards, schemes for CCGT plant emerged in increasing number from all parts of the British ESI. At the same time there was increasing concern for the viability of the CEGB's proposals for new coal-fired steam turbine plants. As well as the challenge of CCGT technology, the Government's protective measures for nuclear power, announced in the February 1988 White Paper (4.2.3) and the December 1988 Electricity Bill (4.3.1), put additional pressure on the market for coal-fired generation. This was felt both directly, through the reservation of much of the baseload supply for Nuclear Electric, and indirectly, as the creation of a neo-duopoly in generation gave additional motivation on the part of RECs and large users to minimise their dependency on existing generation plant.[17]

Nevertheless, in the second reading of the Electricity Bill in December 1988, despite increasing concerns inside and outside parliament for the future of coal-fired generation, the Energy Secretary Cecil Parkinson argued that "if there is to be a privileged fuel for the future it will be – as it has been in the past – coal, which will have a five times bigger share of the market than nuclear power".[18]

In a climate of continued uncertainty, the CEGB announced the deferral of its application for the proposed Fawley B steam turbine plant in October 1988. The *Financial Times* reported that the CEGB's decision was a result of Area Boards' reluctance to give the CEGB any long-term commitment to purchase power from the plant. It added that the CEGB privately acknowledged that none of the proposed steam turbine plants would now be built, and that the Board was instead planning to build CCGT plants.[19] In its 1988/89 Annual Report, the CEGB confirmed that it had decided to cancel Fawley B after failing

16 ibid:212

17 In this respect, Henney stated, the "final legacy of nuclear power" was to create additional difficulties for British Coal" (Henney, op cit:288).

18 HC Debates, 1988-89, Vol.143, c675

19 Maurice Samuelson and Nick Garnett, 'Coal-Fired Power Station Plans Hit by Privatisation', *Financial Times*, 27th October 1988, p1

to secure any commitment from the Area Boards/RECs to contract for the output from the proposed plant.[20] At the same time, it stated that the second proposed steam turbine plant, West Burton B, was "under consideration".

In April 1989, the Labour MP Joe Ashton expressed his concern in Parliament about the threat CCGT technology now presented to the CEGB's proposed coal-fired steam turbine plants (one of which, West Burton B, was to be located in his constituency).[21] Ashton referred to a letter he received from Lord Marshall, stating that the CEGB would be unable to progress with any of the proposed plants unless they were given assurances from the Area Boards that they would contract for power provided. In response to Ashton's concern, Cecil Parkinson again made clear the Government's reluctance to intervene in generation technology choice in the fossil fuel part of the ESI. At the same time, he argued that the size of coal imports would be restricted by the limited size of the international coal market, and also the limited capacity of bulk importing facilities, and he maintained that "the prospects are extremely good for the British coal industry".[22] Nevertheless, in May 1989, National Power cancelled the proposed West Burton B plant, and stated that they had been as yet unable to secure long term power purchase agreements with the RECs.[23]

Despite their public expressions of confidence in the future of coal-fired generation, evidence emerged that, in private, the Government recognised the scale of the threat presented by ESI privatisation to British Coal. In October 1989 a presentation to the Cabinet by the new Energy Secretary, John Wakeham, was leaked. The report – evidently written some time earlier – forecast that in the first three years after ESI privatisation, British Coal would lose 15mt of its annual market, resulting in the loss of 30,000 jobs and the closure of one-third of its mines.[24] *Power in Europe* argued that the document revealed an "almost unbelievable bias against coal and in favour of nuclear power".[25]

At the beginning of December 1989, after considerable pressure from the Energy Secretary, John Wakeham, National Power and PowerGen agreed to contracts with British Coal for the first few years after privatisation. The contracts ran for three years from April 1990 to April 1993; they required National Power and PowerGen to take 70mt

20 *CEGB Annual Report 1988-89*, London, CEGB 1989:15
21 HC Debates, Vol.150, 1988-89, c281-282
22 ibid, c302
23 *Power in Europe*, No.49, 11th May 1989. In the event, three-quarters of the power purchase contracts agreed between the National Power and PowerGen and RECs ahead of privatisation were of only 3-5 years (the rest were 6 months short term contracts) *Power in Europe*, No.52, 22nd June 1989.
24 *Power in Europe*, No.61a, 31st October 1989:6
25 ibid:6

of BC coal for the first two years, and 65mt in the third.[26] Although they ran for a far shorter than BC was asking for, the agreements meant that coal imports would be much less than had been feared, and they were initially thought to secure the future of British Coal, at least in the short-term. They were greeted by Sir Robert Haslam, the Chairman of British Coal, as evidence that forecasts of the contraction of the coal industry were "seriously overstated".[27]

In the same month, the Energy Secretary, John Wakeham, discussed the prospects for the coal industry after ESI privatisation with the Energy Select Committee.[28] A number of Energy Committee members, with longstanding support for the coal industry, argued that three year contracts were wholly inadequate for securing the future of British Coal. Wakeham defended the contracts as providing a "good opportunity", for BC provided they continued to reduce their costs, but he refused to speculate further on the impact of privatisation on the coal industry. At the same time he recognised that gas turbine/CCGT technology was by now presenting a substantial threat to coal-fired generation technology. He stated that he "would anticipate that ... [British Coal's] competition will be very much from gas, which I think will have a good share of the future market".[29]

6.3 Steam Turbine Generation Technology after Privatisation

6.3.1 The Accelerating Threat to Steam Turbine Technology

In mid-1991, shortly after the flotation of National Power and PowerGen, the Energy Select Committee undertook an inquiry on *Clean Coal Technology and the Coal Market after 1993*.[30] As well as discussing the prospects for the different types of clean coal technologies (see 6.5, below), the inquiry provided a forum for concern about the accelerating threat to coal-fired generation.

The consensus amongst the evidence submitted to the select committee at this time was that the British coal industry was greatly threatened by both cheap coal imports, and also gas turbine generation technology. Particularly alarming evidence was submitted by the industry analysts Gerald McCloskey and Guy Doyle. They predicted a dramatic decline in the use of coal for electricity generation, so that by 1995, British Coal would be left

---

26 *Power in Europe*, No.64, 7th December 1989, pp1-3

27 Maurice Samuelson, 'Electricity Contracts Safeguard Coal Jobs', *Financial Times*, 5th December 1989, p20

28 House of Commons Energy Committee, *The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector: Minutes of Evidence*, HC 96, 1989-90:1

29 ibid:1

30 HC 208, 1990-91, published in July 1991.

with just 10-15 pits, and a total annual output of just 28mt.[31] By 1998, they suggested, the market for indigenous coal in Britain may have virtually disappeared. This decline, they suggested, would be the result both of large increases in the use of gas turbines for generation, and also imported coal.[32]

A number of witnesses to the Select Committee called for the protection of the British Coal industry. For example, the Watt Committee on Energy stated that "at some level of reduction the coal industry, or part of it, would justify being ring-fenced on the grounds of national need for adequate diversity of supply as per the nuclear industry".[33] In his evidence the Energy Secretary John Wakeham rejected the suggestion that the Government should intervene to restrict coal imports or investment in gas turbines. He maintained that "British Coal has an excellent future", and dismissed McCloskey's and Doyle's predictions as being "overly pessimistic"; he added that he would be "very concerned" if such a collapse were to come about.[34]

Both National Power and PowerGen were planning to import significant amounts of coal at this time, and both were progressing with the construction of deep-harbour port facilities. National Power told the select committee that they considered that as much as 50% of their coal needs could be imported after the expiry of the current fuel contracts with British Coal in 1993.[35] NP's Commercial Director, Mr. J. Webster, argued that the much greater use of imported coal was made inevitable by the Government's measures to liberalise the industry: "we have been placed by this legislation in a competitive situation. There is nothing we can do about that ... we must buy competitively".[36] Although the dash-for-gas was well under way mid-1991 (see 5.3.2), the Energy Committee concluded that "at present ... the most serious threat to British Coal's existing markets appears to be imported coal rather than gas".[37] The Committee argued that in the long term, natural gas would not be able to maintain its market share in generation. It added that, by 2000, much coal-fired steam turbine plant would be around 30 years old, and need replacing by advanced clean coal technologies, but warned that the development of these technologies in Britain was being sacrificed in the market-based ESI.

---

31 ibid, Vol.III:99

32 ibid:104-5 McCloskey and Doyle pointed out that on the international market, virtually no British deep-mined coal was competitive, since large opencast mines in Australia, South Africa and the USA could produce coal far more cheaply than anywhere in Western Europe. They added that the collapse of the British coal industry was not dependent on CCGT technology or the extra cost of desulphurisation technology, since imported coal would have replaced British coal irrespective of these developments (ibid:104-5)

33 ibid, Vol II:40

34 ibid, Vol.III:235

35 ibid, Vol.III:167

36 ibid:167

37 ibid, Vol I:xxxvi

By the time the Energy Select Committee's inquiry into the *Consequences of Electricity Privatisation* was published in February 1992,[38] the dash-for-gas was by now clearly the dominant threat to British Coal's market, and the Committee were forced to reconsider their view of just over six months ago in their *Clean Coal Technology* report. The Committee conceded that "it now appears that the threat to British Coal's market from gas-fired generation is more serious than that from imported coal ... New evidence has made it brutally apparent how drastically and rapidly Britain's coal industry will contract if present policies continue".[39]

A number of witnesses to the Committee at this time were highly critical of the Government for allowing free rein to the dash-for-gas. One of the most outspoken of these was Malcolm Edwards. Although still the Commercial Director of British Coal, Edwards was by now a marginalised figure, and he was openly critical of the Government's energy policy, and also what he saw as British Coal's compliance in its own demise. Like many others (see 5.3.3) Edwards argued that the dash-for-gas was being driven by non-economic forces. He stated that "it arises out of rivalry. The RECs were very concerned to have something with which to bargain with the generators ... the generators reacted to defend their market share ... and also to mop up the surplus gas".[40]

Edwards stated that vertical separation of generation and supply meant that the generators now resisted all but the shortest contractual commitment with fuel suppliers, and he claimed that short-termism was now endemic in the ESI.[41] He claimed that five year contracts were the minimum needed for British Coal, but stated that securing these required considerable managing of the total energy market, "something which in the end only the Department of Energy can do".[42] He went on to present an alternative agenda for a government-directed British energy policy, which continued to give a central role to indigenous coal supplies. He argued that if the Government was prepared to "manage the market", and ensure that proposed CCGT plants "stand up to a really thorough economic examination", then the British coal industry, although still likely to contract, would be "capable of being built upon and sustaining itself".[43]

In his evidence to the Energy Committee at this time, the independent energy analyst Dieter Helm also argued that institutional self-interests – particularly those of the

[38] HC 113, 1991-92
[39] ibid, Vol.I:li
[40] ibid, Vol.III:142
[41] ibid:141. By contrast, Scottish Coal found it much easier to negotiate with the vertically-integrated Scottish boards. As Edwards pointed out, there was no equivalent dash-for-gas in the Scottish ESI.
[42] ibid:143
[43] ibid:145-6

Government itself – had profoundly shaped the ESI privatisation process. Helm claimed that before privatisation, the Government had deliberately arranged contracts between British Coal and National Power/PowerGen to be in place for the period 1990-1993, so that the inevitable consequence of freedom of choice in fuel supplies for the generators – the collapse of British Coal – would be delayed until after the 1992 General Election.[44] He also argued that after the withdrawal of nuclear power from privatisation in 1989, some of National Power's and PowerGen's fossil fuel plants should have been sold off to third parties, despite Government protestations that there was insufficient time to change the structure of the industry.[45]

6.3.2 The Coal Crisis and the Coal Review

The General Election of April 1992 returned the Conservative Party to power for a fourth successive time, with a commitment to privatise British Coal. One of their first acts of the new Government was the dissolution of the Department of Energy (and alongside it, the Energy Select Committee). Government responsibilities for the ESI now passed to the Department of Trade and Industry, under the President of the Board of Trade, Michael Heseltine. Parliamentary scrutiny of energy policy was passed to the Trade and Industry Select Committee. The abolition the Department of Energy further marked the apparent depoliticisation of energy policy, at least within the fossil fuel sector. Within a few months, however, the fallout of the Government's market-led approach to fossil fuel choice and generation technology became a national political crisis, and focus for the Government's critics.

In October 1992, after failing to agree new fuel contracts with the generators after March 1993, British Coal announced that 31 of their 50 deep mines were to close within 6 months, with the loss of 24,000 jobs (from a total of 54,000).[46] A number of pits were to close within a few days, and, for the first time in the history of the nationalised coal industry, the closures would involve compulsory redundancies. British Coal stated it had been forced into such drastic measures; National Power and PowerGen, it emerged, were only prepared to offer 5 year contracts for 40mt in the first year, and 30mt for the next four, compared to 65mt p.a. under the present contract. BC suggested that this meant that they would be running just 15 pits by 1997.

---

44 ibid:55
45 ibid:54
46 Cmnd 2235, March 1993:1-2

The announcement caused a public outcry, and in response, Michael Heseltine announced a moratorium on 21 of the 31 pits earmarked for closure, pending a 30-day consultation period, during which the Government would undertake a review of British Coal's plans, and also consider some wider issues of energy policy.[47] At the same time, the Trade and Industry Select Committee announced that it would also undertake its own enquiry into the coal crisis.

The Select Committee report, *British Energy Policy and the Market for Coal*[48], was published first, at the end of January 1993. The Committee heard evidence from Michael Heseltine on the events leading up to BC's announcement. He stated that the DTI had been trying to arrange for contracts to be agreed between BC, the generators, and the RECs for much of 1992, but added that the Government's influence on contractual negotiations were now greatly constrained.[49] In his evidence to the Select Committee, the Chief Executive of National Power, John Baker, made brutally clear the approach of the privatised generators to coal contracts. Baker stated that "the electricity industry has no commercial need for long term contracts for coal supplies"[50], and that given the abundance of low-cost coal on the international markets, National Power would ideally prefer just one year contracts with BC, so as to be able to take advantage of any short-term price reductions in the market. At the same time, Baker repeated his view that the more recent independent CCGT plants provided electricity more expensively than existing coal plant.[51]

Much of the debate during the coal crisis inevitably focused on the dash-for-gas. By this time fifteen CCGT stations were expected to come on-stream by 1995, displacing around 25-40mt of coal. A large body of opinion presented to the Trade and Industry Select Committee was now of the view that the scale of investment in CCGT plant was disproportionate to its economic opportunity, and reflected instead problems with the structure for generation in the privatised ESI. The licensing and regulation of CCGT plant was given particular attention at this time. Under the 1991 Electricity Act, all new power plant schemes required Government consent for operation. Since ESI privatisation the DTI had not turned down any applications for consent, arguing that the decision to build and operate power stations was a commercial matter for generating companies.[52]

---

47 DTI Press Notice, 21st October 1992. The other ten pits, he stated, were so clearly uneconomic as to be beyond saving under any circumstances.
48 HC 237, 1992-93
49 ibid:3
50 ibid, Vol.v:85
51 ibid:93
52 ibid, Vol.i:15

The Electricity Act also granted substantial regulatory powers to the Office of Electricity Regulation (OFFER). Each new generator was required to gain a *generation licence* from OFFER, and each domestic supplier a *public electricity supply* (PES) licence. Under the terms of the PES licence, suppliers were required to "purchase electricity at the best effective price reasonably obtainable having regard to all the sources available".[53] In deciding their choice of generator, however, suppliers were also allowed to have regard to other matters, such as "future security, reliability and diversity". To date, the Director General of Electricity Supply, Professor Stephen Littlechild, had approved every application for generation licence he had received. In OFFER's first full annual report in 1991, Littlechild stated that he "did not believe it would promote efficiency and economy, or be in the wider public interest, to use licensing as a barrier to entry ... I have not found it necessary to reject any application for generation licences".[54]

When questioned on this policy by the Trade and Industry Select Committee, Littlechild argued that since National Power and PowerGen, as existing generators, did not require permission from him to build new plant, he did not consider it appropriate to refuse licences to any independent company or REC. Such refusal, he argued, would favour the continued market dominance of the large generators. Littlechild stated that he saw his role as "an attempt to use as far as possible market forces ... not to predecide ... and preconstrain what kind of fuels companies chose to invest in".[55]

A number of independent observers were highly critical of the perceived leniency of the Director General's treatment of the RECs, in failing to give adequate attention to the supply licence requirement on electricity purchasing. Dieter Helm, for example, identified regulatory weakness as an important element in the coal crisis and the dash-for-gas. In his evidence to the select committee, Helm stated:

> There is no doubt that a primary reason why gas stations are coming onto this system is due to a particular act or omission of the regulator. These gas stations do not compete with the two dominant generators for coal, they are on long term contracts on the assumption that the RECs can pass through the cost to their final customers ... There are no independent gas stations in Britain, they are all dependent on REC contracts ... This is vertical integration through contract ... the development of these gas stations is in large part an act of regulatory omission.[56]

[53] Office of Electricity Regulation, *Annual Report 1992*, HC 646, 1992-93, May 1993:8
[54] Office of Electricity Regulation, *Annual Report 1990*, HC 355, 1990-91, May 1991:4
[55] HC 237, 1992-93:68
[56] ibid:55-57

Helm was also highly critical of the conduct of Government in regard to the ESI. He claimed that "current policy ... consists of public rhetoric about competition and, in fact, Government fixing contracts", and referred to "this illusion of competition, illusion of market force, whereas in fact, it has been fixed contracts and fixed regulatory arrangement".[57] Like many other witnesses to the Trade and Industry Committee at this time, Helm called for a greater government direction of energy policy. He stated that: "what we need is some kind of framework for deciding the rough mix of fuels ... that is something the market is unlikely to arrive at ... it is a job ultimately for energy policy and for Government".[58]

Various other parties gave submissions to the Select Committee highly critical of the Government's *laissez-faire* approach to fossil fuel and generation technology choice. Gerard McCloskey claimed that baseload coal-fired electricity generation was "a good deal cheaper" than baseload gas-fired electricity, and suggested that the emerging pattern of generation technology in Britain – in which gas-fired plant was used as baseload supply and coal-fired plant as a mid-merit supply – was unparalleled anywhere else in the world.[59] Professor Ian Fells of Newcastle University was also highly critical of Government energy policy. Fells argued that "the strategy we have at the moment ... leads inescapably to the mess that we are in ... short termism of the worst kind and going for the cheapest fuels that are available".[60] The General Secretary of the Trades Union Congress, Norman Willis, argued that the dash-for-gas was a manifestation of the longstanding rivalry within the ESI between generators and distributors:

> This unprecedented rush has occurred not because gas is more efficient, but because of acute distortions in the energy market engendered by electricity privatisation and deregulation ... Gas-fired capacity is the RECs latest weapon in the long-running battle with the generators for market power and profits.[61]

In his evidence, Peter Rost, a former member of the Energy Select Committee, now representing the Major Energy Users Council, claimed that the scale of the dash-for-gas – and the coal crisis – was an outcome of the Government's failure, ahead of privatisation, to break up the CEGB into more than two generators, so as to introduce more competition into generation. Rost stated that "the result of having only a duopoly ... has led the RECs

57 ibid:56-58
58 ibid:56-58
59 ibid:49
60 ibid:50
61 ibid:127-29

to go into probably more power generation than they would have done if they felt confident they could shop-around in a competitive generation market".[62]

In their report conclusions, the Trade and Industry Select Committee stated that despite substantial productivity increases and cost reductions in recent years, BC pithead prices for coal were still far higher than imported coal. However, they also found that BC were offering future price reductions to the generators such that by 1997/98, their prices would become competitive with imports, so that limited government support during BC's transition to competitiveness was justifiable. The Committee were also highly critical of OFFER for not undertaking an earlier investigation into the economics of the dash-for-gas.[63]

The findings of the Government's own *Coal Review* were published in March 1993.[64] The Review announced that 12 of the 31 pits earmarked for closure were to be reprieved and undergo a period of market testing to judge their competitiveness. On the relative costs of gas-fired and coal-fired plant, the Government argued that "new gas plant is significantly cheaper than new coal plant, and when decisions were made on most of the current tranche of gas-fired stations, it stood to produce cheaper electricity than the existing coal plants".[65] However, the Review also conceded that "more recently the balance of cost advantage has shifted towards existing coal stations". Nevertheless, the Government made clear that they were not prepared to impose any restrictions on investment in CCGT technology, and maintained that "even now, it is quite possible that further gas projects may be economic".[66] Therefore, they stated, the approach to licence applications for new plant would continue unchanged, since "as a general rule, matters such as the need for a generation station, its capacity, choice of fuel and type of plant are the commercial matters for the applicant".[67] The Review essentially amounted to a restatement of the Government's commitment to market-based decisionmaking in the fossil-fuel sector of the ESI:

62 ibid:201

63 At the beginning of the coal crisis OFFER announced that, in order to inform debate on the future of the ESI, they would bring forwards their own review of *economic purchasing* by the RECs. By the time the select committee's report was published, OFFER had already published the early findings of its own inquiry (Office of Electricity Regulation, *Review of Economic Purchasing*, December 1992). As reported in Chapter 5 (5.3.5), OFFER concluded that none of the RECs had breached their supply licence conditions in their involvement in CCGT projects.

64 Department of Trade and Industry, *The Prospects for Coal: Conclusions of the Government's Coal Review*, Cmnd 2235, 1992-93

65 ibid:5. The Government also claimed that on an avoidable cost basis, existing nuclear plant was cheaper than either coal or gas plant.

66 ibid:46

67 ibid:35. The Government also argued that there was little basis for concern over gas reserves; it estimated that there were probably 40 years of economic reserves in the North Sea. It also argued that some of the gas reserves developed for CCGTs would not be recovered for any other use.

> Government should not attempt to impose all-embracing plans about how much energy of what kind should be produced or consumed by whom. The uncertainty of supply and demand, of technology, and above all of the behaviour of people and companies, doom such plans to failure ... Security and diversity of supply are best achieved through the operation of competitive and open markets.[68]

The Review concluded that "despite considerable progress, British Coal proved unable ... to achieve cost levels fully competitive with world coal prices".[69] The Government called for further reform of British Coal organisation and working practices, but accepted that even after these had been achieved, British-mined coal would not become internationally cost competitive in the short term. Therefore, a number of measures were announced to support the British coal industry, including the offer of subsidies for additional deep-mined coal beyond the 5 year contract for 30mt p.a. that National Power and PowerGen had recently agreed to. It was also decided to offer for sale any pit no longer required by BC, and to provide additional 3 year transitional support for the Coal Research Establishment. The Government argued that these measures "should ensure that British Coal remains a competitive fuel for electricity generation".[70] The review also announced the Government's intention to bring forward its plans for the privatisation of British Coal.

6.3.3 Industry Analysis of the Coal Crisis

Interviewed in 1994, Graham Wilman, Major Projects Manager at Norweb Generation, argued that the attention given to the dash-for-gas and the behaviour of the RECs during the coal crisis was misplaced. Rather than a response to the introduction of CCGT technology, Wilman argued, the coal crisis was largely a result of changed policies by National Power and PowerGen:

> When the dash-for-gas was making headlines ... attention was successfully diverted by National Power and PowerGen onto the RECs. They said they were buying less coal because the RECs are building CCGT plants – 'the RECs are putting miners out of work'. But at that time there were only two CCGT plants coming on stream – yet National Power and PowerGen had reduced their coal tonnage's from around 60mt p.a. to 40mt p.a.. That was due to a running down of the massive stockpiles the generators had built up, and [also] because they were buying foreign coal – the flack surrounding the dash-for-gas was rather engineered.

68 ibid:12
69 ibid:20
70 ibid:21

In considering the impact of ESI privatisation on the British Coal, Wilman stated that BC had suffered a backlash from its protected position under nationalisation, during which, he stated, "the electricity industry was used as a vehicle for supporting other nationalised industries". National Power and PowerGen, he suggested, had inherited the CEGB's resentment at being forced to pay "a high cost for coal to support deep coal-mine technology" during nationalisation.

Similarly, Colin Robinson, a long-standing analyst of the industry, argued that rather than resulting from Government free-market dogmatism, the collapse of the British coal industry (in which the coal crisis was only industry the latest episode) should be traced back to government interventionism, and the relations between British Coal and the CEGB in the nationalised ESI.[71] Ironically, suggested Robinson, it was the dominance of coal-fired generation in the nationalised ESI that had led successive governments to continue to promote nuclear power in the 1970s, 1980s, and during ESI privatisation, despite knowing that it was uneconomic:

> Although ... [nuclear power] had been originally conceived in the 1950s and 1960s as means of producing low cost electricity, it became obvious by the late-1970s that nuclear costs always far exceeded initial estimates, and that it was a relatively high-cost means of generation. Nevertheless, governments, concerned at the power which their own policies had given to the mining industry and its unions, continued to promote nuclear fission as a counterweight to that monopoly power.[72]

As early as 1985, Robinson had argued that the retention of British Coal in public ownership after privatisation of the ESI would result in the sharp decline of demand for BC coal.[73] Despite this, he stated, "at the time of electricity privatisation, the Government apparently gave little thought to the likely disastrous impact on the coal industry".[74] Like others, Robinson recognised that the presence of a neo-duopoly in generation after ESI meant that the dash-for-gas was inflated beyond that which would have been seen in a more competitive environment for generation: "the lack of competition in generation ... led to more investment in CCGT plant ... than would otherwise have been likely".[75]

In considering the best response to the coal crisis, Robinson rejected any further protection for domestic coal production, but instead called for further liberalisation of the ESI. He stated that "more competition is needed in electricity as a precondition of any

---

71 Colin Robinson, *Making a Market in Energy*, Current Controversies No. 3, London, Institute of Economic Affairs, December 1992

72 ibid:14

73 Colin Robinson and Eileen Marshall, *Can Coal be Saved?*, London, IEA Hobart Paper No.105, 1985

74 Colin Robinson, *Making a Market in Energy*, op cit:17

75 ibid:21

action which will help the British coal industry", and he proposed the breaking up of National Power and PowerGen into a greater number of competing generators, and the withdrawal of all forms of protection for nuclear power.[76] Robinson concluded that "the Government should follow along the path on which it has already started – which is to de-politicise decisions about the energy industries and to open up individual energy markets to competition".[77]

6.3.4 The Privatisation of British Coal

Despite the transitional support announced in the Government's Coal Review, British Coal continued to contract throughout 1993. By early-1994, eight of the twelve pits "reprieved" by the Government had been closed. In reviewing events since the Coal Review, Alistair Bruce stated that "it is tempting to conclude that, so far as the Government was concerned, the success of the review related more to its ability to defuse a highly sensitive and potentially damaging political issue than its capacity to extend the life of the 'reprieved' pits'."[78]

In January 1994, one year after the coal crisis, the Trade and Industry Select Committee briefly reviewed the state of the coal industry.[79] By this time British Coal's assets had shrunk to 22 mines and 14,800 miners. Despite continued cost reductions, coal-fired generation had continued to be squeezed out of the electricity market as more CCGT plant came on stream (a total 18GW of CCGT licences had now been approved), and also due to the improved performance of nuclear power stations (see Appendix 1, Figures 2 and 3). Coal imports, by contrast, had been reducing. The Chairman of British Coal, Neil Clarke, told the Trade and Industry Committee that "the picture looks gloomy, despite the enormous progress being made, because the markets are being taken away".[80] Clarke also stated that a combination of high coal stocks, and the pressure on generators to act competitively, had meant that the Government's additional measures to support the coal industry announced in the Coal Review had had little effect. He maintained that existing coal-fired steam turbine generation, even with the extra costs of desulphurisation, was cheaper than that from new CCGT plant; he stated that "that argument in financial terms is well-founded".[81] He concluded that the decline in British Coal was "undoubtedly a

---

76 ibid:29
77 ibid:26
78 Alistair Bruce, 'Heseltine's 'reprieved' Pits: Twelve Months On', *Energy Policy*, May 1994, pp432-435:435
79 *British Energy Policy and the Market for Coal: Follow - Up*, HC 188, 1993-94
80 ibid:3 At the same time international coal prices had continued to decline, to historically very low levels (around £1/GJ).
81 ibid:9

consequence of the privatisation of the electricity industry. That has resulted in the profound imbalance of market power where we sell 80% of our coal to two customers, and they have many sources of supply".[82]

The Select Committee also took evidence at this time from the Minister for Energy at the Department of Trade and Industry, Tim Eggar. Eggar rejected the Committee's suggestion that new CCGT plant was by now clearly more expensive than existing coal plant fitted with desulphurisation equipment. When asked to what extent he was prepared to allow gas-fired plant to dominate electricity supply in Britain, he replied that he could "not foresee making arbitrary decisions as to what level should come from one particular productive source", and repeated the Government's view that this was "essentially a matter which has to be decided by the individual decisions of different companies".[83]

At the same time as the Select Committee's inquiry, the legislation enabling the privatisation of British Coal was passing through Parliament. In January 1994, during the second reading of the Coal Industry Bill, the President of the Board of Trade, Michael Heseltine, conceded that had British Coal been privatised earlier – before ESI privatisation – it could have "headed-off at least part of the dash-for-gas".[84] The Labour Industry Spokesman, Robin Cook, argued that the demise of the coal industry was a result of the longstanding Conservative Party vendetta against the British coal industry, which found expression in a "rigged privatisation", which had "opened the door for the dash-for-gas".[85] MPs of both sides of the House recognised that privatisation was coming too late to save any sizeable indigenous coal industry.

As Bruce and Wright described, British Coal's continued contraction and loss of market in 1994 made its privatisation problematic.[86] Bruce and Wright argued that Government inaction "denied coal the chance to establish a more competitive position".[87] During the passage of the Coal Industry Bill through Parliament, it was widely anticipated that much of BC would be sold by management buy-out. The Government invited bids for five British Coal regions. British Coal's English mining assets were sold to the mining

---

[82] ibid:8 By contrast, Scottish Coal enjoyed reasonable mid-term prospects; it had recently completed the signing of a 5-year contract with Scottish Power for increasing tonnages. Clarke argued – as was widely accepted – that this reflected the retention of vertical integration in the Scottish ESI after privatisation.
[83] ibid:16
[84] HC Debates, Vol.235, 1993-94, c714-5
[85] ibid, c723. Cook referred to recent National Power figures which suggested that the cost of electricity from new gas fired plant was now one-third more than that from coal plant now being closed.
[86] Alistair Bruce and Mike Wright, 'Privatizing British Coal: An Evolving Policy Problem', *Energy Policy*, January 1994, pp57-67
[87] ibid:66

company RJB Mining at the end of December 1994.[88] RJB inherited just 15 operating deep mines and 7000 miners, producing a total output in 1994 of 48mt.[89]

By the mid-1990s the decline of coal-fired generation was attracting little new comment, and the Trade and Industry Select Committee's 1995 inquiry into *Aspects of the Electricity Supply Industry*, heard little discussion on this theme. Amongst the few witnesses addressing this issue was Dieter Helm. Helm argued that "the cost of ... [the] artificially fast dash-for-gas is to be measured in the rapid decline of coal".[90] He added that "there is now considerable evidence to show that [CCGT plant] has come into the market at an artificially high rate, at prices higher than those reflected in the costs of operating the existing coal stations, and on a contractual basis which seriously distorts the operation of the market".[91] However, another independent observer of the industry, Colin Robinson, commended the dash-for-gas – claiming that it reflected the opening-up of generation to competition, and greater freedom of choice of fuel and technology. At the same time, Robinson also recognised that there was "some bias against coal" in the post-privatised industry.[92]

In evidence to the Trade and Industry Select Committee in 1996, RJB Mining claimed that they had recently offered the generators new fuel contracts after 1998 to supply coal at a price which compared well to generation costs for CCGT and nuclear plant.[93] They asserted that "unequivocally, coal-based generation offers the best deal for electricity customers in the UK in the medium-to-long term".[94] Nevertheless, in 1997, with the ending of its existing contracts with National Power and PowerGen coinciding with the ending of all REC franchises in April 1998, the prospects for coal-fired generation in the British ESI remained very poor, and there was no prospect for the construction of any new coal-fired steam turbine plant in Britain. At the end of 1997 RJB announced that greatly reduced demand from National Power and PowerGen in 1998 meant that they would be forced into a further closure programme.[95]

---

[88] Peggy Hollinger, 'RJB ends 48 years of Nationalised Coal', *Financial Times*, 30th December 1994, p17

[89] Department of Trade and Industry, *The Energy report Vol.1: Competition, Competitiveness, and Sustainability*, London, HMSO, April 1995

[90] HC 481, 1994-95, Vol.II:87. In a similar vein, Alex Henney entitled his memorandum to the Select Committee: *A Case Study in Regulatory Failure* (ibid:131).

[91] ibid, Vol II:87

[92] ibid:110

[93] *Nuclear Privatisation*, HC 48, 1995-96, published in February 1996 RJB quoted a price of 125p/GJ, equivalent, they claimed, to electricity at 1.8p/kWh, compared to 2.5-2.8p/kWh for CCGT plant, and at least 2.9p/kWh for nuclear plant.

[94] ibid, Vol II:13

[95] In response, the new Labour Government announced a moratorium on the approval of any new CCGT plant proposals. (Christine Buckley, 'Shaft of Light that could be merely a Stay of Execution', *The Times*, 29th December 1997, p46)

6.4 Industrial Perspective: Rolls-Royce/NEI

In an interview carried out in December 1994, Ron Haywood, Director of Engineering at Rolls-Royce Industrial Power Group, Newcastle upon Tyne, reflected on the impact of ESI privatisation on coal-fired steam turbine technology, and on some wider changes to the industry since privatisation. Haywood began by describing the dominant position of Rolls-Royce and Northern Engineering Industries (NEI became part of Rolls-Royce in 1989) in the nationalised British ESI:

> NEI was the supplier for most power station components, coal and nuclear, through Parsons, International Combustion, NEI Nuclear, and others. Going right back, it was principally NEI companies that built Calder Hall. In fast reactors, we supplied replacement heaters and steam turbines at Dounreay in the mid-1980s. We were big. If you take boilers there was ourselves and Babcock. For steam turbines there was ourselves and GEC. That's how it stacked up.

The development of electricity generation plant in the nationalised ESI involved intimate working relationships between the British plant manufacturers and the generating boards – the CEGB and SSEB were even involved in detailed issues of component design. Haywood stated that Rolls–Royce enjoyed "very close relationships with CEGB and SSEB" at this time, and he also conceded that there was very little competition between the major manufacturers: "although everyone would deny it, ... [we] used to operate a 'muggins turn' – if you got the last contract, chances are you wouldn't get the next and so on". Haywood argued that this close involvement was a consequence of the generating boards' statutory obligation to supply:

> Previously the Central Electricity Generating Board, South of Scotland Electricity Board, and Scottish Hydro-Electric Board had a statutory responsibility to supply electricity. I think that is very important to what I am about to say. That meant that when they bought a power station, they were responsible to parliament to ensure that it worked. They had to guarantee the supply of electricity. That forced them into the position of being an 'informed buyer'. It also meant they shared risk with the manufacturers ... [The generators] were power system designers – they developed the design of stations, rather than going to the market and seeing what was available ... This is understandable in terms of their responsibilities. Because they developed the system design, they would go to the manufacturers with very detailed technical specifications. It was very much a risk sharing operation, and – to be honest – from a manufacturers position, quite a comfortable situation.

Haywood then compared this to the very different institutional arrangements for investment in generation technology that emerged after ESI privatisation. He argued that these differences were primarily the result of the removal of any statutory obligation to supply on the part of the generators:

> Once you move to a privatised market things change. Independent power producers emerge, without statutory responsibilities. They are motivated to shed risk. Risk is shed by issuing a detailed specification, [so that] if anything goes wrong the manufacturer can say: 'well, you issued the specification'. The Independent Power Producers, though, go to the market and say: 'we have a need for 'x' megawatts, what can you offer?' Its a beautiful way of shedding risk. You end up with a turnkey contract, and tie up the commercial conditions such that, if anything goes wrong, the manufacturer is responsible. That's the big change. The manufacturers now have to be systems integrators, a role previously performed by the CEGB.

In the nationalised ESI, generation technology R&D effort and expenditure was shared between the CEGB and the British plant manufacturers, under the Power Engineering Research Scheme (PERSC). Haywood stated that "the manufacturers invested, but the CEGB also funded research by the manufacturers ... [and] also did its own research – it comes back to [their role] as a system designer". Comparing this to the pattern of R&D responsibilities after privatisation, he stated that "the utilities are no longer interested in plant design, hence their downsizing. They see it now as the responsibility of the manufacturer".

As well as changing the pattern of institutional responsibilities, Haywood also pointed out that ESI privatisation had had an effect on the *character* of generation technology development: "in R&D, the trend is that efficiency improvements are becoming less important, relative to capital cost and availability. This is a natural consequence of privatisation. Research has become highly focused ...world energy markets are now in transition under [the influence of] privatisation".[96]

From being in a dominant position in the nationalised ESI, Rolls-Royce/NEI, and the other large British steam turbine manufacturer, GEC, found themselves in marginal position in the privatised ESI. CCGT plant orders were based almost without exception on imported gas turbines. Amongst British plant manufacturers only smaller or licensee companies such as John Brown Engineering and Hawker Siddeley offered gas turbines.[97] Privatisation was associated with a sudden switch to overseas equipment manufacturers, building CCGT plants on turnkey contracts. Eric Jeffs pointed out that "there was no ... British experience of building large-frame [CCGTs] ... the main suppliers of steam turbines had for too long concentrated on large coal-fired and nuclear sets to the

[96] The "Industrial Trent" is a 50MW industrial version of Rolls-Royce's 'Trent' aero-engine.
[97] Nick Garnett, 'Confusion for Equipment Makers', *Financial Times*, 29th March 1990, in 'FT Survey of the Electricity Industry', pII

exclusion of others".[98] Only after the liberalisation of gas regulation, Jeffs stated, did the CEGB begin to look at CCGT technology in earnest. He concluded that "the most significant consequence of privatization is the opening up of the market to foreign equipment suppliers".[99]

Haywood traced the origins of improvements in industrial CCGT technology to the development of military aero-engines (as described in 5.2.2 and 5.2.4): "the [innovations] were transferred from Military to Civil and Industrial. The big benefit came from single crystal blades, allowing for higher inlet temperatures. The companies involved were General Electric, Pratt and Witney, and Rolls-Royce". As one of the world's leading turbojet manufacturers, Rolls-Royce played an important role in the development of advanced aero-engine technologies. Rolls-Royce were not involved in the conversion of these technologies for large electricity generation, however, and although they introduced relatively small "industrial versions" of their aero-engines in the early-1990s, their Industrial Power Group had no experience of building large gas turbines for power production, and were not in a position to compete for CCGT orders during the dash for gas. Haywood conceded that "there is no UK designer of large industrial gas turbines".

In an attempt to gain access to the rapidly expanding market for CCGT technology in the early-1990s, Rolls-Royce entered into an alliance with the American firm Westinghouse, who had greater expertise in industrial turbines.[100] Haywood stated that the timing of ESI privatisation – coincident with low gas prices – was the cause of much of the problems faced by British manufacturers:

> The unfortunate thing about privatisation from the point of view of the manufacturers was that the [EC] Directive on the use of gas for base load power generation was rescinded. Once that was done nothing was going to stand in the way of CCGT. Unfortunately it was not a technology that was available from UK manufacturers.

At the same time, Haywood was critical of the Government's failure to anticipate the damage to British plant manufacturers arising from their proposals for ESI privatisation, and for not establishing mechanisms which would have allowed for greater continuity in the transition to a more competitive structure for the industry:

---

98 Eric Jeffs, 'British Gas Turbine Industry Returns Experience to Home Market', *Turbomachinery International*, May/June 1991, pp74-77:74-75

99 Eric Jeffs, 'British Energy Situation After Privatisation', *Turbomachinery International*, May/June 1991, pp60-72:60

100 Fierce competition amongst international plant manufacturers in the 1990s eventually led Rolls-Royce to sell their Power Generation group to Siemens ('Siemens buys Ailing R-R Power Generation Plant', *The Times*, 10th April 1997, p26).

> With hindsight, one of the things that was not put in place in privatisation was a means for transferring resources from CEGB to the manufacturers ... If there had been a lot of contracts in place there would have been a natural mechanism for transferring people, but it didn't happen, because we went to combined cycle ... There was an opportunity lost by not having a mechanism for people to transfer, people with a knowledge of system design ... they went into National Power and PowerGen. The manufacturers were product oriented – turbines, generators, boilers – not station. We have moved that way ... [but] nobody had sat down and looked at the precise relationship between the CEGB and the manufacturers.

Haywood conceded that the dominant position of coal-fired steam turbine technology in British ESI under nationalisation "could be said to have been too much from a diversity point of view". Nevertheless, he maintained that despite their present difficulties, clean coal technologies would be important in the future. He suggested the commercialisation of many clean coal technologies may be achieved "at around 2010, depending on increased gas prices". He stated that "coal is still supplying a sizeable chunk of electricity in the UK ... clean coal technologies are important ... there has to be a future for coal – sufficient work is being done, especially in the US, to ensure it will be available".

Like others disadvantaged by ESI privatisation, Haywood was critical of the Government for failing to intervene to secure diversity of fuel supplies. He argued that "the difficulty in predicting long term fuel prices has two responses: either develop a diversity of supply programme, or just ignore the problem and leave it to the market. The latter is the present UK response". He stated that "my overall feeling about privatisation is that it wasn't well thought through. There was little concern for the implications for manufacturing industry".

Finally, Haywood considered the dash-for-gas in the light of previous episodes of radical changes in electricity generation technology. He argued that there were parallels between the causes of the sudden switch to CCGT technology in the 1980s and 1990s, and the introduction of oil-fired steam turbine plant and nuclear power in the 1950s. He pointed out that "12 GW of oil [fired] plant was built when OPEC was established. Then came Suez, and the UK went for Magnox". Haywood observed that despite its apparent continuity and incremental progression, the development of electricity generation technology in the twentieth century had been greatly shaped by sudden and unpredictable changes in the international political economy of energy supplies. He concluded that "the things that really determine technological change are not continuous, but discontinuous world events. This is the history of the electricity generation technologies ... so much depends on the availability and supply of fuel".

6.5 Privatisation and Steam Turbine Research & Development

The development of advanced coal-fired steam turbine technology attracted almost insignificant funding in the nationalised ESI as compared to nuclear power technology. In 1991 the Energy Secretary John Wakeham told the Energy Select Committee that just 2% of the Department of Energy's R&D budget was spent on coal-fired combustion, compared to 65% on nuclear power.[101] The development work that was undertaken involved two major projects. During the 1980s the CEGB and British Coal jointly funded an 85MW pressurised fluidised bed combustion (PFBC) plant at Grimethorpe. By 1988 the CEGB and BC had spent £28m on the Grimethorpe project. Over the same period, British Gas and Lurgi had spent around £20m on the development of integrated gasification combined cycle (IGCC) technology at Westfield.[102] British Coal was also developing a combined PFBC and IGCC system known as the 'Topping Cycle'. A 1988 review of clean coal technology by the Advisory Council on Research and Development concluded that "for the near-term large scale generation of electricity, none of the fluidised bed designs examined offers an advantage over conventional 900MWe pulverised fuel units".[103] At smaller sizes, the report added, PFBC was "potentially attractive", whilst IGCC technology was said to show "promise of being able to compete with conventional plant with flue-gas desulphurisation".[104]

After 1988, it quickly became clear that the very different structure now being considered for the ESI would carry with it significant consequences for the established pattern of R&D in the industry. For the most part, however, industry insiders expressed little concern on this issue in evidence the Energy Select Committee's inquiry on ESI privatisation in 1988. Typical was the response of Sir Philip Jones, the Chairman of the Electricity Council, who stated that he was "clear that [the companies to be privatised] do all recognise the importance of long-term research".[105] In keeping with its general approach to the coal industry, the Government was not prepared to make any special provisions for clean coal R&D as part of its proposals for ESI privatisation. In January 1989, the Energy Minister, Michael Spicer, stated that "after privatisation, the nature and level of the [CEGB] successor companies research programmes will be matters for them

101 HC 208, 1990-91:218

102 Department of Energy, *Prospects for the Use of Advanced Coal Based Power Generation Plant in the United Kingdom*, Energy Paper 56, London, HMSO, July 1988

103 ibid:36

104 ibid:36

105 HC 307, 1987-88, Vol.III:302

to decide".[106] In July 1989 Spicer conceded that "after privatisation, the electricity industry may focus on near market and operational research and development".[107]

In practice, even before their flotation, National Power and PowerGen had already adopted very different attitudes and policies towards technology development compared to that of the CEGB. This was apparent in the comments to the Energy Select Committee in their inquiry into *Flue-Gas Desulphurisation*, carried out in early-1990.[108] Ed Wallis, the Chief Executive of PowerGen, when discussing his company's approach towards clean coal technology, stated that it was important to "get alongside the technology and spot the winner, and exploit the opportunity when it comes".[109] Rather than undertaking the development of generation technologies themselves, the large generators would in future concentrate on monitoring the efforts of the equipment manufacturers.[110]

Alongside the many proposals for CCGT plant announced during the ESI privatisation process, British Coal announced that they were intending to construct a 150MW clean coal demonstration plant at Bilsthorpe colliery in Nottinghamshire, based on circulating fluidised bed combustion technology.[111] The proposal was welcomed by the supporters of the coal industry, as demonstrating that the underdevelopment of clean coal technology in the nationalised ESI was about to be corrected; it was also thought to represent the first step towards a programme of clean coal generation plants. In Parliament, those MPs who supported ESI liberalisation anticipated the development of a number of similar plants after privatisation. In December 1988, Peter Rost, for example, stated that as well as CCGT technology, independent producers would also wish to develop fluidised bed technology.[112] In the event, however, British Coal withdrew its application for construction of the plant, stating that it had been unable to secure finance, or agreement with the local REC, East Midlands Electricity for output from the plant.[113] In the privatised ESI, electricity suppliers refused to contract for electricity from any plant using generation technology other than the most competitive CCGTs. It was clear that without Government support, no clean coal demonstration projects could progress in the new ESI.

---

106 HC Debates, 1988-89, Vol.146, c90

107 HC Debates, 1988-89, Vol.157, c594

108 HC 371, 1989-90

109 ibid, Vol II:17

110 ibid:19. Wallis also told the Select Committee that he believed that PFBC was now competitive with conventional coal combustion with FGD added on – though not with combined cycle gas turbines. He added that IGCC may also become competitive around the turn of the century.

111 *Power in Europe*, No.73, 10th May 1990, p3

112 HC Debates, 1988-89, Vol.143, c721

113 Maurice Samuelson, 'Cheap Natural Gas Threat to Green Power Station', *Financial Times*, 12th May 1990, p4. Samuelson reported that the capital cost of Bilsthorpe would be around three times higher than a similar-sized CCGT plant.

In mid-1991, just a few weeks after the flotation of National Power and PowerGen, the Energy Select Committee undertook an inquiry into *Clean Coal Technology and the Coal Market after 1993*.[114] The Select Committee surveyed the different types of emerging clean coal combustion technologies, such as fluidised-bed combustion and coal gasification. The Committee reported that *Pressurised Fluidised Bed Combustion (PFBC)* was already commercially available by this time, and by using a combined cycle it provided a 15% efficiency improvement over conventional (pulverised fuel) combustion, with 20% more expected in the second generation of development. *Circulating Fluidised Bed Combustion (CFBC)* was also thought to be important for the future. *Integrated Gasification Combined Cycle (IGCC)* was just beginning its demonstration phase (a 250MW plant was under construction in The Netherlands), but the Committee stated that it had greater medium and long term potential because it provided very low sulphur and nitrous oxide emissions.

The general consensus amongst the witnesses to the Energy Committee was that, although clean coal technologies were not yet cost competitive with either CCGT or conventional coal combustion technology, they would become so around the end of the decade, at around the same time that much old steam turbine plant would be in need of replacement. The submission from Shell UK, for example, stated that "there is a need for large amounts of new generating capacity from the turn of the century, and clean coal technology could play a large part in these developments".[115] Therefore, the Select Committee recommended that clean coal technologies should be supported by Government during the intervening development and demonstration stages, since the market for such technologies would, it argued, develop strongly in the medium term.[116]

Malcolm Edwards, the Commercial Director of British Coal, drew the Energy Committee's attention to the stark asymmetry between nuclear and coal research spending. Nuclear power, he claimed, had attracted almost one hundred times the R&D support given to coal technology over the past decade.[117] Edwards identified a historic failure on the part of the British ESI to develop clean coal technologies ahead of environmental regulation. He attributed this to the long-standing complacency of the CEGB towards coal-fired generation technology:

> The technical interest of the former CEGB was concentrated on developing nuclear, whereas the path for them on developing coal was fairly well mapped out; you bought roughly the same sort of plant you

---

114 HC 208, 1990-91
115 ibid, Vol.:51
116 ibid, Vol I:xxii
117 ibid, Vol II:16

bought ten years ago, only you bought it in a very much larger form, and you got considerable efficiency gain in the process. I think the CEGB was not basically interested in novel methods of coal technology because it did not believe that the environmental problems were going to catch up with it.[118]

The Select Committee also questioned representatives from the CEGB successor companies on their interest in clean coal technology. Both National Power and PowerGen made clear that responsibility for the development of clean coal technologies lay not with them but with the plant manufacturers. They now saw themselves as 'informed buyers', rather than developers, of generation technology – as reflected in their much reduced commitment to R&D compared to the CEGB. Mr J. Webster, the Commercial Executive Director of National Power, stated that, regarding the different types of clean coal technologies, National Power were "not backing any winners", but he indicated that coal gasification technology was the most promising, since it could be readily combined with CCGT technology.[119] Similarly, Dr Alf Roberts, the Commercial Director of PowerGen, stated that his company favoured gasification technology because it offered the possibility of repowering CCGT plant with coal at the end of their initial gas contracts.[120]

One technological option discussed at the beginnings of the dash-for-gas was the retrofitting of a combined cycle turbine on the front-end of conventional coal plant, enabling coal to gain advantage from the general improvements taking place in combined cycle turbine technology. Dr Roberts explained the problems involved with this: "There are very considerable technical risks with [retrofitting] which would have severe implications for economics ... the key to the economics of gas-fired power stations is high availability. They must run all the time and must not be unreliable ... there is a clear commercial risk in attaching new technology to something that is very old".[121] Similarly, Mr J. Webster, of National Power, stated that National Power did not believe that the price of natural gas would rise to "anywhere near the cross-over point that would favour new or even expensive retrofitting of clean coal technology".[122]

On PowerGen's more general attitude to R&D, Dr Roberts told the Committee that his company undertook research in order to "get the best out of present plant, and make informed investment decisions".[123] He stated that "we do not feel it is proper for us to try to pick winners from amongst all the technologies, when it is very difficult for us to

118 ibid:15
119 ibid:164
120 ibid:153
121 ibid:153-4
122 ibid, Vol.II:166
123 ibid:149

benefit, even if we are successful ... The people whose business it is to make profits out of developing a winning technology are the plant manufacturers".[124] Roberts suggested that the removal of the generator's ability to pass on costs was critical in the changes in R&D activity since privatisation: "with the obligation to supply must go the right basically to pass on the cost of meeting that obligation ... that was essentially where the CEGB was. The Government took the view that there was a more economic way of providing electricity to consumers".[125] The restructuring of the ESI also meant that the generators were no longer concerned with diversity of supply issues. For example, when the suggestion is put by the Energy Committee to Dr Roberts that there is a national interest in the setting-aside of, say, 20% of electricity demand to be met from indigenous coal, he replied that "it is for the Government to determine that policy".[126]

A number of witnesses to the Energy Committee at this time identified a particular a problem of support for clean coal technologies in the development and demonstration phases. By 1991, there were no remaining clean coal demonstration projects in the UK. Nevertheless, in his evidence to the select committee the Secretary of State for Energy, John Wakeham, reaffirmed the Government's faith in the ability of private companies to provide what R&D was necessary. Wakeham admitted that the privatised generators were more likely to target their R&D spend on projects that were likely to provide them some clear benefit, but he indicated that he felt that this was a reflection of excessive R&D spending under the CEGB.[127] The Energy Committee was less confident of the adequacy of the Government's provisions for R&D in the industry after privatisation. In their conclusions to their *Clean Coal Technology* report, they stated that they looked forward to "discovering exactly how the Government proposes to ensure the continuation of coal R&D in Britain following the proposed privatisation of British Coal".[128]

In 1991 the Department of Trade and Industry established a Coal R&D Programme, to coordinate research in the development of clean coal technologies. The programme was to be managed under contract by the Energy Technology Support Unit, with only minority funding from Government. By the end of 1996, ETSU reported that there were just under 50 advanced coal-fired power generation projects running under the scheme, with a total DTI contribution of £11.7m.[129]

---

124 ibid:151
125 ibid:154
126 ibid:154
127 ibid:233
128 ibid, Vol I:xxii
129 'Is There a Future for Coal R&D?', *Energy World*, No.247, March 1997, pp16-19:19

In early-1992 the Energy Select Committee again investigated research and development in the ESI as part of its inquiry into the *Consequences of Electricity Privatisation.*[130] The Select Committee found that total R&D spending within the British ESI had more than halved since ESI vesting in 1990, from over £200m p.a. to under £100m p.a.; it now represented less than 2% of sales.[131] Over half of research expenditure was made by the still publicly-owned Nuclear Electric (£50m), the rest from National Power (£26m), PowerGen (£14m), and the National Grid Company (£7m).[132] The Energy Committee reported the closure of two former CEGB research laboratories, and a chronic funding problems elsewhere. Throughout the ESI, the Select Committee found, there was a concentration on short-term development work.[133] The Secretary of State, John Wakeham, recognised that the industry was undergoing a significant reduction in R&D at the centre, but claimed that equipment manufacturers would increasingly compensate for this.[134]

In its evidence to the Energy Committee, the Watt Committee pointed out that privatisation marked a move to building power stations on a turnkey basis, so that National Power and PowerGen no longer needed to conduct basic research into power generation. The Watt Committee expressed concern for the consequences of privatisation on electricity-related research, arguing that "the suddenness of the transition, and the somewhat casual attitude of the Department [of Energy] towards electricity-related R&D has resulted in needless damage to R&D programmes, especially long-term programmes".[135] There was growing concern at this time for the future of British Coal's Coal Research Establishment (CRE). Malcolm Edwards, the Commercial Director of British Coal, told the Select Committee that the CRE would close without greater central government support. Edwards called for Government funding and planning of strategic R&D across the ESI.[136]

In its Coal Review, published during the coal crisis in March 1993, the DTI announced an additional £12m funding for the Coal Research Establishment, spread over three years.[137] In September 1993 the Energy Minister Tim Eggar announced the establishment of a Clean Coal Power Generation Group to co-ordinate the development of components for the clean coal generation technology. At the same time a dedicated 'Topping Cycle' group

---

130 HC 113, 1991-92
131 ibid, Vol I:lvi
132 ibid, Vol II:42
133 ibid, Vol I:lvi
134 ibid:lvi
135 ibid:lvi
136 ibid, Vol III:149
137 Cmnd 2235, 1992-93:10

was set up after British Coal stated it would no longer be interested in developing the technology.[138]

After British Coal was privatised at the end of 1994, the new owners of BC's mines, RJB Mining, in evidence to the Trade and Industry Select Committee, criticised what it stated was a neglect of clean coal technology in the ESI after privatisation, compared to the considerable support given to nuclear and renewable technologies under the non-fossil fuel obligation.[139] The 1995 *Technology Foresight* review of energy technologies confirmed that "priorities for energy R&D have changed significantly" since ESI privatisation.[140] The Report identified three "high priority" generation technologies where there were significant market potential: CCGT, clean coal, and photovoltaic technology.[141]

In an interview carried out in August 1994, Stuart Ffoulkes, of Enron Power Operations, argued that in the case of clean coal technology, a similar missed opportunity to that experienced in the case of CCGT technology was being created by the decline of British Coal since ESI privatisation. Ffoulkes stated that US companies developed CCGT technology in response to the earlier liberalisation of the use of gas for electricity generation compared to Europe, and concluded that "there was no impetus in the UK to develop power generation gas turbines because there was a ban on burning gas in that way ... Europe effectively created no market for CCGT technology for a long time". He then argued that "the same thing will happen, I think, with clean coal technology. There is now no real market for British Coal, so they will get left behind in terms of clean coal technology."

An *International Energy Agency (IEA)* review of the impact of greater competition on innovation in the ESI in a number of countries, published in 1996, concluded that the research efforts of generation utilities had been greatly reduced under fierce competition in recent years. The IEA report stated that "as generators are unsure which customers they will be serving at the expiration of short term generation contracts, there is little or no incentive for them to engage in RD&D efforts which aim to reduce the cost or raise the efficiency of generation technologies over the longer term".[142] As part of the IEA report, Jeffrey Skeer compared the experiences of ESIs in different OECD countries; he stated

138 Department of Trade and Industry, *Clean Coal Technologies: A Strategy for the Coal R&D Programme*, Energy Paper 63, London, HMSO, 1994:31

139 *Nuclear Privatisation*, HC 48, 1995-96. Under the most recent NFFO round, argued RJB, renewables were providing electricity at an average 4.5p/kWh, whereas clean coal technologies, they claimed, would achieve unit costs of 3.0p/kWh in the near future.

140 Office of Science and Technology, *Progress Through Partnership: No.13 Energy*, London, HMSO, April 1995

141 ibid:3

142 IEA/ OECD, *Competition and New Technology in the Electric Power Sector*, Paris, 1996:9

that the UK was the only country among those studied to have had "extensive experience" with increased competition.[143] Skeer reported that "whereas the UK's electric sector had a time horizon of five to ten years for evaluating RD&D projects at the time it was privatised, most projects in today's nearly fully competitive environment are evaluated with a one or two year time horizon", and he concluded that "only RD&D efforts with a nearly immediate market payback can be considered".[144]

Another analysis of the British ESI in the same IEA report was made by J. A. Walker, the Executive Director of EA Technology – a part of the Electricity Association with responsibilities to coordinate research activity in the privatised ESI. Walker stated that since privatisation, "the balance of spending in R&D in the UK [ESI] has changed quite dramatically, driven both by the financial concerns of the electricity companies, and the legislative and regulatory pressures following privatisation".[145] Walker stated that "prior to privatisation, the research performed [in the UK ESI] ... arose in the main from 'technology push'"[146], but that since privatisation, generation technology development was much more a response to 'market-pull. He argued that R&D activity in post-privatised ESI in Britain was under pressure because private ownership had created "a much greater drive for cost reduction", and R&D programmes in particular were being "analysed and scrutinised in a search for relevance and value for money".[147]

6.6 Summary and Review

6.6.1 Steam Turbine Technology and Privatisation

From the mid-1950s onwards, the dominance of coal-fired steam turbine technology was in-part a reflection of the political management of the energy industries, as the ESI was used by various governments to provide a protected market for the British coal industry (3.3.4). After 1979, under successive Conservative Governments hostile to the NUM, this continued support derived from a reluctant recognition of political necessity. After the 1987 general election, with the NUM disempowered, it became clear that the Government saw this support ending with ESI privatisation, and it was unprepared to make any concessions to the coal industry in its privatisation proposals (6.2). The Government

[143] Jeffrey Skeer, 'How is Electric Power Technology Development Affected by Growing Power Sector Competition?, in *Competition and New Technology in the Electric Power Sector*, Paris, IEA/OECD, 1996, pp7-12
[144] ibid:9. Skeer also stated that, whilst the UK had experienced the most dramatic changes of all OECD countries, more gradual R&D spending cuts had taken place in the US and Australian ESIs.
[145] J. A. Walker, 'The Influence of Privatisation on the Direction and Scale of Research and Development: Recent UK Experience', in *Competition and New Technology in the Electric Power Sector*, Paris, IEA/OECD, 1996, pp69-76:69
[146] ibid:72
[147] ibid:72

offered no protection for coal-fired generation in their privatisation proposals, and in their 1988 White Paper, they readily anticipated the emergence of "new types of power station" (4.2.2). At the same time, such was the established domination of coal-fired plant in the British ESI, and such were the apparent technical and economic barriers to any challenge to this dominance, that there was little or no expectation of any serious threat arising from advances in generation technology.

In the mid-1980s, the CEGB and GEC had developed proposals for the construction of new coal-fired steam turbine plants which were a continuation of incremental improvements in economies of scale and thermal efficiency, the development pathway that had characterised coal-fired steam turbine technology for most of the century. By 1988 this new generation of larger and improved coal-fired steam turbine plants was ready for implementation.

In debate on the likely impact of ESI privatisation in 1987 and 1988 (6.2), whilst there was considerable recognition of the threat presented by privatisation to the dominant position of British Coal, there was very little suggestion that there would be any significant erosion of the dominance of coal-fired steam turbine technology – the dominant technical form of electricity generation in Britain since the early-twentieth century. Concern for coal was overwhelmingly focused on the threat to the British mining industry of cheap coal imports. This was clearly reflected, for example, in the views of the CEGB's Chairman Lord Marshall, when he told the Select Committee that "the major issues will be about the use of coal and whether coal is imported or we use British coal". The Energy Secretary, Cecil Parkinson, maintained that "seventy to seventy-five per cent of all our future electricity is going to come from coal" (6.2). Although they made some mention of CCGT, this was also the dominant view expressed in Area Board evidence to the select committee (5.3.2). Robert Peddie, a prominent independent advocate of liberalisation of generation at this time, expressed his opinion to the Select Committee that the coal industry "would be capable of retaining the bulk of the power stations market" after privatisation (6.2).

Even the CEGB's critics and rivals apparently saw little alternative to coal-fired steam turbine technology, and the early independent power plant schemes developed in 1987 and early-1988 were mostly based on the recommissioning of former CEGB coal-fired steam turbine plant. Only a few independent analysts, such as David Andrews, and Peter Rost, recognised that ESI privatisation represented a significant technological threat to coal, and suggested that there was a pent-up demand for alternative technical forms of generation (5.3.2). Significantly, both Andrews and Rost had reached their conclusions after many years of frustrated efforts to introduce small-scale gas-fired CHP plant in the

British ESI, in the face of overwhelming CEGB opposition. Within the ESI insider institutions, no such awareness of the vulnerability of dominant technologies was evident.

The commitment to established forms of generation technology in Britain was ended only after the issuing of the EC's Large Combustion Plants Directive in June 1988. Before this, the challenge to established generators was mostly taking shape within the technological conventions of the British ESI, using coal-fired steam turbine plant, the favoured technical forms the first independent power proposals (5.3.2). Only after the LCP Directive placed them under a greater relative burden relative to the established generators, did the embryonic independent producers make the radical switch to gas-fired generation technology (5.3.2). This was indicated by Graham Wilman's account of the Roosecote project – the first CCGT scheme in Britain (5.4.1). Without the issuing of the LCP Directive at a critical time coincident with the liberalisation of the British ESI ahead of privatisation, although CCGT technology would have gained some use, it is likely that much of the independent plant introduced in the British ESI just after privatisation would have been based on the much more familiar technology of coal-fired steam turbines. In the event, however, coal-fired plant was unable to compete with CCGT technology on economic or environmental grounds, and it was abandoned with unexpected speed.

During the ESI privatisation process itself, the previously powerful coal industry institutions exercised little or no influence. In the regulatory and contractual negotiations that took place throughout the ESI in 1988 and 1989, BC was unable to secure the continuation of its primary position (6.2). The three year contracts for reduced tonnages were only agreed to by National Power and PowerGen after considerable pressure from the Government – acting, according to Dieter Helm, to delay any dramatic contraction of the British coal industry until after the 1992 general election (6.3.1). By the end of 1989, coal-fired steam turbine technology – always the dominant technology of electricity generation in Britain – was institutionally weakly represented and essentially abandoned by Government. Given its poor economic and environmental competitive position with gas-fired generation technology, there were now no significant barriers to prevent its demise in the post-privatisation period.

Ultimately, the three-year contracts established with National Power and PowerGen in 1989 proved to do little more than postpone British Coal's decline, but for a time they appeared to have headed off what was seen to be the main threat to the British coal industry during the ESI privatisation process – cheap coal imports. As late as July 1991, this was identified by the Energy Select Committee as "the most serious threat to British Coal's existing markets" (6.3.1). The consensus at this time was that restrictions on the availability and price of natural gas would limit the impact of CCGT technology on the

ESI. In his evidence to the Select Committee at this time, the Energy Secretary John Wakeham repeated the Government's public view that "British Coal has an excellent future" (6.3.1). Just over six months later, the Energy Committee recognised that gas-fired generation was a more serious threat than that from imported coal (6.3.2).

In considering the coal crisis of late-1992 and early-1993, it is difficult to separate-out the institutional and political manipulation of events, from the underlying technical, economic, and institutional forces that were driving changes in electricity generation in the post-privatisation period. The coal crisis was a supremely *political* event – precipitated by British Coal in order to draw attention to its difficulties, and informed throughout by the vested interests of Government, National Power, PowerGen, the RECs and others. At the same time, however, the coal crisis was also a reflection of the underlying institutional and economic forces driving technological change in the ESI by the early-1990s.

The liberalisation of the RECs upon privatisation meant that they, and in-turn the major generators, were unwilling to enter long-term contractual arrangements. Even after considerable public outcry during the coal crisis, the Government was unwilling to offer any significant support for the British coal industry, except where it perceived that it might be politically damaging not to do so. In particular, the Government made clear that it was not prepared to intervene in the dash-for-gas, nor remove any of their protection of the nuclear industry ahead of their nuclear review. As Bruce concluded, the Government's actions at this time "related more to its ability to defuse a highly sensitive and potentially damaging political issue" rather than any significant intervention in fuel and technology choice in the ESI (6.3.2).

For some industry analysts, such as Dieter Helm the changes affecting coal-fired generation technology in the ESI privatisation had primarily *political* rather than *economic* origins (6.3.2). Ultimately, however, technical, economic, institutional and political influences were all deeply intertwined in the rapid decline of coal-fired steam turbine generation technology after ESI privatisation. The development of CCGT technology meant that seemingly insuperable technical and economic barriers to challenging steam turbine technology were overcome. Before the dash-for-gas became a reality, the technical and economic barriers on coal imports were repeatedly invoked by Government, in their rejection of the need for more direct support for the coal industry – see, for example, the comments of Cecil Parkinson in Parliament in March 1988 (6.2.1), and again in April 1989 (6.2.2).

At the same time, the creation of a distorted market for generation, dominated by the neo-duopoly of the CEGB's successors, encouraged uneconomic investment in new CCGT plant. Nevertheless, even after the threat to steam turbine technology became clear, a Government with deep-rooted hostilities to the coal industry was unprepared to intervene. Clearly, whilst it reflected an economic and environmental preference in the partially-liberalised ESI for gas-fired generation, the turn away from coal-fired steam turbine technology was also substantially motivated by institutional rivalry, and Government partisanship.

6.6.2 Steam Turbine R&D and Privatisation

The organisation of R&D that had developed in the ESI under public ownership was centred on the CEGB, an organisation which was largely created for such a role. However, although it dominated the nationalised ESI in terms of installed capacity, fossil fuel steam turbine technology occupied only a marginal position in the R&D efforts and technological interests of the CEGB, as suggested by British Coal's Commercial Director, Malcolm Edwards, in evidence to the Energy Select Committee in 1991 (6.4). At the same time, the CEGB was central to the design of steam turbine plant technology. As Ron Haywood described, even in detailed design work, the CEGB was closely involved with the plant manufacturers (6.4). Although Haywood claimed that the CEGB's statutory obligation to supply in the nationalised ESI had led them to assume the role of "informed buyers" (6.4), in practice their involvement in the development of generation technology went much further, and cannot be explained simply by reference to its statutory responsibilities. (It would have arguably been possible to meet these by adopting a truer position of informed buyer, as assumed by National Power and PowerGen after privatisation.) Instead, this close involvement requires explanation within an understanding of the historical evolution of the British ESI. As described in 3.3.3, the CEGB was created in the 1957 Electricity Act so as to assume a leading role in the development of generation technology, and to advance more rapidly the adoption of advanced techniques in British plant design. As well as reflecting immediate concerns in the mid-1950s, this was also motivated by a long-standing concern within the British ESI. From its origins, the growth of the British electrical plant manufacturing industry, had been frustrated by restrictive legislation and had never grown to rival its Continental and American counterparts (3.2.2).

After 1957, the senior managers of the CEGB – overwhelmingly electrical and nuclear engineers – were allowed to shape the development of electricity generation technology in Britain largely in accordance their own technical preferences, rather than in response to international changes in technology and fuels. Other than the CEGB and AEA, the only other major influence on generation technology development in this period was Government intervention to ensure supply diversity and support domestic industries. As the Plowden Committee identified, however, the CEGB's strength in plant design had its counterpart in weakness and dependency on the part of the British plant manufacturers. The Plowden Committee also pointed out that any weakening of the CEGB's position carried potentially damaging consequences for the electrical plant industry (3.6.4). Given the impregnable authority of the CEGB, this could be overlooked. In retrospect, it led the manufacturers to develop a false sense of security, and a dangerous insularity, reflected in a commitment to internationally uncompetitive domestic technological designs, such as the AGR (3.5.3). It also meant that the manufacturers shared the CEGB's unresponsiveness to developments in gas-fired generation technology (5.2.3).

Along with the CEGB, the British plant manufacturers remained heavily committed to the further development of large steam turbine plant in the mid-1980s. The dangers of this concentration of research effort were only revealed by the ESI privatisation process from 1987 onwards.

The Government made few provisions for R&D in its proposals for ESI privatisation, and it appears to have considered the reduction of research spending in the industry was an inevitable part of liberalisation. After the 1988 White Paper made clear the disempowerment of the CEGB, the seemingly powerful technocentric culture of the ESI that had dominated R&D activity in the nationalised ESI, proved remarkably fragile. Established research programmes, predicated on the presence of a monopoly generator with the means of passing-on costs, were ended, and investment in the industry was quickly focused on short-term revenue earning activities. Aggregate spending on R&D in the British ESI collapsed after privatisation, in large part as a result of the ending of the fast reactor research programme, but also because of generating companies' unwillingness to support programmes for near-commercial clean coal technologies (6.5).

Once the CEGB had been broken up, the vulnerability of the British manufacturers to international competition was rapidly exposed. As both Eric Jeffs and Ron Haywood pointed out, the post-privatisation dash-for-gas was based on technology that was largely unavailable from the British manufacturers, and had to be imported (6.4). Whilst Haywood argued that some remedial action should have been taken by Government to allow the British plant manufacturing industry a smoother transition to ESI liberalisation, the Government was more concerned by this time to foster independent generation by whatever means possible – particularly within an ESI structure that it recognised was likely to inhibit new entry. After decades of protection by Government and the CEGB, the British plant manufacturers were wholly ill-prepared for the technological, economic, and institutional context for generation technology investment introduced in Britain in the late-1980s.

The rapid run-down of fossil fuel R&D effort in the British ESI after privatisation reflected that fact that the major generators, who had hitherto occupied a dominant position in R&D activity (financially and institutionally), now saw themselves as nothing more than 'informed buyers' of plant. Despite a strong body of opinion, from within and outside the industry, that clean coal technology had an important medium and long term role in the British ESI, its extra costs as compared to gas-fired generation technology meant that it was unable to attract significant funding or institutional backing in the post-privatised ESI. Under demanding financial conditions, proposed schemes that were unable to secure a guaranteed market – notably those involving the use of technologies other than CCGT, such as clean coal technology – could not raise finance, and were abandoned.

The changes to ESI R&D in Britain, although more extreme than elsewhere, reflected international changes in innovation in electricity generation technology. The worldwide trend towards privatisation and liberalisation of electricity supply utilities in the 1990s was associated with a shift towards international trade in generation technology, and to turnkey power plant construction contracts. As a result, R&D was increasingly the domain of a few international electrical equipment manufacturers, with generating and supply utilities assuming the role of informed buyers of technology developed on this international stage.

CHAPTER 7:

TECHNOLOGY STUDIES THEORY AND

THE ESI PRIVATISATION PROCESS

7.1 Introduction

This chapter returns to the concepts and models from the technology studies literature introduced in Chapter 2. They are discussed here in the context of the changes to generation technology within the British ESI associated with privatisation, as examined in previous chapters. In each case, a two-way discussion between technology studies theory and the evidence suggested by the ESI case study has been attempted: the various theories are considered in terms of the insights they provide in to the changes experienced by the British ESI, and at the same time, the ESI case is used as a test of the strengths and weaknesses of the assumptions and postulations of the various theories and models.

Section 7.2 considers notions of technological autonomy and determinism, particularly as developed by Langdon Winner, and applied to nuclear power technology (as introduced in Section 2.2). Section 7.3 returns to Thomas Hughes' model of sociotechnical systems (introduced in Section 2.3). Section 7.4 assesses micro-level constructivist and actor-network approaches (introduced in Section 2.4). Section 7.5 considers intermediate/institutional approaches (introduced in section 2.5). Finally, Section 7.6 provides a summary of the chapter, and offers a broader comment on the of the insight offered by a social-shaping view of technological change as applied to the British ESI privatisation process.

7.2 Technological Autonomy and Determinism in the ESI

7.2.1 Introduction: The Return to Autonomy and Determinism

At the end of Chapter 2, it was argued that an autonomous or determinist perspective offered an inadequate perspective for analysing the process of technological change. In particular, such approaches were thought to be inherently limited because of their high-level generalisation, investment in the force of technology itself, and their neglect of the various social forces underpinning and shaping technological change (2.6.1). At the same time, however, it was recognised that autonomy and determinism have been popular and recurrent themes in the analysis of technological change, particularly in the case of electricity generation technology – suggesting that they capture something of the character of technological change in the ESI. On this basis, it was decided that they merited further consideration in the context of the present study.

7.2.2 Autonomy and Determinism in the ESI before Privatisation

Before the 1920s, the dominant influence on generation technology within the British ESI appears to have been municipal authority control of public service provision, rather than any technological imperatives (3.2.1). The first technologies of electricity generation fitted into the established organisational and legislative framework for locally-provided public services. Only after the introduction of steam turbine generators and AC transmission technology at the turn of the century were the first obvious techno-economic imperatives impressed on the industry. Hennesssey credited these innovations with "destroying the technical rationale" of the established institutional and legislative framework for the British ESI (3.2.1). In reality, the subsequent development of the industry provides no support for simplistic technological determinist interpretations. The emergence of the steam turbine as the dominant form for electricity generation was not only a result of the innovations of Parsons and others, but reflected also growing demand for electricity, and other factors such as the high price of real estate (3.2.1). In the British ESI in particular, techno-economic imperatives clearly did not exert a deterministic influence, as the desire for larger franchise areas and larger-scale steam turbine plant was frustrated before the 1920s.

The 1926 Electricity Act marked the end of the age of local government control of the British ESI, and ushered in a period of progressive centralisation and rationalisation. The development of the British ESI during the interwar years has been interpreted as a response to the technological imperatives of coal-fired steam turbine generation technology and the national transmission grid. Undoubtedly, there is a much clearer case for technological determinism and autonomy in the interwar period than before; Hughes stated that "the high momentum systems of the interwar years gave the appearance of autonomous technology" (3.2.2). In practice, however, the interwar expansion of the industry cannot be explained solely by recourse to the imperatives of generation and transmission technologies. The timing of the rationalisation and expansion of the industry was clearly as much a response to the legislative reform of the industry – after the 1925 Weir Report made clear the urgent need for reform – as any immediate technological developments. The growth of the ESI in the interwar years also involved the greatly accelerated diffusion of electric power throughout the economy. It was also predicated on central government support for a nationally-integrated supply system, and was twice greatly accelerated by the demands of war. Nevertheless, although autonomous and determinist explanation of the interwar expansion of the British ESI remain untenable, the years after the mid-1920s did at least see the ESI grow in accordance with the techno-economic imperatives of certain generation technologies, rather than opposing them, as had been the case before the 1920s. As Hannah and Hughes both pointed out, the interwar period also saw the development, for the first time, of a 'technocratic tradition' within the industry (3.2.2).

The trend to rationalisation and centralisation culminated in the nationalisation of the British ESI in 1947. For many, nationalisation was seen as a logical progression of the development of the industry under the direction of techno-economic imperatives (3.3.1). The postwar Labour Government promoted ESI nationalisation in particular as an appropriate response to the imperatives of electricity technology. Douglas Jay, for example, argued that technical progress in the ESI could only be achieved through the integration of the industry under government control (3.3.1). Throughout the postwar period up to the late-1980s, successive governments and industry institutions would repeatedly invoke similar such technological imperatives in support of various reforms to the ESI, or particular forms of generation technology. However, as Donald MacKenzie suggested, (2.5.4), rather than assuming that this offers evidence for technological determinism, the invocation of technological imperatives in this way requires consideration of the particular institutional and political interests involved (3.3.1).

For the first decade after nationalisation, the ESI was dominated by a security of supply crisis, and generation technology design remained essentially unchanged from the 1930s – restricted by Government edict and BEA conservatism (3.3.1). Thereafter, however, for a thirty year period from the mid-1950s to the mid-1980s, technological determinism appears to have had a powerful presence in the industry. The reorganisation of the industry in the mid-1950s was largely a response to certain technological imperatives. The dissolution of the CEA and the creation of the CEGB was justified in large part because of the perceived need give advanced technology a much higher profile in the ESI, and in particular, to accommodate an expanded programme of nuclear power (3.3.3). The 1956 Herbert Committee called for greater orientation towards high-technology within the industry, in order to both improve the design of conventional steam turbine plant, and also, to better meet the "technical problems ... in nuclear power engineering" (3.3.3). Government policy statements and Parliamentary debate on the restructuring of the industry at this time were infused with technocentrism and the advocacy of technocracy. The Minister of Power, Geoffrey Lloyd, justified the reforms of the 1957 Act on the basis that "if we are to obtain all the benefits of nuclear power" there was a need to "speed up the operation of the [ESI] machine" (3.3.3). Lloyd also offered a autonomistic vision of nuclear power with his anticipation of a time when "there is not enough baseload for the number of atomic energy stations". For the Labour opposition, James Callaghan similarly argued in a deterministic fashion that the ESI "must be built around ... [the nuclear] programme" (3.3.3).

In retrospect, however, rather than a demonstration of technological determinism, the prevalence of technocentrism in debate on the industry at this time can be seen as a reflection of particular economic, political, and cultural circumstances. Government support for the initial nuclear programme was largely a response to fears for the adequacy of coal supplies, and intense concern for supply security (3.3.2), and broader issues of sovereignty and national pride, related to the Suez Crisis (3.3.3). In such a context, the Government willingly reorganised the industry around the perceived techno-economic imperatives of nuclear power. The CEGB was created as an overtly pro-nuclear power, technology-led organisation. Although it only ever provided a small part of the CEGB's output, nuclear power technology dominated the ESI's technology strategy and R&D spending up to the late-1980s. Thereafter, coal-fired steam turbine technology, whilst dominant in terms of capacity installed and power generated, was secondary in the CEGB's technological interests (as Malcolm Edwards later suggested, 6.5).

At the same time, it is misleading to represent nuclear power technology as simply a reflection of economic and political circumstances without any consequences for the industry. The introduction of nuclear power was predicated on a certain degree of technocracy amongst industrialists and politicians, but having been become established at the centre of the ESI from 1958 onwards, the imperatives of nuclear power exerted a powerful influence thereafter, and it greatly accelerated the developing technocratic tendencies in the industry – seemingly offering support for Winner's suggestion of that inherently political technologies become autonomous once established. Certainly, the Labour Government of the 1960s offered overtly technocentric support of nuclear power technology, as demonstrated by its conclusion, in 1967, that a regular sequence was desirable to realise the "full potential" of nuclear power technology (3.3.4).

The oil-shocks of the 1970s provoked an exaggerated return to security of supply fears, and the reinforcement of technology-led corporate planning. The technocentric response to the energy crisis was demonstrated by Walter Marshall's explicit omission of "non-technological factors" in ETSU's 1976 review of energy technology (3.4.2). Marshall's implicit assumption here was that the process of technological change could be dictated by 'internal' technical matters alone.

The powerful influence of nuclear power technology on ESI organisation in the 1970s dominated the thinking of the 1978 Plowden Committee. The Plowden Report was informed throughout by a technocentric perspective. It called for the unification of the industry on the basis of a series of techno-economic imperatives (3.4.3). The rejection of the Plowden Committee proposals by the new Conservative Government after 1979 confirmed that rather than a straightforward result of technological determinism or the autonomy of nuclear power, the Committee's views were a product of prevailing economic circumstances and political/policy ideals.

In retrospect, the appearance of the autonomy of nuclear power in the British ESI from the late-1950s to the late-1980s was made possible because of the stability of the institutional and legislative framework for the industry, and the continuity of government support for the technology. However, rather than a real demonstration of autonomy or determinism, it is more accurate to state that, in an industry without exposure to competitive market forces, and in supportive institutional and political circumstances, the techno-economic imperatives of nuclear technology were *allowed* priority over other considerations. In effect, the illusion of technological autonomy and determinism was deliberately created and sustained. For central government, this illusion had its advantages: it provided a technical rationale for the nuclear power programme, and disguised any more overtly political motivations.

By the 1970s, however, the economic and political stability of the ESI was becoming increasingly undermined (3.4.1). Even at the height of technocentrism in the wake of the energy crisis, a number of industrial and political voices were promoting a decentralised market-based approach to energy policy (3.4.2). The 1970s also saw increasing public opposition to the nuclear power programme. These trends continued in the early-1980s, but for as long as Government support for the nuclear power programme and the CEGB continued, and the structure of the industry remained basically unchanged, the illusion of technological autonomy and determinism in electricity generation could be sustained.

7.2.3 Autonomy and Determinism and ESI Privatisation

Privatisation quickly brought about the demise of technocracy in the industry – and with it, the discrediting of any suggestion of technological autonomy and determinism. Winner's argument that once established, nuclear power technology is able to "justify the adaptation of social life to technical requirements" was confounded by the Government's conduct in the ESI privatisation process. The CEGB's attempts to maintain its monopoly status by invoking supposed technological imperatives (4.2.1) were largely overridden by the Government's determination to introduce competition into generation. By first designing a structure for generation in which costs could not automatically be passed on, and – after it became clear that their proposals could not secure the successful privatisation of nuclear plant – by cancelling the proposed new nuclear power PWR programme, the Government chose to give priority to their policy commitment to privatisation, over and above their longstanding support for nuclear power. At this point, the supposed autonomy and determinism of nuclear power technology was revealed as an illusion, a *paper-tiger*. Rather than offering support for claims for the autonomy of nuclear power, the events at this time reinforce the point made by MacKenzie and others that all technologies are dependent upon their surrounding institutions (see 7.5.3, below).

The 1988 White Paper on ESI privatisation amounted to a substantial rejection of the supposed technological imperatives for the retention of the existing structure for the industry (4.2.2). The splitting up of the CEGB and the transfer of grid ownership to the RECs meant that Government's desire to liberalise the generation sector had prevailed in the face of CEGB's opposition, and techno-economic imperatives could no longer be seen as determining the structure of the industry. The White Paper also contained unprecedentedly critical remarks about the CEGB. In Parliament, the Energy Secretary of State, Cecil Parkinson, made clear that he shared the views of the proponents of liberalisation of the ESI, and stated that there was "no natural monopoly in electricity generation" (4.2.2).

Nevertheless, nuclear power technology continued to exert a powerful influence on the ESI privatisation process. As Cecil Parkinson conceded, the Government's proposed organisational structure for generation after privatisation was, in large part, a response to the techno-economic imperatives of nuclear power technology (4.2.3). By devising a structure which, they believed, would enable the privatisation of nuclear power alongside conventional plant, the Department of Energy had accepted the CEGB's arguments for the retention of a single dominant generator with considerable market protection (4.2.3). However, rather than a demonstration of technological determinism, the building of ESI privatisation around nuclear power – what the Energy Select Committee referred to as the "the nuclear tail ... wagging the ESI dog" (4.2.3) – stemmed from a political decision, by Government, to attempt the privatisation of nuclear plant at the same time as the rest of the industry. As a number of independent analysts made clear in 1987 and 1988, the Government could have instead chosen to retain nuclear power plant under public ownership, and to have implemented a much more competitive structure for the non-nuclear ESI, featuring a number of competing fossil-fuel generators (4.2.3).

The withdrawal of nuclear plant from privatisation in 1989, although provoked by the techno-economic properties of nuclear power, was again ultimately a political choice by Government. As a number of independent observers of the industry suggested before and after 1989, the privatisation of the AGR plants and the future of the PWR plant programme could have been secured, had the Government been prepared to meet National Power's demands for what Energy Secretary John Wakeham referred to as "unprecedented guarantees". Wakeham himself stated that the Government had decided that they were "not willing to underwrite the private sector" (4.3.2). Kleinwort Benson, the Department of Energy's investment analysts, also argued that the Government had ultimately refused to "pay the price" for privatising nuclear (4.3.3). Rather than a demonstration of technological or economic determinism, therefore, the withdrawal of nuclear may be described as a result of techno-economic pressures given sanction by Government.

The CEGB Chairman Lord Marshall's reaction to the cancellation of the PWR series was very much a confirmation of his personal technocentric commitment to PWRs. In announcing his resignation as CEGB Chairman and Chairman Designate of National Power in December 1989, he justified his role in the ESI solely in terms of the construction of nuclear plant, rather than any more general responsibilities (4.3.3). In the last-ever CEGB Annual Report, published in December 1989, he described the cancellation of the PWR programme as "a tragedy for civil nuclear power in the UK, and a personal disappointment too large to describe" (4.3.3) At the beginning of the privatisation process the ESI was still essentially under the control of powerful figures who shared a very strong commitment to nuclear power. The powerful individual influences of both Thatcher and Marshall were undoubtedly significant factors in the Government's and CEGB's failure to anticipate the unworkability of the White Paper proposals (4.3.3).

The institutions that had promoted nuclear power under nationalisation had been largely disempowered by the Government's proposals for liberalisation, and the dominant organisations in the new ESI – the RECs, National Power, and PowerGen – were all to be subject to some competitive pressure. As Cecil Parkinson stated in early-1989, the Government's proposals for the ESI meant that "in future ... [nuclear power] will have to justify its existence" (4.3.1). The arbiters of investment decisions in generation technology would no longer be the engineers and managers of the CEGB, but rather private financiers and shareholders, who applied an *economic* rather than *technical* test to generation technologies. Marshall was unwilling to accept that generation technology choice was no longer to decided by technical issues and experts alone. Throughout the privatisation process, he discussed the merits of the Government's proposals almost exclusively in terms of their impact on the prospects of the PWR programme. In his valedictory speech to the British Nuclear Energy Society in November 1989, he still equated the long-term health of the ESI with the degree to which it invested in nuclear power (4.3.3). Marshall himself never wavered in the assumption that, so long as they were freed from "government interference" or "short-term market considerations", nuclear engineers could be relied on to "get the technology right", and axiomatically, do what was best for the country. Under such an assumption, nuclear power technology became an end in itself. In this way, for Marshall and others, it is accurate to say that nuclear power technology *did* have an autonomous and deterministic character.

Following its withdrawal from privatisation, although it continued to benefit from the protection of the Levy and NFFO, nuclear power occupied a very different position within the ESI as a whole. Rather than any shaping of the industry by the technical imperatives of nuclear power, it makes more sense, after 1989, to discuss the shaping *of* nuclear power technology – like other forms of generation technology – by market forces and electricity supply institutions. Whilst this was most clearly demonstrated by the dash-for-gas (CCGT technology, with its relatively low capital cost and short lead times, was particularly well suited to the new principles governing the industry), it was reflected also in changes to the nuclear industry. In other words, from 1990 onwards, rather than having the ESI built around it, nuclear power had largely to conform to the economic and financial imperatives governing the ESI as a whole – albeit from a highly privileged position as compared to the rest of the industry.

After 1987, although they continued to offer a technocentric manifesto, formerly powerful figures such as Lord Marshall and Alistair Cruickshank were no longer able to impose their vision on the Government and the wider ESI. Far from being autonomous and deterministic, the powers residing with the nuclear industry were revealed by the privatisation process as having been dependent throughout on Government approval and support. Whilst government shared some of the ESI's technocentrism for much of the postwar period, their support for nuclear power also derived from wider considerations, such as the power of OPEC and the NUM, which were entirely unrelated to the imperatives of nuclear power technology itself. In reality, a range of political and economic factors were critical to the establishment and maintenance of the British nuclear power programme, and the removal of these supports during the ESI privatisation process provided a powerful revelation that any suggestion of technological determinism and autonomy was misleading.

7.2.4 Conclusion: The Fallacy of Autonomy and Determinism

Even before privatisation, although technological imperatives were allowed a powerful influence on the development of the industry, Winner's claims for the autonomy and determinism of nuclear power represent a mistaken interpretation of events. Although the imperatives of nuclear power (and large scale generation technology in general) appeared to have a powerful influence on the structure and development of the ESI, their potency was dependent throughout on political sanction and support. Nevertheless, the apparent power of autonomous and determinist notions as applied to the ESI, was such that they were often invoked in support of particular institutional and political interests. This is most clear in the promotion of nuclear power by both the CEGB and AEA (reflecting their concern to promote their own authority), and also successive Governments (reflecting their concern to reduce their exposure to overseas oil and British coal suppliers).

From the mid-1950s to the mid-1980s, the supposed imperatives of nuclear power technology were used to justify centralised and monopoly control of the British ESI. This was still evident in CEGB resistance to ESI reform in 1988. Rather than an absolute determinant of events, nuclear power was deliberately *portrayed* as autonomous and deterministic force in order to provide backing for particular interests at particular times in the industry's history. At the same time, however, technocracy was a very real force within the industry, and those in positions of greatest authority concerning generation technology – particularly nuclear scientists – held views that approached a belief in the autonomy and determinism of nuclear power.

Within a very short period from 1987 onwards, however, the Government's attempts to liberalise the ESI revealed that the autonomy and determinism of nuclear power technology was predicated on sustained institutional and political support. Once a decision was made by the Government to end this support, the apparent autonomous and deterministic power of the technology evaporated very quickly. Rather than a central and determining role, nuclear power was marginalised within the new ESI. The events of the British ESI privatisation process therefore amount to a rejection of Winner's suggestion for the special status of nuclear power as an inherently political technology. Rather, they support the social shaping critique of technological autonomy and determinism, as described in section 2.2.3.

A number of concepts associated with social shaping are of particular value in understanding technological change in the ESI. For example, the experience of the ESI provides considerable support for Arnold Pacey's emphasis both on the close association of technologies with specific organisational arrangements, and also on the irregular pace of technological change, with "crucial moments ... when a varied collection of different factors fit together and a new form of practice takes off" (2.2.3). As was described in Chapter 5, the dash-for-gas in the ESI during and after privatisation was a consequence of just such a coming together of diverse technical, economic, and political factors. Pacey's and others' suggestion that the powerful vested interests associated with mature systems tend to foster conservative innovations, and exclude radical innovations, is also resonant with the British ESI privatisation case – particularly the exclusion of CCGT technology in the nationalised ESI (3.5.4). Particular concepts and models of social shaping are now re-examined in more detail in the context of the present case.

7.3 Hughes' Sociotechnical Systems Approach and ESI Privatisation

7.3.1 Sociotechnical Systems and the ESI before Privatisation

Hughes' analysis of the development of electric power systems in *Networks of Power* ended in 1930. By this time, he suggested, the sociotechnical system of the British ESI had acquired considerable momentum, and had developed entrenched vested interests around the dominant form of generation technology, coal-fired steam turbines. Hughes also pointed out that changes in generation technology, by this time, although advancing at a considerable pace, were essentially conservative and incremental, under the guidance of powerful institutions which were committed to established organisational and technological forms (3.2.2). He added that generators and plant manufacturers directed their R&D efforts at securing progressive gains in the thermal efficiency of steam turbines, scale economies, and the overall efficiency of use of the supply network.

After 1930 the British ESI continued to develop along the lines observed by Hughes. Progressively larger and more efficient coal-fired steam turbines were introduced, and organisationally, the industry became increasingly rationalised and centralised. The trend towards centralisation was greatly accelerated during World War II, and culminated in the postwar unification of the industry under the control of the BEA (3.3.1). From the sociotechnical systems perspective, nationalisation may be seen as the successful extension of ESI's system-builders' efforts to extend control to their economic and institutional environment (2.3.3).

Although it was borne out of longstanding tendencies within the industry, nationalisation brought about a significant re-ordering of the 'contextual influences' shaping the development of electricity generation technology. The nationalised utilities were not required to meet any demanding financial targets, and what Hughes had identified as 'soft determinisms' in the development of the ESI in the interwar years – economic principles, such as capital interest rates – became much less influential. Instead, the most powerful contextual influences on generation technology in the nationalised period were institutional and political – the interests and values of the CEGB and AEA, and the concerns of successive governments for diversity and security of supply.

The changed environment of the British electric power system in the 1950s was reflected in changes in the forms of generation technology. Although coal-fired steam turbine technology continued to provide the bulk of electricity generated, government security of supply fears prompted the politically-led diversification into oil-fired steam turbines – an essentially conservative technology without significant consequences for the structure of the industry – and nuclear power – a much more radical technological departure. Although the first British nuclear power programme was accommodated in the existing structure for the ESI set up in 1947, the demands for an expanded nuclear programme led to the re-ordering of the industry around nuclear power technology, enacted in the 1957 Electricity Act. As well as reflecting certain political interests, from the systems perspective, the changes to the industry at this time may be seen as a powerful demonstration of the action of the *technical core* of nuclear power. From this perspective, the exploitation of the highly complex and capital intensive nuclear power technology *required* the creation of a technocentric monopoly generator. Thereafter, having been established at the centre of the ESI, nuclear power promoted the further centralisation of the industry.

At the beginning of the 1970s the British ESI could still be characterised as a high momentum sociotechnical system, whose organisational form was a largely a reflection of internal system dynamics, particularly the technical core of steam turbines and nuclear power, and also the success of the industry's system builders to control their economic and political context. In his 1970 anticipation of the next 25 years of the ESI, the CEGB Chairman Stanley Brown was confident that the established trends for electricity generation technology would continue, and the context for the industry would remain stable (3.4.1). Brown's views echoed the outlook of an earlier generation of the industry's leaders; as Hughes' stated, before the First World War, "the combination of growing momentum and reinforcing context was expected to overwhelm contingent perturbations" (2.3.3).

In the event, after 1970 the momentum of the British electric power system, in common with many others, was increasingly undermined by changing environmental circumstances. The 1970s energy crisis and the challenge of North Sea gas ended the market assurances that had supported the confidence of the industry's system-builders (3.4.1). At the same time, from the 1970s onwards, the development of both coal-fired steam turbine and nuclear power technology came up against what Hughes might have referred to as intractable 'reverse salients' (2.3.3). In more recent work, Hughes himself recognised the disturbances to electric power system development since the 1970s (2.3.3).

Despite these difficulties, however, the integrity of the ESI system remained basically intact, and in 1985 the CEGB Managing Director John Baker was still in a position to be able to anticipate the future technological development of the industry for the next 35 years as essentially the continuation of existing trends – what Hughes described as "prediction by extrapolation" (2.3.3). Although it had experienced a number of significant changes, the basic pattern of development of the electric power system had continued essentially unbroken from the 1920s to the 1980s – apparently in broad accordance with Hughes' sociotechnical systems model. In particular, throughout this period, changes to the industry seem to have enhanced the control of industry's system-builders, and to this extent seems to confirm the pattern of development suggested by the Hughesian model.

7.3.2 Sociotechnical Systems during and after ESI Privatisation

The development of the British ESI during the privatisation process presents substantial difficulties for Hughes' sociotechnical systems model. The Conservative Governments of the early-1980s expressed their continued support to the CEGB, and the established pattern of generation technology. By 1987, however, having been frustrated in their initial efforts to liberalise the industry (3.4.5), and increasingly concerned about criticism of privatised neo-monopolies, they were openly prepared to confront and overrule the CEGB's system-builder authority.

From the point at which the Government decided to force competition on the industry in the face of CEGB opposition (4.2.1), it was clear that the leading system-builders in the nationalised ESI – most notably the CEGB Chairman Lord Marshall – no longer exerted significant control over the system. The 1988 White Paper made a series of implicit criticisms of the CEGB, and in unveiling the proposals in Parliament, Parkinson readily admitted that he "did not expect the CEGB to welcome the reorganisation" (4.2.2). Marshall's personal disempowerment after 1987 symbolised the decline of the established pattern of system-building in the ESI, and with it, arguably, much of the analytical power of the sociotechnical systems approach.

In his later work, Hughes stated that the possibility of the overthrow of established sociotechnical systems "can be seen as a conflict between technological momentum and the social construction of technology" (2.3.3). In these (rather polarised) terms, the liberalisation of the British ESI amounted to the victory of constructivism over momentum.

As critics of the sociotechnical systems perspective have pointed out, Hughes' analytical emphasis on system-building and the perspective of the system-builder implicitly carries with it the assumption that, in general, the most powerful influences on change are to be found *within* the system (2.3.4). For much of the twentieth century, this was apparently reasonable, as applied to the British ESI. However, it was also the case that throughout this period, the efforts of the system-builders for greater control of the industry were supported by Government policies sympathetic to centralisation and unification (see 7.2.2 above). To this extent, system-builder power in the nationalised ESI – rather like technological autonomy and determinism – can be seen as something of an illusion: in reality, any power residing with the industry's system-builders was dependent throughout on Government sanction and support. Hughes' himself stressed that sociotechnical systems were never autonomous, but to the extent that he downplays the regulatory and political preconditions of system-building, he credits the system-builders themselves with too much authority. In this way the British ESI privatisation case exposes weaknesses with the sociotechnical systems approach not apparent during more stable periods of change, and validates the criticisms of Hård and others concerning Hughes' over-concentration on system-building in the process of technological change (2.3.4).

Another of Hård's criticisms of the systems approach – that it is overly consensus-oriented, and fails to recognise conflict over competing technical forms – is less easy to sustain on the evidence of the present case. Undoubtedly, certain forms of generation technology *were* disadvantaged and excluded in the nationalised ESI. Russell explored this in the case of CHP technology, and a similar exclusion is evident in the case of CCGT technology (3.5.4). However, although he downplayed the development of rival technologies, Hughes pointed out that established systems tended to "suffocate" more radical technological options (2.3.3), and the emphasis on dominant technologies in the systems approach may be seen as an appropriate reflection of the exclusion of radical technologies in mature systems.

Whilst he stressed the control of system development by the system-builders, Hughes also recognised the possibility of sudden disruption to system development by what he referred to as "contingent historical events". For the period analysed by *Networks of Power*, this was most clearly exemplified by the First World War. Hughes argued that this "cleared away the political, economic, and other non-technological factors that prevented or retarded the utilization of existing technologies" (3.2.2). From the same perspective, the ESI privatisation process may itself be considered just such a contingency. Certainly, as proponents of liberalisation such as Peter Rost anticipated, it can be seen as 'clearing away' the institutional and political factors that had held-up the greater use of gas-fired generation technology in Britain. ESI privatisation conformed to Hughes understanding of historical contingencies, in that it usurped the momentum of the established sociotechnical system, put in place a new set of contextual factors, and demonstrated that electricity generation technology development is "not necessarily a simple extrapolation of its past, or a working out of inherent technological implications" (2.3.3).

However, ESI privatisation was very different, in 'intention' and consequence, than previous examples of contingent events. All earlier cases – including both World Wars, the Suez Crisis, and the oil-shocks – were external events that 'unintentionally' resulted in an acceleration of the industry's tendency to centralisation and unification; by promoting economic and political uncertainty, they deepened political faith in technology-led searches for supply security, and led governments to act so as to bolster system-builders' efforts to gain greater control of the electric power system. By contrast, ESI liberalisation and privatisation involved the deliberate *removal* of system-builder control of their environment, and the replacement of centralised technology-led planned solutions to electricity supply by decentralised market-based provision.

In his more recent consideration to the possibility of mature system breakdown, Hughes suggested that "dinosaur-like" long-established technologies were vulnerable to an "overpowering change in environmental circumstances", as a result of their embodiment of anachronistic economic and political values (2.3.3). This is clearly a fitting description of both nuclear power and coal-fired steam turbine technology by the late-1980s, as reflected in their declining fortunes during and after privatisation. In the nationalised ESI, nuclear power technology embodied a number of institutional and political interests – government fears for security of supply arising from the threat of hostile fuel suppliers, and also the powerful technocentrism within the industry and across wider society for much of the postwar period. In the same way, the dominant position of coal-fired steam turbine technology can be seen as embodying the institutional power of the NCB and NUM, the CEGB's commitment to established large-scale generation technology in the pursuit of scale economies, and an economic and legislative framework for the industry which gave negligible weight to environmental pollution. By the late-1980s, both nuclear power and coal-fired generation technology were essentially anachronistic technical forms whose vulnerability was swiftly exposed in the course of privatisation.

Hughes has also recently given some suggestions of the possible causes of the breakdown of mature systems. He stated that to achieve this, "a counterforce of comparable magnitude" to the momentum of the established system was needed. (Since the momentum of the British ESI had been considerably eroded since the 1970s (3.4), its overthrow in the late-1980s was a greater possibility than at earlier times.) Hughes went on to suggest that "the most likely cause of displacement of large, centrally controlled systems would seem to be a confluence of contingency, catastrophe, and conversion" (2.3.3). In searching for the possible source of such a change, he discussed further fuel supply interruptions, technological catastrophes, and broader social "value changes" such as environmentalism and anti-consumerism. Perhaps surprisingly, he did not mention the potential of economic liberalisation to affect such a change.

Hughes went on to argue that the removal of old systems was followed by their replacement by new ones which showed essentially similar characteristics of system-building and momentum-gathering, albeit operating on a wider international scale (2.3.3). He added that in the case of the ESI, this was demonstrated by the continued search for scale economies and load diversity, and by the increasing concentration of international electrical plant manufacturers. The British ESI case offers mixed evidence in support of these claims. Certainly, as Haywood and others described, the liberalisation of the industry was associated with a much greater role for international plant manufacturing companies (6.4).

However, the evidence from the present case suggests that the ESI systems of the 1990s are fundamentally different to the ones they replaced – to the extent that it is misleading to suggest that system-building at the level of the international plant manufacturers has substituted that formerly done at national level by state-owned utilities. In particular, monopoly generators such as the CEGB were able to exert far greater influence on their economic and political environment than is possible for the international plant manufacturing companies in the 1990s. Indeed, the organisational and regulatory framework developed for the British ESI in the course of privatisation was purposely designed to minimise the control exerted on the industry by any one institution or company through vertical or horizontal integration.

The accounts of those involved in the development of generation technology projects in the post-liberalised ESI (5.4) offer no real evidence of system-building by the international manufacturing groups. Rather, the manufacturers were restricted to offering tenders for plant projects in a fiercely competitive market. To some extent, the liberalisation of the British ESI appears to have resulted in-part in the *localisation* rather than globalisation of system-building; IPP projects were largely financed and managed on a project-by-project basis, with new consortia established for each project (5.3.3, 5.4). At the same time, however, there have been some moves towards greater concentration and re-integration in the industry since privatisation – such as seen in the takeover of RECs by US power companies. As yet, however, these changes have not provided for the development of centralised system-building on anything like the extent seen under nationalisation, and given the new institutional and regulatory framework for the industry, they appear unlikely to do so.[1]

The case-studies of CCGT projects also revealed the extent to which British ESI privatisation has been associated with a transformation of the Hughesian 'contextual factors' of the environment of the electric power system. Liberalisation resulted in the re-emergence of economic principles as a powerful influence on generation technology, to the extent that they again fit Hughes' description as 'soft-determinants' in the interwar years. In other respects, however, the electric power system of the 1990s is very different to that of the inter-war years. In particular, the dominant role of economic factors is not accompanied by what Hughes identified as the other soft determinant in the interwar years – the momentum of the system itself. Indeed, the liberalisation of the industry resulted in a transformation in the industry from being *producer-led* to *consumer-led* – the consumers in this case being the public electricity suppliers and large users. (The transfer of power from the generators to the suppliers was a deliberate part of the Government's proposals for privatisation, as described in 4.2.2). The weaknesses of Hughes' approach as applied to consumer-led industries was previously recognised by Carlson (2.3.4).

However, whilst the ESI privatisation case exposes some substantial weaknesses of the systems approach, in other areas, it confirms its continuing value, and it would be going too far to suggest that the systems perspective is completely invalidated by the present

[1] Nevertheless, this is an area which remains in some flux, and the application of Hughes' systems-building perspective on newly emerging international alliances in the power industry offers considerable potential for further investigation.

case. It was recognised from the outset of the present study that certain aspects of Hughes' analytical approach – the emphasis on the perspective of the system-builder, and the various stages of system evolution – were inappropriate, and these aspects were deliberately downplayed in the review of Hughes' work in Sections 2.3 and 2.6.1. Instead, attention was focused on those areas of the systems approach which appeared to offer particular insights to ESI privatisation. Particular focus was therefore given to Hughes' distinction between 'system' and 'contextual' influences on technological change, and the insight that this provides to the role of technology as both *cause* and *effect* of social change, and to the distinctive and potentially unpredictable action of the *technical core* (2.3.2).

Applying these concepts to the recent changes in electricity generation technology in Britain directs attention to the role of CCGT technology as cause and effect of change in the industry, and the distinctive action of the CCGT technical core. As stated earlier in this section, privatisation may be considered as a powerful contingent event which reconstructed the financial, legislative and institutional environment for electricity generation technology, and thereby resulted in the replacement of one established sociotechnical system – with a nuclear power and steam turbine technical core – for another, with a gas turbine technical core.

Gas turbine generation technology was essentially excluded from the nationalised ESI in Britain (3.5.4), and was developed by overseas manufactures and utilities, using techniques developed for turbojet engines (3.5.2, 3.5.3). As a result, the gas turbine/CCGT technical core exhibits quite different technical and economic properties than those of the established ESI system – it is far less capital intensive, is competitive in small units, has short lead times, and is capable of minimal environmental pollution. As such, it provides a powerful demonstration of a technical core developed for a specific context (the aerospace engine industry) which proved to have unanticipated consequences when transferred to another – electric power systems, particularly the British ESI. As discussed in Chapter 5, few predicted the speed or scale of the dash-for-gas (5.3.1).

CCGT technology was far better suited to the liberalised environment for the British ESI than the established core – and thereby *reflected* the institutional, economic, and legislative changes made to the industry by Government. However, CCGT technology was a *cause* as well as an effect of the changes affecting the industry after 1987. By reducing entry barriers to generation, the CCGT technical core enabled the development of independent generation to an unforeseen extent. When the Government's proposals for privatisation were first unveiled, the consensus amongst industry insiders and independent analysts was that there could be no significant independent generation challenge to the CEGB successors for many years after flotation (5.3.1). Such forecasts were confounded by the dash-for-gas. CCGT technology effectively transferred novel economic characteristics to electricity generation in Britain, and thereby enabled the realisation of IPP projects to a far greater degree than would otherwise have been possible. By doing so, it also accelerated the decline of established interests in the industry, particularly those associated with coal-fired generation, to a degree that the Government and others apparently thought inconceivable (6.2.1) .

The changes to the British ESI since privatisation also offer support for Hughes' concept of technological *style*, and his suggestion for the causes of similarity and difference in the adoption of technologies (2.3.2). In a similar fashion as Hughes described for steam turbines, CCGT technology was developed internationally, and has been adopted by different ESI's in the past decade to degrees which reflect their particular economic and political circumstances. As MacKerron pointed out (5.3.4), the British dash-for-gas has not been repeated in speed and scale in any comparable country – reflecting the unprecedented nature of the structural and regulatory reforms to the ESI in Britain (6.5.2). In Hughes' terms, the environment for the electric power system in Britain reflected a particular emphasis in British politics with economic liberalisation, and this provided for a distinctive style of generation technology in the British ESI of the 1990s, featuring an unparalleled use of CCGT technology.

Although it provides some support for the analytical value of associating distinctive properties with a technical core, the British ESI case also provides a warning against any lapse into technological determinism in discussion of the action of the core. Whilst the CCGT technical core *enabled* changes to the British ESI after privatisation, the dash-for-gas was also a result of the longstanding desire for independent generation in the British ESI, fed by institutional rivalry and the perceived inefficiencies of the CEGB (as discussed in Section 5.6). Therefore, rather than the straightforward acting-out of the techno-economic imperatives of the CCGT technical core, the dash-for-gas should be seen as an outcome of the interaction of the potential of CCGT technology with the institutional and regulatory changes to the ESI environment associated with privatisation, and also the historical development of the industry before these changes were realised.

In *Networks of Power*, Hughes himself tended to discuss the technical core in rather deterministic terms. When he referred to steam turbines introduced in the interwar years as "supply in search of demand" (2.3.2), he over-privileges technical imperatives, and underplays the market and political factors supporting ESI expansion in these years. Although steam turbines made possible cheap and abundant electricity, without favourable organisational, economic and legislative conditions, they would have remained undeveloped. Similarly, in the case of the post-privatised ESI, the action of the CCGT technical core was greatly circumscribed by context. The reorganisation of the fossil fuel generation sector ahead of privatisation was *not* a response to the technical core of CCGT (or any other) generation technology. Rather, the CCGT core exhibited properties well-adapted to the new ESI's 'selection environment'. (Interestingly, when the Government attempted to introduce an organisational structure for generation which *was* a response to the technical core of nuclear power, its policies proved unsustainable in the course of liberalisation.)

In a consideration of the suitability of Hughes' systems approach to recent changes in the US ESI, Richard F. Hirsh and Adam H. Serchuk concluded that, although there have been significant changes in the US ESI in the past 20 years, the industry's established system managers had retained control, and radical technological options, such as wind turbines, had been integrated into the existing systems, rather than being associated with the overthrow of the systems.[2] In the same terms, the privatisation of the British ESI represents a *radical* rather than conservative change, in the course of which the industry's established system managers were disempowered.

7.3.3 Conclusion: The Value and Limits of Sociotechnical Systems Theory

Hughes' broad based social shaping approach to the analysis of technological change provided an analytical starting-point for the present study, and his view of technologies as "cultural artifacts" that reflect and shape the society around them is firmly supported by the events described here. Hughes went further than many other social shaping analysts in recognising and exploring the ways in which technologies act as agents of economic, institutional, and political change. This perspective is highly informative as applied to the events in the British ESI associated with privatisation. Within this, certain aspects of the sociotechnical systems model have offered particular insights. For example, Hughes' distinction between the internal and contextual influences on sociotechnical system development has provided a rewarding insight into the displacement of the dominant system in the course of privatisation associated with the reconstitution of the industry's environment, and also into the way in which CCGT technology acted as both cause and effect of changes in the post-privatised ESI.

---

2 As such, they concluded, supposedly radical innovations had had an essentially conservative role: "though we concede the presence of change, we classify it as conservative ... employment of wind turbines ... constituted responses to conserve the utility system with as little change as possible" (Richard F. Hirsh and Adam H. Serchuk, 'Momentum Shifts in the American Electric Utility System: Catastrophic Change – or No Change at All?', *Technology and Culture*, Vol.37, No.2, pp280-311, April 1996:281, 310

At the same time, however, the British ESI privatisation case presents a number of difficulties for the sociotechnical systems approach, and draws attention to some of its underlying weaknesses. Hughes' stages of system development ends with system maturity, and he offered little with which to examine the decline and overthrow of systems, and the replacement of one system by another. Essentially, all that can be said here is that privatisation may be conceived as an external 'contingent event', powerful enough to usurp the momentum of the existing system, and impose new institutional, legislative and economic priorities that were associated with a radical change in generation technology.

The limitations of the systems approach for the ESI privatisation case may be seen to some extent as an inappropriate application of Hughes' model to a situation for which it was not designed. In more recent work, Hughes himself pointed out that his model of sociotechnical system development developed in *Networks of Power* was designed to describe the growth of young systems, and he recognised its limitations as applied to declining or disconnecting systems – and the need for other perspectives in such cases. Undoubtedly, some of the difficulties associated in applying the sociotechnical systems model to the present case relate to the very different conditions of the British ESI of the 1990s as compared to the 1920s.

At the same time, however, the British ESI case exposes underlying flaws in the assumptions and perspective of the systems model. In particular, the present case confirms many of the weaknesses of the systems approach highlighted by its critics. A particular difficulty is the emphasis on the perspective of the system-builder; this inevitably locates too much power on the system builders and the technological core, and gives too little recognition to the importance of supporting institutional structures and policies. By locating the system as the most influential source for the causes of technological change, it encourages functionalist and determinist interpretations. The demise of technocracy associated with privatisation, as well as discrediting autonomous and determinist notions, also exposes the more technocentric aspects of the sociotechnical systems model. ESI restructuring revealed the (often hidden) supports of the dominant generation technologies of the nationalised system, and with it, exposed the extent to which the systems model privileges certain dynamics above others in explanations of technological change.

Hughes himself recognised the dangers of deterministic interpretations of his approach, and he warned against anything more than a "loosely-structured" use of theory. Used with an awareness of its limitations, the sociotechnical systems model remains of considerable analytical value. Despite its weaknesses, it has provided uniquely valuable insights on the changes in the British ESI associated with privatisation.

7.4 Constructivist/Actor-Network Approaches and ESI Privatisation

7.4.1 Introduction

As was discussed in Chapter 2, social constructivist and actor-network approaches have considerable limitations as applied to highly politicised technologies, such as those of electricity generation. They both presume primacy for micro-level dynamics, and tend to underplay structural and political influences on technological change (2.4.3). At the end of Chapter 2 (2.6.1) it was decided that such was the extent of these weaknesses in the context of the present case, that neither a constructivist nor an actor-network perspective would be explicitly adopted here. At the same time, however, it was also recognised that both approaches offer particular perspectives and insights into the process of technological change, and these are now considered.

ESI liberalisation was associated with the disempowerment of the formerly dominant ESI institutions, reduction in government intervention in fuel and generation technology choice, and the introduction of an organisational and regulatory framework for fossil fuel generation technology which gave much greater rein to competitive market forces. Within this new environment, much of the decisionmaking processes affecting technology development was relocated to the project level, so that analytical approaches such as constructivism and actor network theory became much more appropriate.

7.4.2 Social Constructivism and ESI Privatisation

Before 1987, the dominant forms of generation technology in the British ESI were essentially a reflection of the entrenched vested interests of the ESI institutions and central government. Against these, rival technical forms were essentially unable to compete, even after the passing of the 1983 Electricity Act (3.4.4). From the perspective of social constructivism, generation technology had achieved closure, and the dominant technical forms – coal-fired steam turbine technology and nuclear power – reflected the dominance of particular groups, namely the CEGB, AEA, NCB, NUM, and government. As Bijker and Law suggested, stability of social form was mirrored by stability of technical form.

The ESI case offers broad support for Bijker's observations on the interconnectedness of technical and social change (2.4.1). ESI liberalisation involved the destabilisation of the economic and institutional environment of generation technology, and with it, the destabilisation of technical forms. In accordance with Bijker's suggestion that "instability is more revealing about a systems characteristics than stability" (2.4.1), the ESI privatisation process exposed the institutional and political supports that had supported the dominant technologies under nationalisation. At the same time, by stripping those supports away, it made social constructivism – a perspective oriented towards instability – a much more relevant framework for studying the development of generation technology.

As discussed in Chapter 5, within a short period in 1988 and 1989, CCGT technology had become overwhelmingly the favoured generation technology in the British ESI (5.3.2). From the constructivist perspective, this can be seen as the establishment by certain *relevant social groups*, such as international plant manufacturers, independent power producers, and international financiers, of a new *preferred design* of generation technology. Established groups in the British ESI, such as National Power and PowerGen, which were formerly committed to coal-fired steam turbine plant and nuclear power, rapidly accepted this redefinition. Other formerly powerful groups, such as the AEA, British Coal, and British plant manufacturers, who refused to accept this redefinition, but were unable to impose their alternative definition, were quickly marginalised.

Although a plausible reading of events, the constructivist description of changes in electricity generation technology after 1987 remains a restricted one. In particular, the success of certain groups in imposing their new 'interpretation' of generation technology cannot be understood without reference to less immediate factors – notably the restructuring of institutional and regulatory environment of the industry by Government. In this sense, the successful actions of independent power producers and RECs in the post-privatised ESI, as Williams and Russell stated, "cannot be explained on their own terms" (2.4.3). Whilst social constructivism is better able to provide insight on change in the industry after privatisation than before, it cannot, by itself, provide a satisfactory account of the dash-for-gas. For this, as Williams and Russell also pointed out, an approach capable of capturing the interplay between action and context is needed, such as Hughes' systems model.

Bijker's later modifications to constructivist theory add little to the understanding of the British ESI case. Clearly, the British ESI before and after privatisation provide cases of very different 'technological frames' (2.4.1), but this offers no new insight not provided by other approaches. Furthermore, what Hård referred to as the "consensus orientation" of constructivism (2.5.2) remains a weakness as applied to the British ESI after privatisation. To view the dominance CCGT technology after privatisation as a reflection of successful consensus formation, through the 'amalgamation' of different interests, ignores the ongoing hostility towards the dash-for-gas from the proponents of other technical forms, most notably the coal industry and its supporters, as was evident during the coal crisis (6.3.2). Overall, the present case offers support for the criticisms of social constructivism as discussed in Chapter 2. At the same time, the post-privatised ESI is much more amenable to constructivist interpretations than previously, and here the approach offers a valuable – if limited – perspective on technological change.

7.4.3 Actor-Network Theory and ESI Privatisation

From the actor-network perspective, the technical and social elements of steam turbine and nuclear power actor-networks in the nationalised ESI in Britain were *durable*, and those actors who tried to introduce alternative technical forms were unable to enrol key technical, institutional and political actors. The relative impotence of micro-level actors is a measure of the limited value of actor-network concepts as applied to the nationalised ESI.

As with social constructivism, however, actor-network theory is more appropriate – and offers considerably greater insight – when applied to the post-liberalised ESI. Indeed, the case-study accounts of those involved in CCGT projects (as described in Section 5.4) offer an implicitly micro-level perspective on technological change that fits particularly well into an actor-network perspective.

The actor-network model highlights the importance of both 'technical' and 'social' elements in the dash-for-gas. The introduction of CCGT technology was predicated on both technical and social innovations – on improvements to gas turbine technology and the price and availability of gas on the one hand – and also on the politically-led removal of economic and institutional barriers to new entry in generation in Britain. From the actor-network perspective, this may be described as the successful enrolling of technical and social actors in the CCGT actor-network. As such, the technology provides a stark contrast with the failure in this respect in Callon's electric-vehicle case (2.4.2). Within CCGT actor-networks, both non-human actors: advanced gas turbine blades, natural gas fuel, combined cycle technology – and human actors: RECs, large users, and international financiers – were all successfully enrolled. For example, Enron's activities in developing the Teeside Power Plant (5.4.3, 5.4.4) can be readily seen as the successful building of a network of heterogeneous elements – both technical (CCGT technology from Westinghouse, gas supply from the North Sea pipeline) – and social (persuading ICI to provide land and purchase power, successfully enrolling RECs as both equity partners and power purchasers, and securing international finance).

Because it allows for recognition of structure and differentiated power, Law and Callon's conception of interacting *global* and *local* networks (2.4.2) is particularly applicable to the British ESI case. Following this model, the implementation of CCGT technology after privatisation can be seen as the successful mobilisation of global and local networks. (Indeed, three different levels of network are identifiable in the development of generation technology projects: local (project), national, and international.) The global network included the international provision of CCGT technology itself, the international financiers supporting their development, and also the institutional and regulatory context for the British ESI. The local network included the various institutional, financial, and technical elements of the IPP consortia. Both global and local networks were essential for the successful development of CCGT projects. The global network provided a new technical form for generation, and the means to finance it, whilst the local network provided a powerful institutional desire to enter generation, and also the secure market which, as Summerton stressed, is essential for the introduction of any radical (and capital intensive) technology (2.4.2).

This distinction in scale makes clear the dependency of micro-level generation technology projects on conducive institutional and regulatory conditions. The local network of a CCGT scheme can be seen to be predicated upon the existence of a higher-level global network – including the new institutions and regulations of the privatised ESI, as well as the international technology of CCGTs. Before privatisation, any local network created to develop CCGT plant projects would have been frustrated by a failure to enrol sufficient support from the 'global network' of the institutions of the nationalised ESI. By contrast, after the liberalisation of the industry, particular CCGT projects such as Roosecote and Wilton (5.4) were able to successfully impose themselves as "obligatory points of passage" between the global and local networks. They enabled the injection of global technical and financial resources into the British ESI, and at the same time, they gave expression to a local desire for entry into generation. For the ESI case, Summerton's emphasis on the interdependency on different actors in the network offers a more appropriate perspective (2.4.2).

Nevertheless, whilst becoming much more relevant to the British ESI case since privatisation, the actor-network approach remains, like social constructivism, an inherently limited perspective on technological change in the industry. Whilst the privatisation process gave power to project-level decisionmaking, it was itself a powerful confirmation of the importance of structural and political factors in the process of change. The focus on project-level dynamics within constructivism and actor-network approaches would tend to suggest that the 'heterogeneous engineers' involved with IPPs were all-powerful figures in the new ESI. In practice, as privatisation revealed, their successful development of such projects was predicated on a supportive political and institutional framework, analysis of which requires a more structurally- and historically-informed perspective.

7.5 Institutional Level Approaches and ESI Privatisation

7.5.1 Russell's Institutional Interests Approach and ESI Privatisation

Stewart Russell's analysis of CHP/DH technology provided a powerful demonstration of the importance of an institutional interests perspective in order to understand the pattern of generation technology in the nationalised ESI (2.5.2). The exclusion of CHP closely resembled the marginalisation of CCGT technology in the same period. CCGT plant was of no real interest to the powerful institutions under nationalisation (3.5.4). For the turbojet manufacturers such as Rolls-Royce (who developed much of the technology which would eventually find application in CCGT plant), it was an irrelevance, given their concentration on aerospace markets. For the large electrical plant manufacturers, its development was not merited because utility disinterest provided insufficient sales revenue. For the utilities themselves, it was a distraction from their long-term focus on coal-fired steam turbine plant and nuclear power. Such was the institutional hostility towards gas-fired plant, that there is evidence that its development was actively opposed by those committed to the existing pattern of energy supply in Britain (3.5.4).

Whilst ESI liberalisation involved the confrontation of entrenched institutions of the nationalised era, institutional rivalries and interests continued to play a powerful role during the privatisation process, and on the changes to generation technology since privatisation. As a result, the institutional interests perspective has remained relevant to the analysis of the fortunes of the different generation technology options. From this perspective, the marginalisation of the historically dominant form of generation technology in the British ESI – coal-fired steam turbine technology – was associated with the disempowerment of British Coal and the NUM. Although this disempowerment became obvious after 1987, it can be traced to the defeat of the NUM in 1985, and a longer term decline under nationalisation (6.3.3). Given Conservative Government hostility to the coal industry, coal-fired generation technology, although still dominant in terms of installed capacity, went into the ESI privatisation process without any significant institutional support (6.6).

By contrast, nuclear power technology went into the privatisation process still commanding the support of the most powerful ESI institutions and Government. Indeed, even after the proposals for the liberalisation of the industry were made known, nuclear technology was still favoured by National Power (who were to retain considerable institutional power after privatisation), and also the Department of Energy. However, a largely unanticipated consequence of the Government's proposals was the significant turnaround it provoked in the vested interest of National Power as compared to the CEGB regarding nuclear power. In the nationalised ESI, the CEGB, protected from competitive market forces, developed a strongly embedded technocentric commitment to nuclear technology. However, the proposed removal of generator monopoly in the Government's privatisation proposals meant that National Power would be ultimately responsible for the costs of nuclear electricity. As a result, from 1988 onwards, it became in National Power's interest to emphasise the costs and risks associated with nuclear power, in order to gain maximum protection from Government ahead of flotation (4.6.1). This reversal provoked a series of disclosures from National Power concerning the uncompetitiveness of nuclear electricity. Even so, such was the continued strength of political support for nuclear power in Britain, that it was only after it threatened the entire ESI privatisation, that the Government abandoned its commitment to new nuclear plant and the privatisation of existing plant.

The dramatic transformation in the institutional interests of the CEGB/National Power towards nuclear power in 1988 and 1989 confirms Russell's contention that institutional support for particular technologies is a contingent matter, sensitive to particular economic and political conditions. Before privatisation, however, this contingency was not at all evident, and institutions such as the CEGB showed an essentially unwavering commitment to nuclear technology. Indeed, for the most committed proponents of nuclear power – such as the CEGB Chairman Lord Marshall, and Alistair Cruickshank of the AEA (4.5.3) – this support was *not* a contingent matter: no change in their views occurred in the course of ESI privatisation. For these individuals in particular, support for nuclear power technology went beyond any concern for its economic viability.

For all parts of the ESI, the transition to privatisation marked a significant change in the character of institutional influences on generation technology. As confirmed by the accounts of those most closely involved in CCGT plant development (5.4), in the post-privatised industry, financial and economic criteria became highly influential factors in the choice of new plant type. Whilst the desire to enter generation was clearly in-part the result of institutional interests and rivalries, the *choice* of generation technology for the expression of this desire was greatly circumscribed by financial restrictions. Independent producers wishing to develop plant proposals based on technology other than CCGT, such as clean coal technology, were unable to secure either a guaranteed market or financial backing for their schemes (6.5). Although the established generators were not subject to these financial constraints, their choice of generation technology in the new ESI was similarly restricted by the need to sell bulk electricity into a market where suppliers were given much greater freedoms. In contrast with the nationalised ESI, even those bodies that retained institutional power after privatisation – National Power, PowerGen, the RECs and Nuclear Electric – were no longer in a position to develop particular technical forms for generation on the basis of their own institutional preferences.

In outlining his analytical approach, Russell pointed to the institutional and political aspects of economic criteria (2.5.1). The radical accounting changes applied by the CEGB/National Power to nuclear power in the course of privatisation is a powerful example of this (4.3.3). Beyond this, however, Russell gave little consideration to economic influences on generation technology – perhaps reflecting the insignificance of market forces on technology choice in the nationalised ESI. His approach is therefore unable to fully reflect the importance of the different economic characteristics of the competing forms of generation technology in the privatised ESI, which – alongside institutional interests – were undoubtedly highly significant factor in the dash-for-gas.

By itself, the institutional interests approach is unable to explain the institutional and technological transformation of the ESI associated with privatisation. Russell argued that throughout the period he analysed, organisational restructuring of the industry had served to preserve the dominance of the producer organisations, and established technological forms. Clearly, the liberalisation and privatisation of the ESI does not conform to this pattern; there is no anticipation within Russell's analysis of the possibility of such a radical reconstruction. Russell himself recognised that an analytical focus on institutional interests had to be placed within "the specific character of the British economy and state" (2.5.1). The institutional interests perspective, although still valuable in considering the development of the ESI after 1987, was devised for a period of broadly stable political and legislative context, within which market forces were insignificant. In the course of privatisation, both government and market influences on generation technology choices changed radically, and the institutional interests perspective, although it provides continuing insight, offers only a partial view.

7.5.2 Hård's Social Conflict Approach and ESI Privatisation

Hård's "conflict theory of technology" (2.5.2), like Russell's institutional interests approach considered above, offers a number of insights into the technological changes experienced by the British ESI associated with privatisation, whilst at the same time being inadequate by itself to fully recognise and describe the diversity of the process of change, and the range of influences involved. Institutional conflict was undoubtedly a significant influence on the dash-for-gas. In particular, from Hård's perspective, the liberalisation of the ESI can be seen as enabling the *manifestation* of conflict between the Area Boards/RECs and the CEGB/National Power/PowerGen, that had remained *latent* within the structure for the industry set up by the 1957 Electricity Act. The role of CCGT technology in this conflict after 1988 (5.3.2), offers a powerful validation of Hård's suggestion that "latent conflicts may become manifest when new technical opportunities appear" (2.5.2). (The same may also be said for the longstanding conflict between Conservative Government and the NCB). Furthermore, the employment of CCGT technology by RECs, overseas power companies and plant manufacturers offers support for Hård's argument concerning the introduction of new techniques by certain groups to gain "positional advantage" (2.5.2).

Hård's observations on the relationship between innovative activity and the distribution of institutional power are also vindicated by events in the British ESI. Along with other analysts (such as Pacey and MacKenzie) Hård suggested that bureaucracy and monopoly was essentially inimical to innovation. This is clearly demonstrated by the CEGB's entrenched commitment to steam turbine and nuclear power technology, and resistance to CCGT technology. Hård also suggested that technological change was most likely in a context where "power and influence were unequally distributed", rather than in a perfectly competitive market (2.5.2). As was discussed at the end of Chapter 5, the limited degree of the Government's liberalisation of the ESI, and the remaining concentration of power in the CEGB successor companies, proved to be a powerful incentive for the RECs and large users to seek entry into generation (5.5).

Nevertheless, whilst offering valuable insights, the social conflict perspective cannot fully capture the range of influences involved in the dash-for-gas. In a similar manner to Russell's institutional interests approach discussed above, it fails to properly consider the extent to which economic pressures influenced the choice of CCGT technology. In addition, the social conflict perspective cannot account for the development of certain technical forms rather than others, and the favouring of one technology over another.

Hård himself recognised that the conflict perspective was essentially complementary to others; used as such, it is of some value as applied to the British ESI case.

7.5.3 MacKenzie's Historical Sociology Approach and ESI Privatisation

Like Hughes, MacKenzie offered a broad based social shaping approach to the analysis of technological change of the kind that has been implicitly followed throughout the present study. As was argued at the end of Chapter 2, such a perspective was considered essential for the development of any realistic understanding of the process of change in the British ESI associated with privatisation (2.6.2). Within this, many aspects of MacKenzie's 'historical sociology' approach devised for *Inventing Accuracy* have been supported by events in the British ESI. Without a historical understanding of the institutional and political interests associated with generation technology in the nationalised industry – and the ongoing development of gas turbine/CCGT technology outside of the British ESI – no understanding could have been reached concerning the pattern of generation technology forms going into the privatisation process, and the subsequent transformation of that pattern.

More specific elements of MacKenzie's analysis have also proved of value. For example, his observations of the role of technological knowledge and expertise in the development of nuclear weapons technology has direct parallels with the British nuclear power programme (2.5.3). Much of the activities of the CEGB and AEA can be seen as the establishment and maintenance of the credibility of nuclear power. As discussed in Chapter 3, the emphasis in the early nuclear power programme was on demonstrating that nuclear power was technically feasible rather than economically competitive (3.3.2). Within such a context, technical expertise became a highly useful resource for the nuclear industry, and technologists had a powerful influence on the development of the nuclear programme. This was particularly true of the fast reactor research programme, which occupied a central role in the British nuclear programme, on the strength, Gowing stated, of "its inherent scientific promise" (4.5.1).

In parliament, the technical expertise offered by former scientists or engineers was privileged in early discussion of nuclear power, and those MPs without such expertise willingly deferred to the views of others, This was most evident in debate on the restructuring of the ESI during the Second Reading of the Electricity Bill in 1956, at the height of the Suez Crisis (3.3.3). The British nuclear power programme has been often judged in primarily technical terms, and its supporters have often seen it as a *technical success* confounded by changing economic or political circumstances. For example, the

1964 White Paper on the Second Nuclear Power Programme stated that "nuclear power, from a technical standpoint, has achieved all that was expected of it" (3.3.4). Similarly, Alistair Cruickshank defended the fast reactor programme by stating that "we proved the technology ... we've done everything we were asked to do, essentially", and described the cancellation of the Dounreay PFR as a "successful operation" in which the "patient died" (4.5.3).

In the nationalised ESI, the CEGB and AEA were successful for many years in maintaining the credibility of the nuclear power programme. At the same time, they seemingly managed to maintain the separation between 'technology' and 'politics' – in MacKenzie's terms, to keep closed the black-box of nuclear power generation technology (2.5.3). In reality, however, to an extent that only became clear in the course of ESI privatisation, their success owed much to a favourable institutional framework created and maintained by government. Whilst governments voiced technical rationale's for the British nuclear programme, their actions fit into MacKenzie's suggestion that technically-based arguments provide a resource for those wishing to justify developments – what Nelkin referred to as the legitimising role of technical expertise (2.5.3). The invocation of the 'technical imperatives' of nuclear power was a less controversial means of justifying support than political concern, for example, to reduce dependency on the British coal industry.

The nationalised ESI also provides a powerful example of MacKenzie's characterisation of conservative technological change within a well-established institutional framework as a *self-fulfilling prophecy* (2.5.3). The industry's R&D programmes under nationalisation encoded the interests and values of the politicians, scientists and engineers, involved in policymaking for the industry. Research efforts were channelled largely according to the preferences of the CEGB, AEA and Government.

Much energy policy debate in the postwar period – especially in the crisis periods of the 1950s and 1970s – was based on presumptions about the inherently 'special' nature of electricity generation technologies, in particular their capital expense, long lead times, and on their long-term strategic importance to the wider economy given projected fuel scarcities. With such assumptions in-place, policy discussions were dominated by the perceived need for long-term planning, and the projected needs of the next generation. On this basis, the favoured generation technology was almost invariably nuclear power – a highly complex technical form, involving high capital costs, long lead-times, but which offered security of fuel supply. From MacKenzie's perspective, the policy process can been seen as providing generation technologies that seemed to confirm the assumptions regarding the special status of electricity generation technology.

By contrast, CCGT technology, the dominant form for generation technology in the British ESI since liberalisation, is characterised by relatively low capital cost and short-lead times. Although it was a radical departure for the British ESI, it was also an adapted form of a well-established technology. Whilst the success of CCGT technology in the late-1980s reflected changed economic circumstances, such as the price and availability of natural gas, it also suggests that much of the earlier presumptions concerning the inherently special character of electricity generation technology were mistaken and self-perpetuating.

The liberalisation of the ESI involved challenging the CEGB's technical expertise in respect of supposed technological imperatives supporting monopoly control of generation and transmission. The 1988 White Paper proposals were a substantial rejection of the CEGB's technical expertise and authority (4.2.2), and revealed the importance of government sanction for such expertise in the nationalised ESI. Whilst CEGB and AEA expertise was increasingly challenged in the 1980s (3.4.4), it remained unopposed by industry's sponsors at the Department of Energy. After 1987, independent expert challenge to the CEGB intensified, but it was the challenge by Government which was critical. In effect, economic liberalisation of generation brought with it the pluralisation of technical authority in regard to generation technology.

The cancellation of the CEGB's nuclear power programme after 1989 offered clear confirmation of MacKenzie's conclusion concerning the "fallacy of technological determinism", and a stark example of his description of the dependency of even the most deeply embedded and apparently autonomous technologies on their surrounding institutions. MacKenzie's words, "take away the institutions that support technological change of a particular sort, and it ceases to seem 'natural' – indeed it ceases altogether" (2.5.3) could have been written to describe the collapse of the British nuclear power programme after the break-up of the CEGB.

ESI liberalisation was associated with the demise of technocracy and the rise of demand-side influences on the process of technological change. From MacKenzie's perspective, the Government's success in introducing market forces into the industry can be seen to reflect the failure of technologists to maintain the separation of 'technology' from 'politics', or to prevent the incursion of external influences into technological development. Within technologists accounts of the recent changes to the ESI, there are some examples of such views. Alistair Cruickshank of the AEA, for example, referred to "political reasons" for the difficulties experienced by the British nuclear power programme associated with privatisation (4.5.3). Similarly, Roger Semmens, a PowerGen engineer, was dismissive of the role of "politics" in the dash-for-gas (5.3.4). In his valedictory speech as CEGB Chairman, Lord Marshall attributed the difficulties of the nuclear power programme with a long history of political interference (4.3.3). In retrospect, the removal of the CEGB's monopoly meant that the apparent separation of generation technology development from its economic and regulatory environment became impossible.

Even so, the 'black-boxing' of technological knowledge is still evident in the liberalised ESI. Since the privatisation, much of the technical expertise concerning generation technology has, literally, been an imported black box, since CCGT plant has generally involved turnkey contracts with overseas plant manufacturers (5.4). This enables other groups, such as the RECs, to rely on others for technological expertise. National Power and PowerGen are no longer concerned with retaining such expertise within their organisations. In the new ESI, however, the dimensions of the black box are strictly circumscribed – not by technologists, but by international financiers – who apply primarily financial rather than technical criteria on technology choices.

The British ESI privatisation process also offered a powerful example of the importance of MacKenzie's attention to ethnoaccountancy, or financial and accounting practices, within a wider social shaping perspective (2.5.3). The liberalisation of the economic environment for generation technology – at least within the fossil fuel sector – was a central part of the Government's proposals for ESI privatisation. As was described in Chapter 4, a number of political and economic concerns – including criticisms of 'privatised monopolies', and the desire to encourage independent generation in a structure which, because of the demands of nuclear power, preserved market power in the CEGB successors – meant that the Government had resolved to separate out the 'natural monopoly' aspects of the ESI from those potentially competitive parts. Within this, generation was seen by both Government and independent analysts as the part of the industry where the greatest benefits from liberalisation were to be found (4.2.1, 4.2.2).

The ending of generator monopoly, and the transfer of ownership of the grid to the supply-side of the industry, meant that, in the new structure for the industry potential generation plant schemes could not be assured of a market for their output. In addition, private sector financial and accounting practices were imposed on the industry for the first time.

Although the Government had intended that nuclear power should be relatively protected from competitive pressures after privatisation, the most immediate impact of liberalisation was the withdrawal from privatisation of existing nuclear plant, and the cancellation of the proposed PWR series (4.3). In the detailed investigations into the withdrawal of the causes of these events (4.3.3), it became clear that the difference in accounting practices between the nationalised ESI and private sector norms was central. In particular, the Energy Select Committee inquiries in late-1989 and 1990 highlighted the change from cost-plus to fixed-price fuel contracts between the CEGB/National Power, and BNFL, and changes in the discount rate and amortisation period (4.3.3). The Energy Secretary John Wakeham told the Committee at this time that the difficulties facing nuclear power were primarily due to the fact that "a different view was taken of the same set of costs" (4.3.3).

In the fossil fuel sector economic criteria appeared to play a similarly powerful role in determining technology choices. The abandonment of coal-fired steam turbine technology, and the adoption of CCGT technology for all new plant was apparently a response to the desire of private investors for shorter lead times, less capital investment, and quicker returns (as well as the collapse of gas prices in the late-1980s). For independent power plant schemes in particular, the international loan arrangements used to finance plant construction clearly had a leading role in the choice of plant type and operation (5.3.3, 5.4).

Although it is apparently possible to interpret the changes in both nuclear and fossil fuel generation technology in the privatised ESI as primarily a response to economic liberalisation and the imposition of a tougher set of accounting practices, such an interpretation disguises many of the forces influencing changes in the industry. It is here that MacKenzie's emphasis on the social constructedness of such practices provides a guide to interpretation. As was discussed above (7.2.3), the withdrawal of nuclear plant from privatisation was a result of a political choice by Government to limit its subsidy to National Power for the running of nuclear plant. Similarly, the dash-for-gas and the demise of coal-fired plant was a reflection of a range of institutional, legislative and political concerns: the imposition of the EC Directive at a critical time coincident with privatisation, the desire on the part of the RECs and large users to reduce their dependency on the CEGB successors, and Conservative Government hostility to the British coal industry (5.5, 6.6.1).

In addition, Russell's observation, in his study of accounting practices in the nationalised ESI, that "there was no single method or universal set of criteria. The terms of appraisal were clearly dependent on the performing institution and the precise constraints on it", applies equally well in the privatised ESI (2.5.1). The starkest contrast here is clearly the very different financial and economic environments between nuclear and fossil fuel generation. Within the fossil fuel sector, however, the financial criteria adopted differed considerably between IPP consortia, who were forced to resort to non-recourse funding, and National Power/PowerGen, who were able to finance CCGT schemes from their own assets and revenues (5.3.3). Although private sector financial and accounting practices assumed a much more powerful role in the privatised ESI, there is no evidence of a economic or financial determinism of generation technology choice. Rather, the case confirms MacKenzie's and Russell's suggestions that financial criteria are formulated and applied in response to particular institutional interests, political priorities, and wider social concerns.

7.5.4 Rip and Kemp's Technological Regimes and Radical Innovation

The changes in generation technology associated with the British ESI privatisation process offers broad support for Arie Rip and René Kemp's emphasis on meso-level technological regimes, and for their analysis of the conditions favourable to the deployment of radical innovations (2.5.4). In Rip and Kemp's terms, the privatisation of the ESI clearly represented an example of a "situation in flux", in which predictability over outcomes was low. Furthermore, the dash-for-gas in the post-privatised ESI provided a powerful example of Rip and Kemp's claims for an association between such situations and the successful deployment of radical innovations.

However, before assessing the 'fit' between Rip and Kemp's characterisation of radical innovations and the dash-for-gas in the privatised ESI, it is first necessary to qualify the status of CCGT as a truly *radical* change in generation technology. Within the technology studies literature, a particular technology is generally understood to be radical in terms of its social *consequences*. Rip and Kemp, for example, defined radical innovations as those which "challenge the existing [socio-technical] paradigm or regime, which ... gradually grow and see the paradigm replaced" (2.5.4). In *Networks of Power*, Hughes also made clear that he understood the political status of a particular technology in terms of its consequences: "a conservative technology will maintain the existing structures and trends, and ... liberal ones will bring changes in the direction of societal development" (2.3.1).

A follow-on from this understanding is that a particular technology can only be described as radical or conservative with reference to its socio-economic context. It also follows that a technology may, in principle, be radical or liberal in one context, and conservative in another. This relativism in the politicisation of artefects is exemplified in Hughes' analysis of the 'impact' of steam turbines. When first introduced in the small-scale ESIs of the turn of the century, coal-fired steam turbines were a radical innovation. Hughes referred to their "unprecedented and unexpected" impact at this time, and added: "the largely unforeseen consequence ... was the sharp acceleration of the quest for load sufficient to fulfill the economy-of-scale potential of a large, efficiently loaded turbine. The turbines were, in effect, supply in search of demand" (2.3.2). One generation later, however – in the expanding systems of the 1910s and 1920s – steam turbines had become established at the core of the ESI sociotechnical system, and were a conservative technology. By this time, Hughes stated, "sociotechnical systems had high momentum, force, and direction ... this momentum was a conservative force ... rarely were radical inventions ... introduced" (2.3.3).[3]

Applying this understanding to the present study suggests that the introduction of CCGT technology to the British ESI in the late-1980s and 1990s should be seen as an example of radical innovation – whereas the introduction of nuclear power (an ostensibly more radical technology) into the postwar ESI was a primarily conservative innovation.[4] Certainly, the initial deployment of CCGT technology in Britain conforms to both Rip and Kemp's description of such innovations as presenting a "challenge the existing paradigm or regime", and also Hughes' qualifier that such innovations should challenge "existing structures and trends". As analysed in Chapter 5, the first CCGT schemes were developed by independent producers seeking to challenge incumbent producers (5.3.2, 5.4). As was also discussed in Chapter 5, however, much of the subsequent dash-for-gas was driven by established generators seeking to pre-empt the challenge of the independent producers and hold on to their market share (5.3.3). In this sense CCGT technology, although initially liberal, was subsequently both liberal *and* conservative. The status of CCGT technology as a radical innovation is now considered further by returning to Rip and Kemp's characterisation of such developments.

The dash-for-gas offers considerable support for Rip and Kemp's detailed description of the dynamics of radical innovation, and the circumstances in which such innovations

---

[3] Within the wider technology studies literature, Hughes has been criticised by some for failing to give enough recognition to the dependency of the impact of core technologies on context. Hirsh and Serchuk, for example, suggested that Hughes had implied that the effects of a technology depended on the intrinsic qualities of the technical core – on whether it exhibited essentially radical or conservative properties. In practice, they asserted, this was entirely a contingent matter: "Nothing inherent in the technologies determined that they would be used either to destroy the existing system nor enhance its stability ... The technologies did not exert a one-way influence on their environment, as if a radical or conservative character was embedded in their design. Those qualities had to be determined as a result of negotiations between actor in the system" (Richard F. Hirsh and Adam H. Serchuk, 'Momentum Shifts in the American Electric Utility System: Catastrophic Change – or No Change at All?', *Technology and Culture*, Vol.37, No.2, pp280-311, April 1996:310-311). Whilst this description of contingency is welcome, the above extracts from *Networks of Power* would suggest that Hirsh and Serchuck's criticism of Hughes here is misplaced. As was described in 5.3.4, although it promoted the interests of independent generators, CCGT technology was also adopted by the established generators to defend their vested interests – it was *at once* politically liberal *and* conservative.

[4] By the time nuclear power was introduced in the mid-1950s, the British ESI was already highly centralised under the control of the BEA (3.3.2). At the same time, however, the emphasis given to nuclear technology in the ESI carried with it significant institutional implications in terms of an accelerated technocentrism under the CEGB (3.3.3).

were likely to prosper. For example, they suggested that the technological variety on which radical changes were built were often already available, but that a change in wider circumstances was necessary for their deployment. Under such circumstances, they added, actors were forced "against their inclination" to look for novel solutions (2.5.4). As was discussed in Chapter 5, CCGT technology was already available by the time the ESI underwent liberalisation in 1988. As Williams and Larson stated, the "revolution ... under way in electricity generating technology ... [involved] not an exotic new technology, but rather the upgrading of the familiar but little-used gas turbine" (5.2). As was also discussed in Chapter 5, the initial proposals for new generation plant in the liberalised ESI were based on conventional coal-fired technology, and it was only after the 1988 Large Combustion Plants Directive imposed an extra cost on such technology that independent producers were forced to reconsider their options, and plans for CCGT technology deployment developed (5.3.2, 5.4.1).

Rip and Kemp's statement that "innovations which are radical for a regime may themselves have been constructed out of incremental use of various complementary technologies", such as the transfer between regimes of advances in engineering and materials technology, is also well demonstrated by the dash-for-gas. As described in Section 5.2, the commercialisation of large scale CCGT technology in the late-1980s was based on the transfer of established turbojet technology, particularly after the collapse of gas prices in 1986.

Rip and Kemp also argued that the success of radical technologies was "in some way linked to structural problems or crises of [the existing] 'system'", such as the perception of a pressing technical or market problem which could not be met with available technology, or the reaching of technical limits or increasing marginal costs with existing trajectories (2.5.4). As was discussed in Chapter 3, steam turbine technology – both nuclear and fossil fuel fired – was reaching technical limits and diminishing returns to investment as early as the late-1960s. Flavin and Lennsen stated that "the advances in ... [steam turbine] technology ... stemmed from a surprisingly narrow frontier of advances ... by the 1960s, this bag of tricks was nearly empty" (3.4.3). A more pressing difficulty to the established technological regime in the British ESI during privatisation was the imposition of the Large Combustion Plants Directive in June 1988. This presented a significant technical difficulty for coal-fired steam turbine plant in terms of pollution emission reduction, and was translated into an extra cost which proved critical in the relative cost of such plant versus CCGT plant for independent power producers keen to develop generation schemes (5.3.2).

Furthermore, Rip and Kemp also suggested that radical innovations were more likely to be promoted by 'outsider' institutions rather than existing leaders, and that such innovations presented an opportunity to outsiders, since "thresholds are temporarily low when paradigms change, and windows of opportunity ... open for new participants" (2.5.4). Again, this accurately characterises the dash-for-gas. The introduction of CCGT technology into the British ESI was fostered by a combination of overseas power companies, international plant manufacturers, Area Boards/RECs, and large users – all of which were marginalised in the nationalised ESI. As testified by those directly involved in such schemes, CCGT was deployed precisely as a means of countering the market strength of the CEGB successor companies (5.4.1, 5.4.2). At the same time, this radical technology offered outsiders significantly reduced barriers to entry in generation, in terms of reduced capital cost and lead times, and also circumvented their disadvantages in terms of established technological know-how. The Wilton CCGT plant scheme, in particular, was rapidly developed and implemented precisely because – as ICI's Phil Smith stated – "Enron decided there would be a good window for them just after privatisation" (5.4.3).

Finally, Rip and Kemp emphasis on wider structural and political factors in the displacement of one regime by another is also resonant with events surrounding the dash-for-gas. In particular their focus on regulatory and institutional change, and on the crucial role of government in "inducing a technological regime shift", is clearly supported by the present case. As was argued at the end of Chapter 5 (5.5), and also in the discussion of technological determinism and autonomy earlier in this chapter (7.2), the Government-imposed institutional restructuring and economic liberalisation of generation in the British ESI was fundamental to the conception and realisation of independent CCGT plant. The Government actions here were largely unintentional: their policies were not developed (as Rip and Kemp go on to propose) with the goal of a technological regime shift – in this case from coal-fired to gas-fired technology – but were rather the outcome of a more general wish to liberalise the industry. As discussed, very few politicians or industry analysts anticipated that such liberalisation would manifest itself in terms of CCGT technology (5.3.3, 5.4.4). Nevertheless, however unwitting its consequences, the Government's direct intervention in the institutional, regulatory, and financial structure of the ESI was an essential precursor to the technological regime shift which followed.

In all of this, the introduction of CCGT technology into the British ESI during privatisation conforms particularly well with Rip and Kemp's characterisation of the dynamics of radical innovation. Beyond this, Rip and Kemp's more general observations on the nature of technological change are also upheld by the present case. The lack of anticipation of the dash-for-gas amongst politicians, industry figures and independent analysts (5.3.1), reflects Rip and Kemp's observation that "technical change has its own dynamics, somewhat independent from firm strategies and actor goals in general". Finally, as has been argued throughout this study, the changes in the British ESI can best be understood in terms of an interaction between distinctive technological, economic, and political forces – or in Rip and Kemp's terms, as a "process of co-evolution of technology and society".

7.6 Conclusions: Technology Studies and the Analysis of ESI Privatisation

7.6.1 Introduction: The Limits of Theory

As stated in Chapter 2, the concepts and models from the technology studies literature discussed here have not been presented as competing or as mutually exclusive. Neither has an attempt been made to establish a comprehensive model for explaining the process of change in the British ESI before and after privatisation. Rather, in reflection of the complexity of the process of technological change and the variety of influences shaping it, it has been argued that the use of a range of analytical concepts and models is most appropriate. The development of generation technology has been the product of particular technical, economic, legislative, regulatory, institutional and political influences. The dominant technical forms of generation, and the pace and direction of change, have been the product of the complex interaction of all of these forces – changes to any one of which would have provided for different technological outcomes. Those analysts who have promoted the importance of one or two particular influences on change, and relegated others as insignificant, have inevitably lapsed into misleading oversimplification.

Within this, the different models considered above have been found to have distinctive points of strength and weakness that have proved more or less appropriate at different points in the ESI's history. At the same time, the present case has offered support for some approaches, and exposed flaws and weaknesses in others. In the distinctive periods of the industry's history, before, during, and after privatisation, there are clear differences in the character and weight of the different influences on change, and on the most appropriate analytical approaches for their examination; these are now briefly summarised

7.6.2 Technology Studies Theory and the ESI before Privatisation

Before privatisation, up to 1987, the pattern of generation technology in the British ESI was primarily governed by powerful institutional and political interests. Sustained institutional backing meant that considerable momentum was built up behind large steam turbine plant and nuclear power, reflected in continued incremental progress in steam conditions and scale economies up to the 1970s. After 1970, the technical and economic progression of established generation technology began to falter, but the continued support of government and the CEGB up to 1987 meant that this had no significant impact on plant choice. Financial and economic pressures carried little influence in this period. Rather, there was a powerful technocratic orientation in the industry, particularly under the structure set up after 1957, which was dominated by the CEGB.

The strength of embedded institutional and political power in this period was such that micro-level analytical approaches, such as social constructivism and actor-network theory, are inappropriate, in that they are unable to reflect the restrictions on technology choice. Hughes' sociotechnical systems model is of much greater value as applied to the nationalised ESI, and is apparently well fitted to the character of change – high momentum and incremental innovation under the control of identifiable system-builders – in this period. At the same time, however, the systems model tends to over-estimate the authority of ESI system-builders, and underplay the importance of less obvious supportive economic and political context. Other approaches, such as Russell's institutional interests, and MacKenzie's focus on the political role of technical expertise, are a necessary complement to the systems approach here. The apparent dominance of technocracy and technology-led solutions to the choice of generation technology in this period gave credibility to autonomous and determinist notions.

7.6.3 Technology Studies Theory and the ESI during Privatisation

During privatisation itself, political dynamics necessarily assumed dominance over technical, economic or other influences. The primary influence on the ESI and on changes in generation technology, resided inevitably with the Government – in particular, its desire to liberalise generation and at the same time secure the successful privatisation of nuclear power. These two policy goals found regulatory and organisational form in significant steps towards liberalisation, but also to some remaining institutional power and political intervention. Nevertheless, ESI liberalisation rendered impotent the technocentric interests that had been a dominant influence on the development of generation technology in the nationalised ESI. During the course of privatisation, the dominant generation technologies were displaced as new investment options, in preference for CCGT technology, which although previously unused, offered a much better fit to the new economic, regulatory and institutional framework for the industry.

Hughes' sociotechnical systems approach becomes much less appropriate for the British ESI after 1987, and it is unable to account for the breakdown of mature systems other than in the most general terms. Nevertheless, particular aspects of the systems model remain useful, particularly in capturing the role of CCGT technology as both cause and effect of change. The overriding influence of Government in the privatisation process means that social constructivism and actor-network theory remain of limited value. During this period, particularly valuable perspectives are provided by Hård's conflict model, and Russell's institutional interests approach, both of which are concerned with the more overtly political aspects of technological change. The dash-for-gas also provides a powerful example of Rip and Kemp's characterisation of radical innovation and the displacement of technological regimes. At the same time, the demise of technocracy in the privatisation process exposed the fallacy of technological autonomy and determinism as applied to generation technology.

7.6.4 Technology Studies Theory and the ESI after Privatisation

After privatisation the British ESI developed in response to new imperatives. Within the limits of the Government-constructed framework for the industry, financial and economic factors became a powerful influence on investment in new generation plant. Those bodies which retained some institutional power: National Power, PowerGen and the RECs, were no longer able to dictate the direction and pace of change in the industry solely on the basis of their own interests, but were instead forced to respond to competitive regulatory and economic pressures. CCGTs was the only technology adopted for new large-scale generation plant in this period. The direct influence of government on generation technology choice was much reduced. Nevertheless, certain institutional interests and rivalries – notably the rivalry between the large generators and the RECs, and Conservative Government support for nuclear power and antipathy towards the British coal industry – remained powerful influences on changes in generation technology.

Economic and regulatory liberalisation was reflected in the emergence of independent generation technology projects, and micro-level approaches, particularly actor-network theory, became much more readily applicable. At the same time, technological development in the post-privatised ESI remains substantially mediated by meso-level institutional interests and structures which are more suited to alternative analytical approaches such as that provided by Russell or Rip and Kemp. Hughes' sociotechnical systems approach is of less value to the post-privatised ESI, although particular aspects of his model – such as the distinction between system and context, and the action of the technical core, remain of value. In addition, changes in generation technology remain predicated on the wider historic and political context for the industry, full consideration of which requires a broad social shaping perspective, such as that offered by Hughes and MacKenzie.

7.6.5 Comment: The Analysis of Technological Change

The concepts and models of technology studies have provided considerable insight into the process of change in the British ESI. In particular, they have allowed for consideration of the distinctiveness of techno-economic dynamics, as they evolve alongside – and interact with – ongoing economic, institutional, and regulatory changes. They have also enabled attention to be given to both the *social shaping of technology* and the *technological shaping of society* –specifically, the ways in which developments in generation technology acted as both cause and effect of wider changes to the ESI.

In applying the technology studies literature to the changes in generation technology associated with British ESI privatisation, however, no single model or conceptual framework has proved capable of a fully-satisfying explanation. Electricity generation technologies are the result of the complex interaction of a range of technical, economic, institutional, regulatory and political forces, operating at various level of social aggregation, whose analysis ultimately requires a broad based social shaping perspective. As the British ESI case demonstrated, technological dynamics retain a distinctive quality and an essential unpredictability within the broader process of economic and social change. In exploring these relations, the insights offered by technology studies concepts and models, whilst being necessarily limited, are of continuing value.

Although this study has not been directed primarily at policymaking in the energy/electricity industries, a number of policy and management lessons can be drawn from its findings. Firstly, whilst the British ESI developed under nationalisation apparently in accordance with technical and economic imperatives, excessive centralisation and technocentrism led to the pursuit of grossly uneconomic forms of generation, that failed to reflect prevailing technological and economic opportunities. As a result, by the mid-1980s, the large British generators and plant manufacturers were internationally uncompetitive, and in a poor position to respond to the challenges of liberalisation and privatisation. This suggests that, as far as is possible, electricity generation technology should be developed within a decentralised and competitive financial, institutional and regulatory framework. At the same time, market forces need to be tempered in the ESI by the need for some central co-ordination of supply and demand, and for sustained commitment to long-term research and development of generation technology options.

Technological change is a complex process, the outcome of a range of technical, economic, organisational and political influences. Whilst technological change is shaped by, and embodies, prevailing economic and political interests, it cannot be controlled by them. Rather, it has its own distinctive dynamism, stemming from unpredictable developments in scientific and technological knowledge and practice. Even in a context of apparently entrenched institutional control, technological dynamics have the potential to introduce unpredictability and subvert established practices and authority. Social science concepts and models which fail to recognise this as a starting point are inevitably misleading and misdirected. Despite this complexity and unpredictability, however, the analysis of technological change as a social process is not without value or reward. In establishing patterns and parallels in technological developments, and by exposing the often hidden forces laying behind such developments, technological change may then be seen more realistically – not as an external force impacting on society, but as a distinctive element within the wider process of social change.

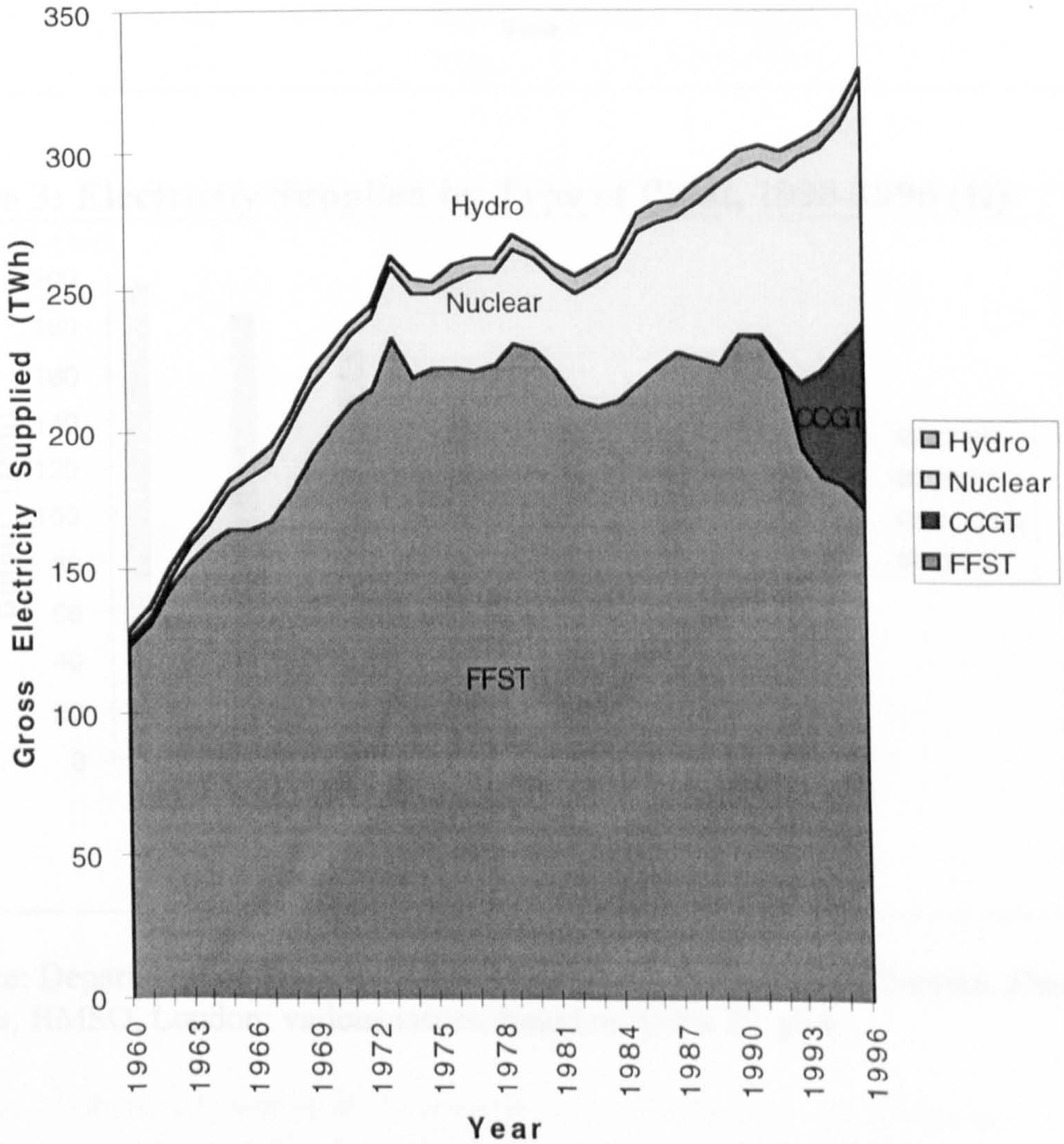
APPENDIX 1:

HISTORIC AND PROJECTED CHANGES IN GENERATION TECHNOLOGY IN THE BRITISH ESI

Key:

FFST:	Fossil Fuel Fired Steam Turbine Plant
CFST:	Coal Fired Steam Turbine Plant
OFST:	Oil Fired Steam Turbine Plant
CCGT:	Combined Cycle Gas Turbine Plant
Nuclear:	Nuclear Power Plant
Hydro:	Hydro-Electric Power Plant

Figure 1: Gross Electricity Supplied by Type of Plant, 1960-1996



Source: Department of Trade and Industry, *Digest of United Kingdom Energy Statistics 1997*, London, HMSO, 1997; based on Table 66, p151.

Figure 2: Electricity Supplied by Type of Plant, 1990-1996 (I)

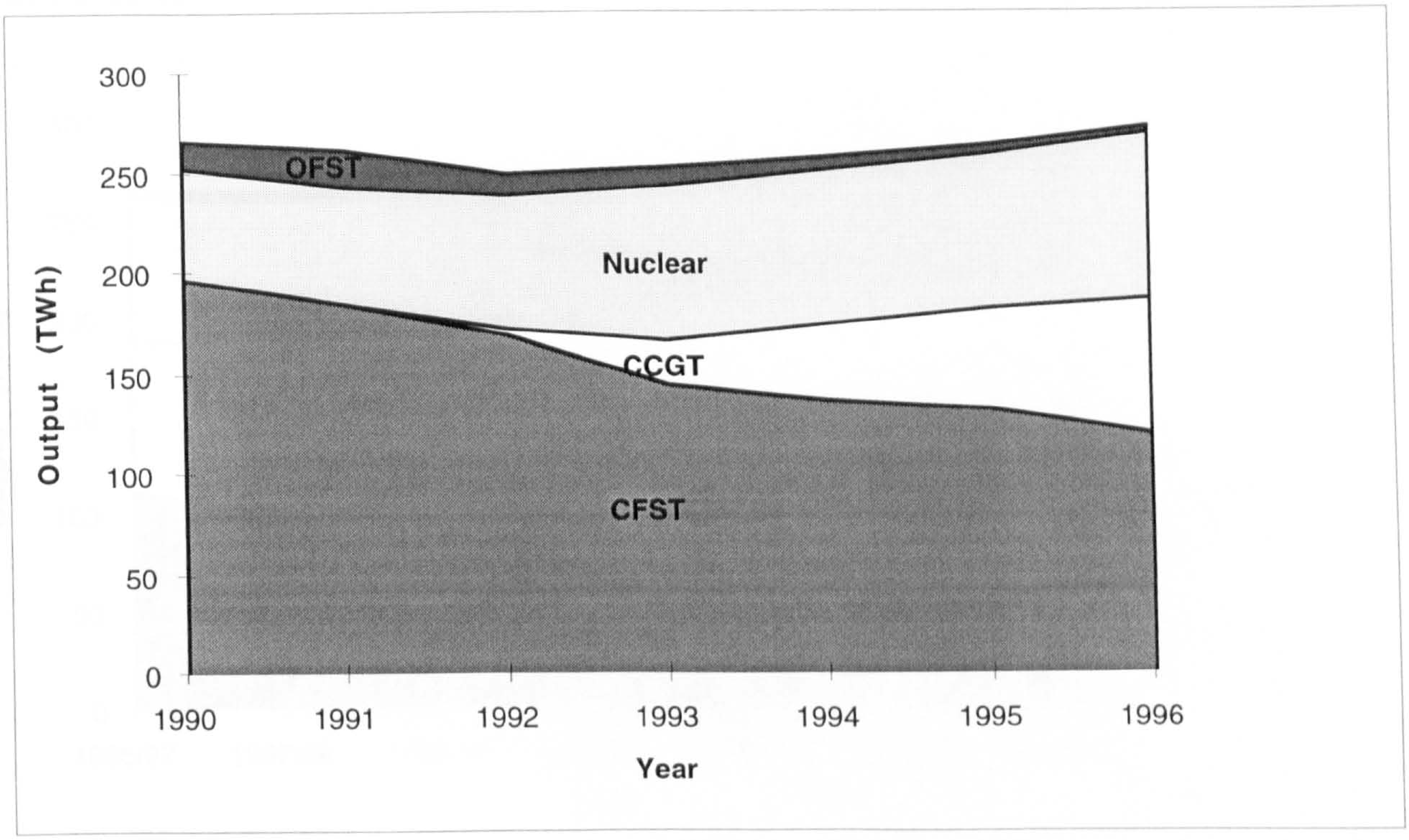
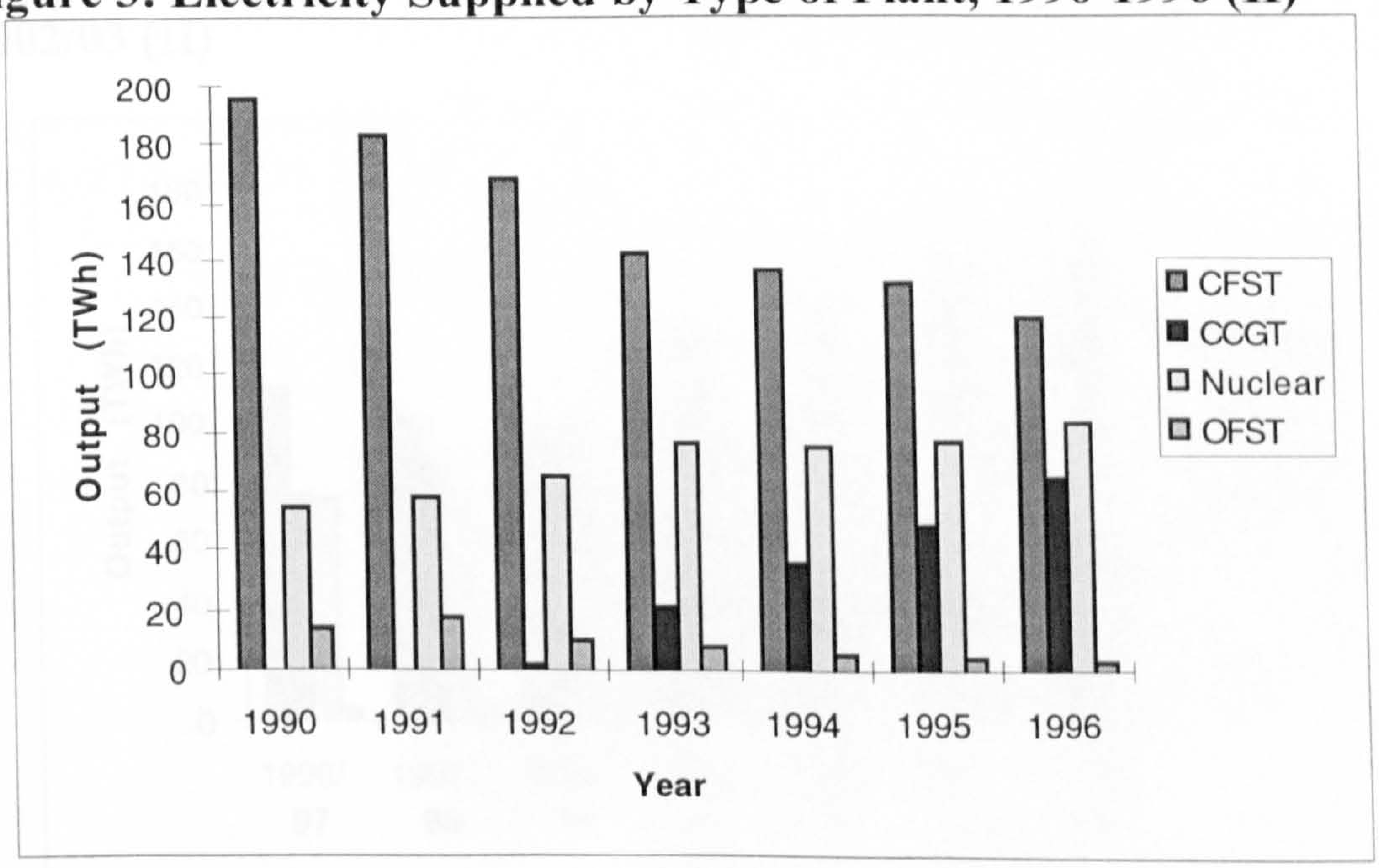


Figure 3: Electricity Supplied by Type of Plant, 1990-1996 (II)



Source: Department of Trade and Industry/Government Statistical Service, *Energy Trends*, HMSO, London; various issues; based on Table 22, p14.

Figure 4: Projected Electricity Supplied by Type of Plant, 1996/97-2002/03 (I)

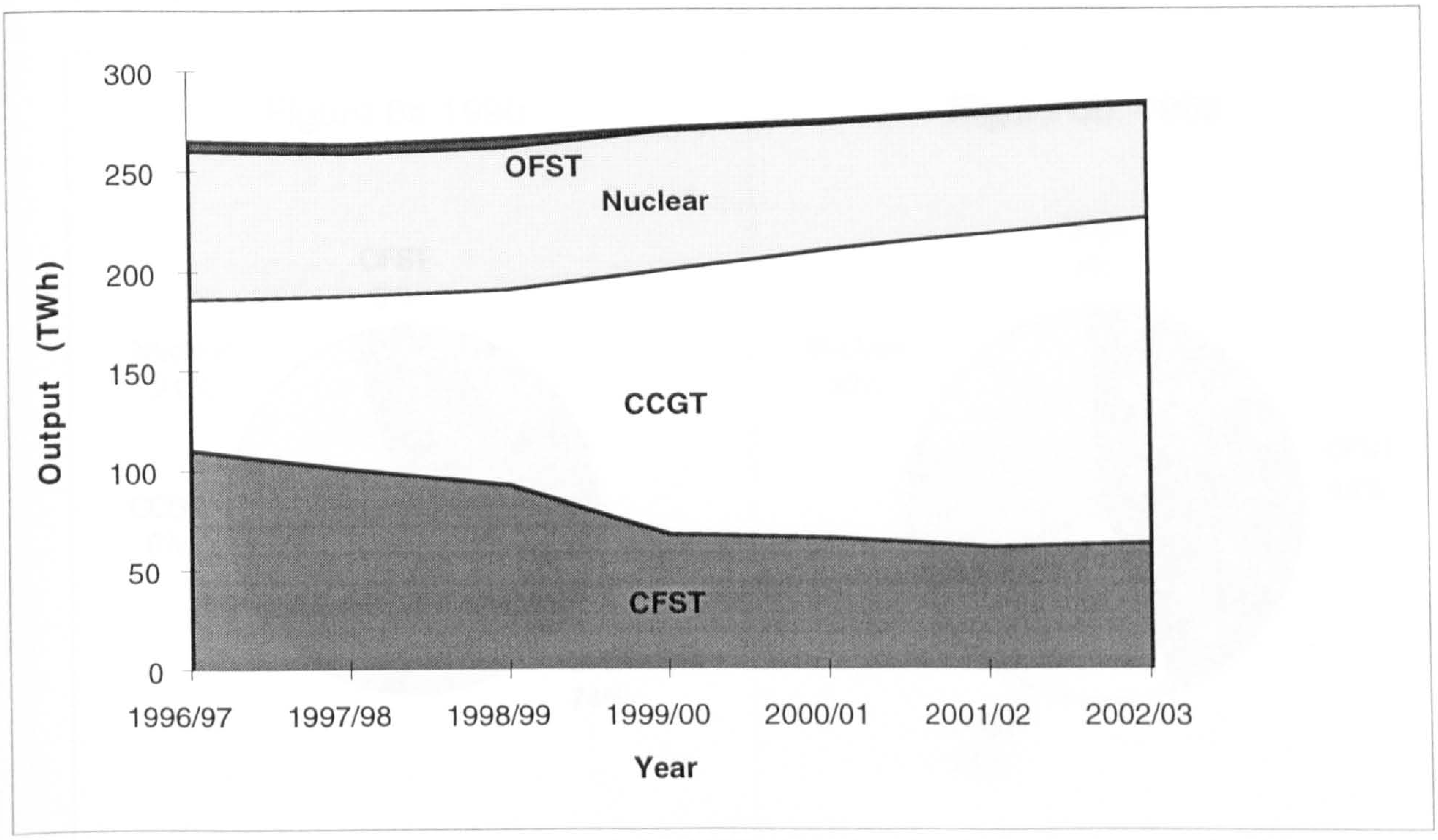
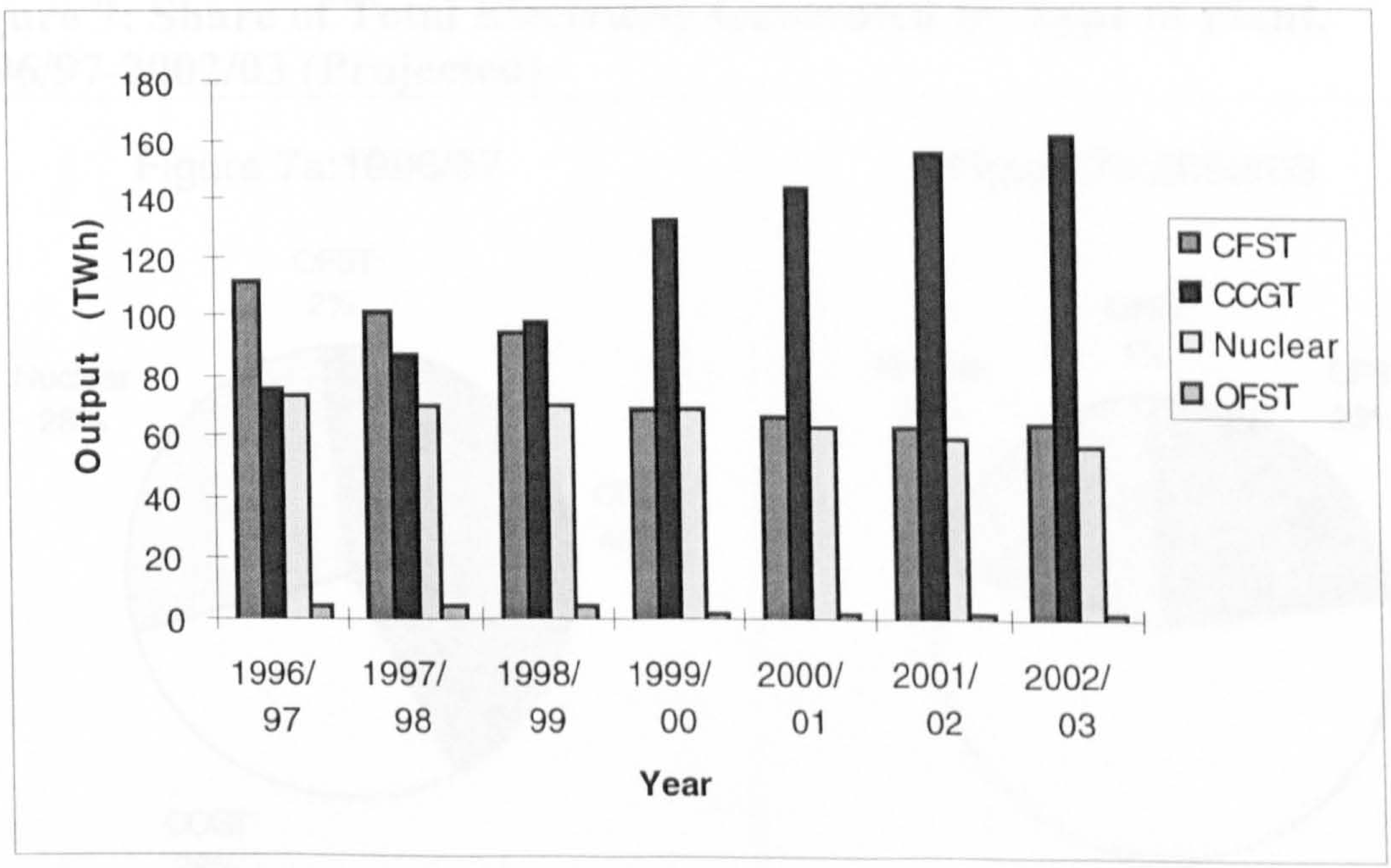
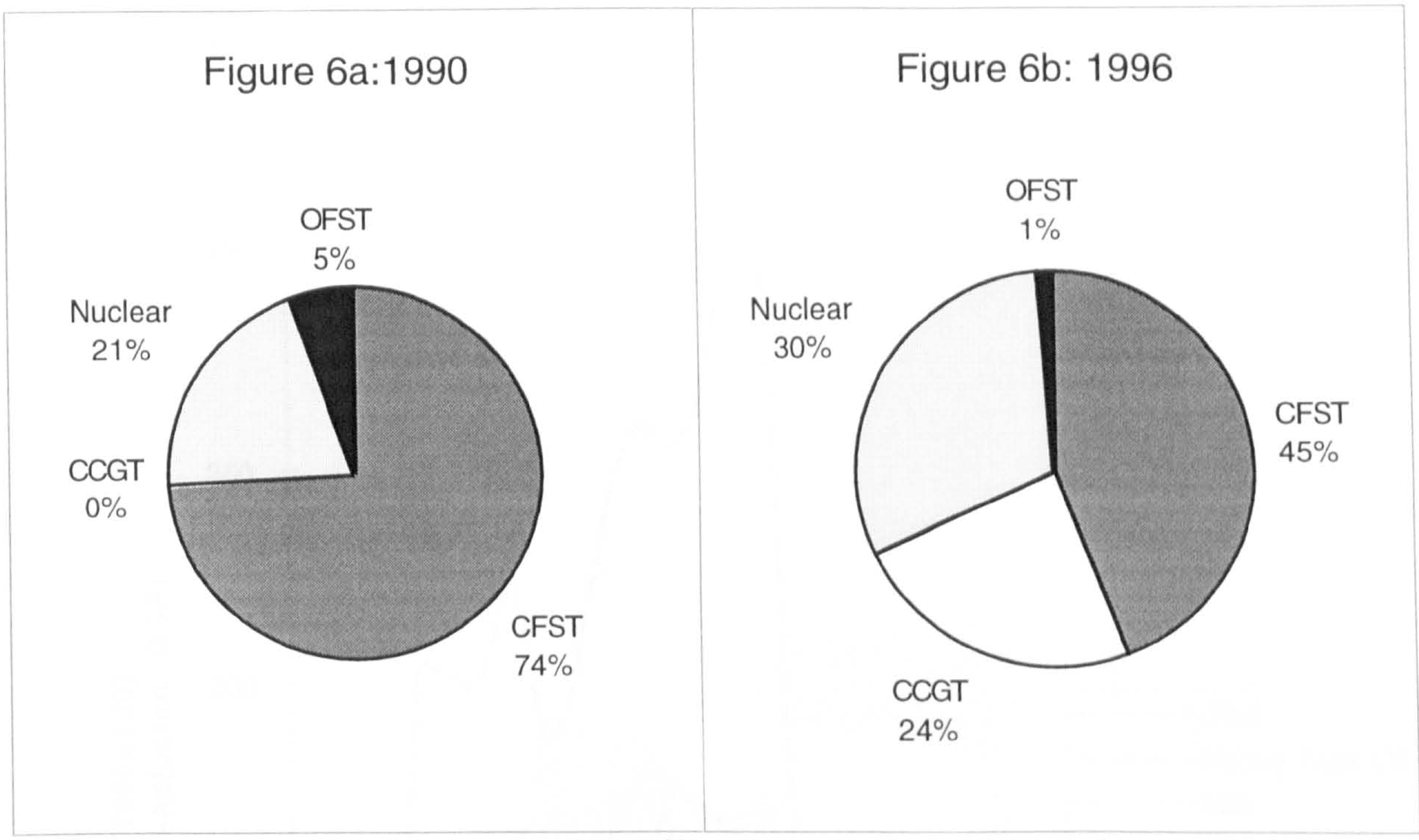


Figure 5: Projected Electricity Supplied by Type of Plant, 1996/97-2002/03 (II)



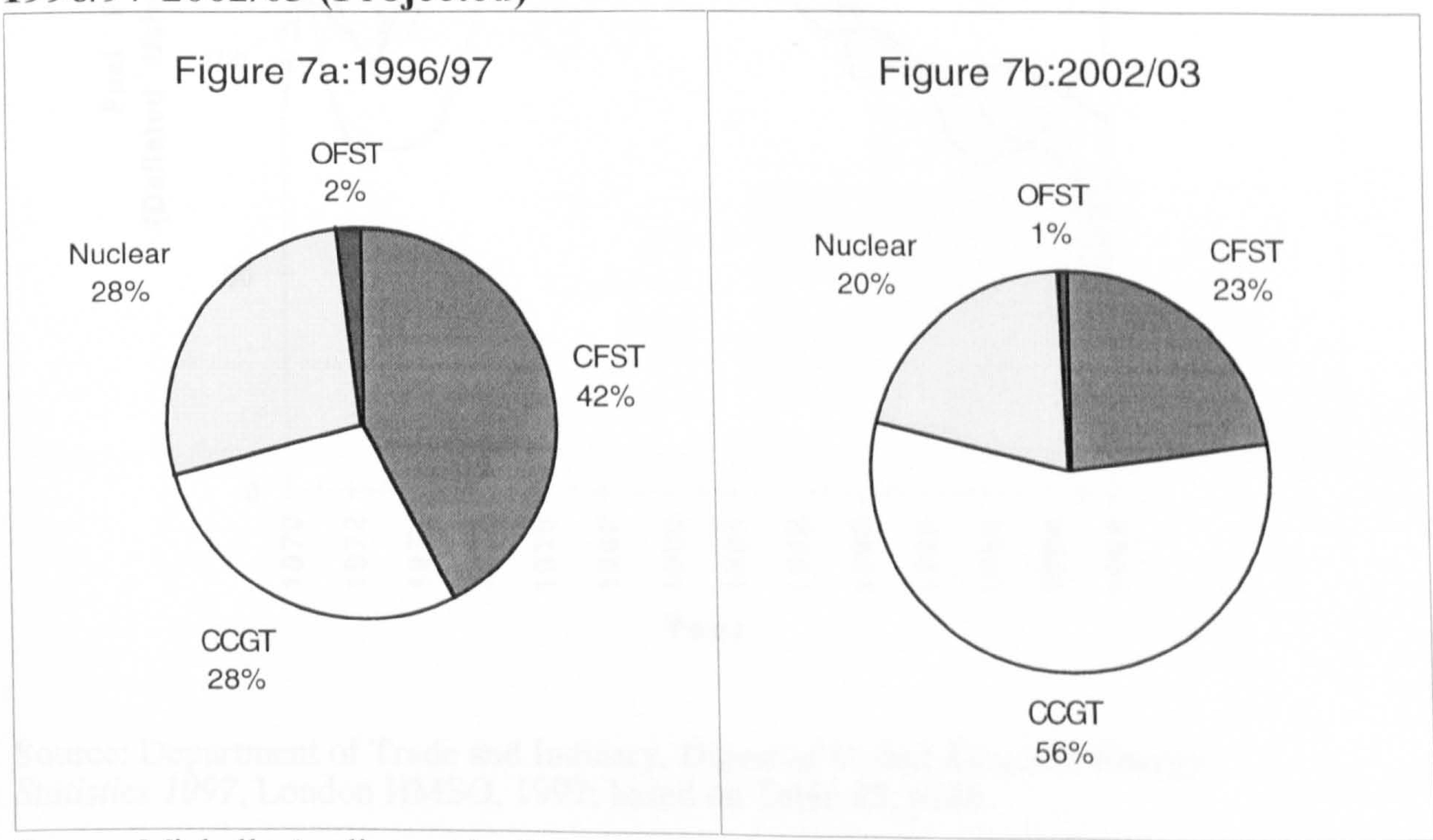
Source: Michelle Aveline et al., *Generation in the 1990s: The 1996 edition*, Oxford, Oxford Economic Research Associates, 1996; based on table 4.23, p47.

Figure 6: Share of Total Electricity Generated by Type of Plant, 1990-1996



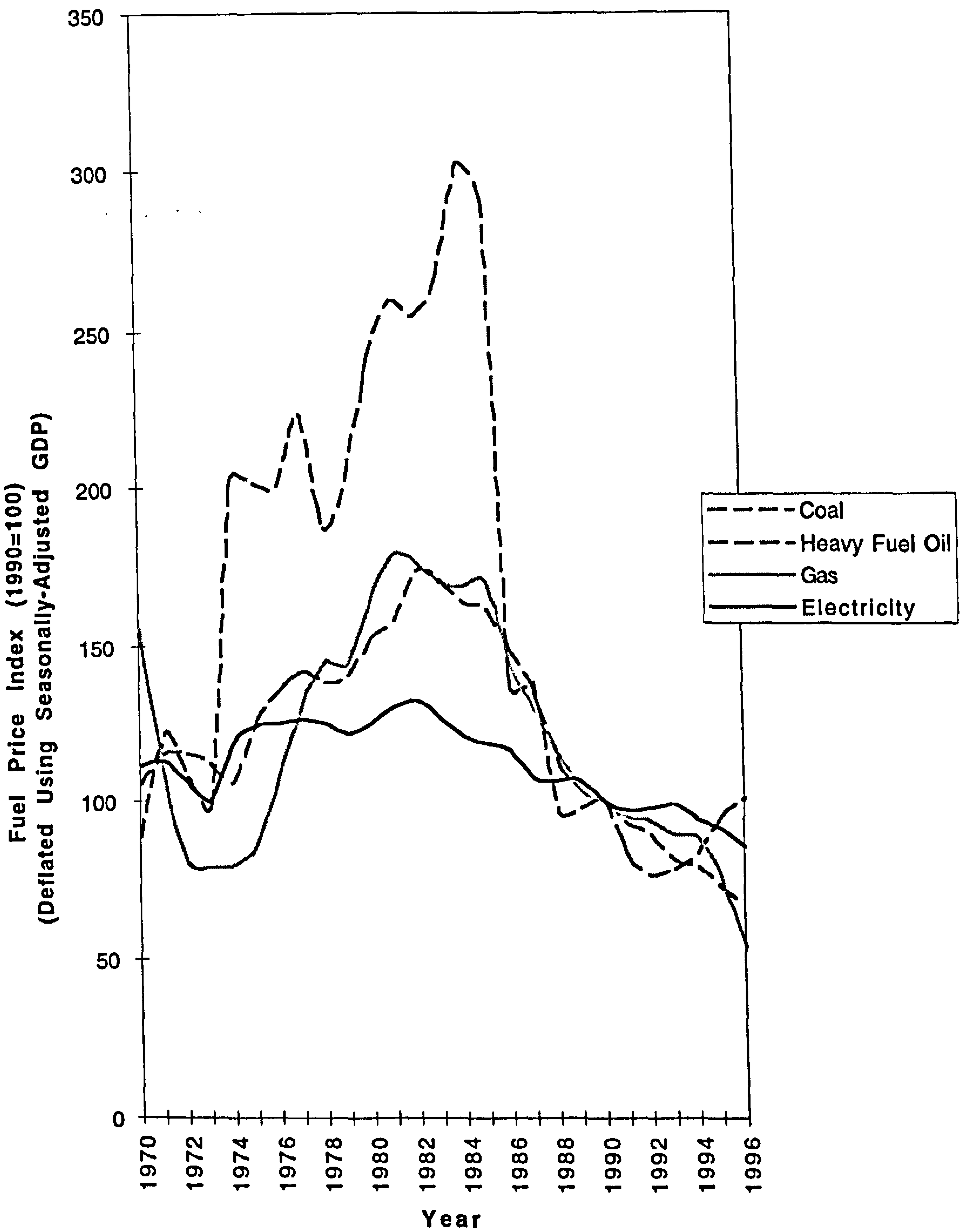
Source: Department of Trade and Industry/Government Statistical Service, *Energy Trends*, HMSO, London; various issues; based on Table 22, p14

Figure 7: Share of Total Electricity Generated by Type of Plant, 1996/97-2002/03 (Projected)



Source: Michelle Aveline et al., *Generation in the 1990s: The 1996 edition*, Oxford, Oxford Economic Research Associates, 1996. Based on Table 4.23, p47

Figure 8: Fuel Price Index for the British Industrial Sector, 1970-1996



Source: Department of Trade and Industry, *Digest of United Kingdom Energy Statistics 1997*, London HMSO, 1997; based on Table 85, p186.

APPENDIX 2: POWER PLANT LAYOUTS

Figure 1: Coal-Fired Steam Turbine Plant

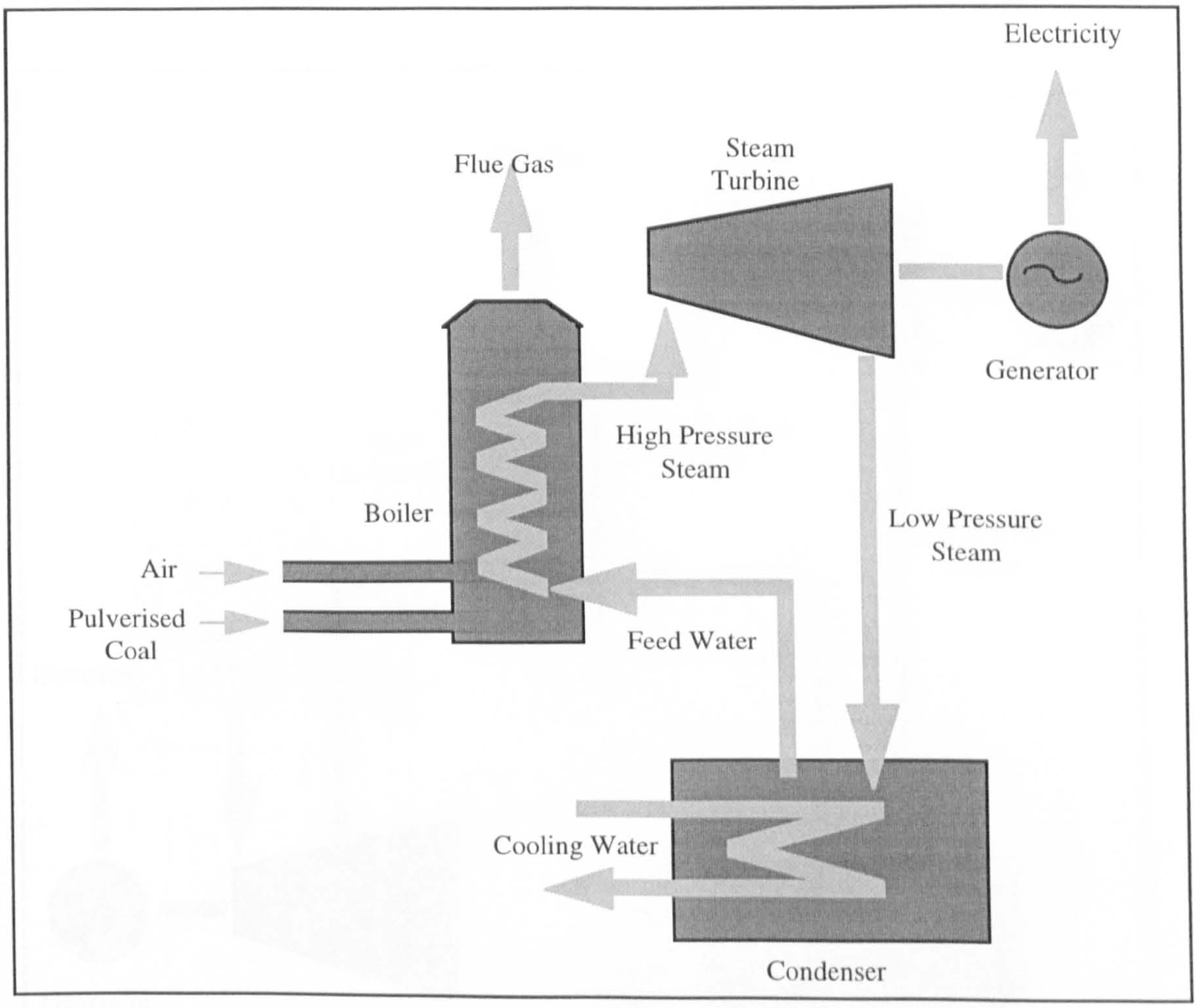


Figure 2: Combined Cycle Gas Turbine Plant

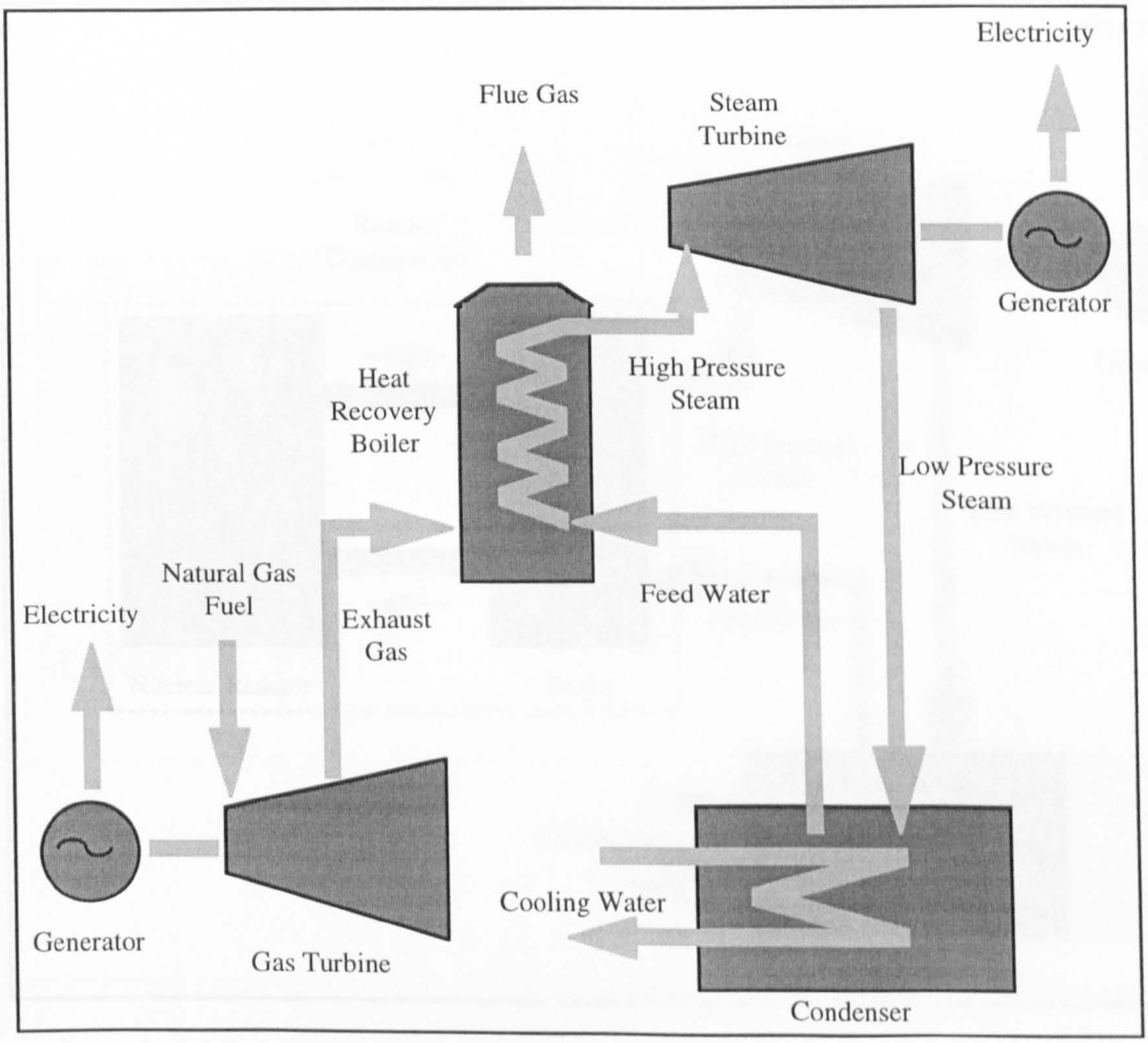


Figure 3: Thermal Nuclear Power Plant

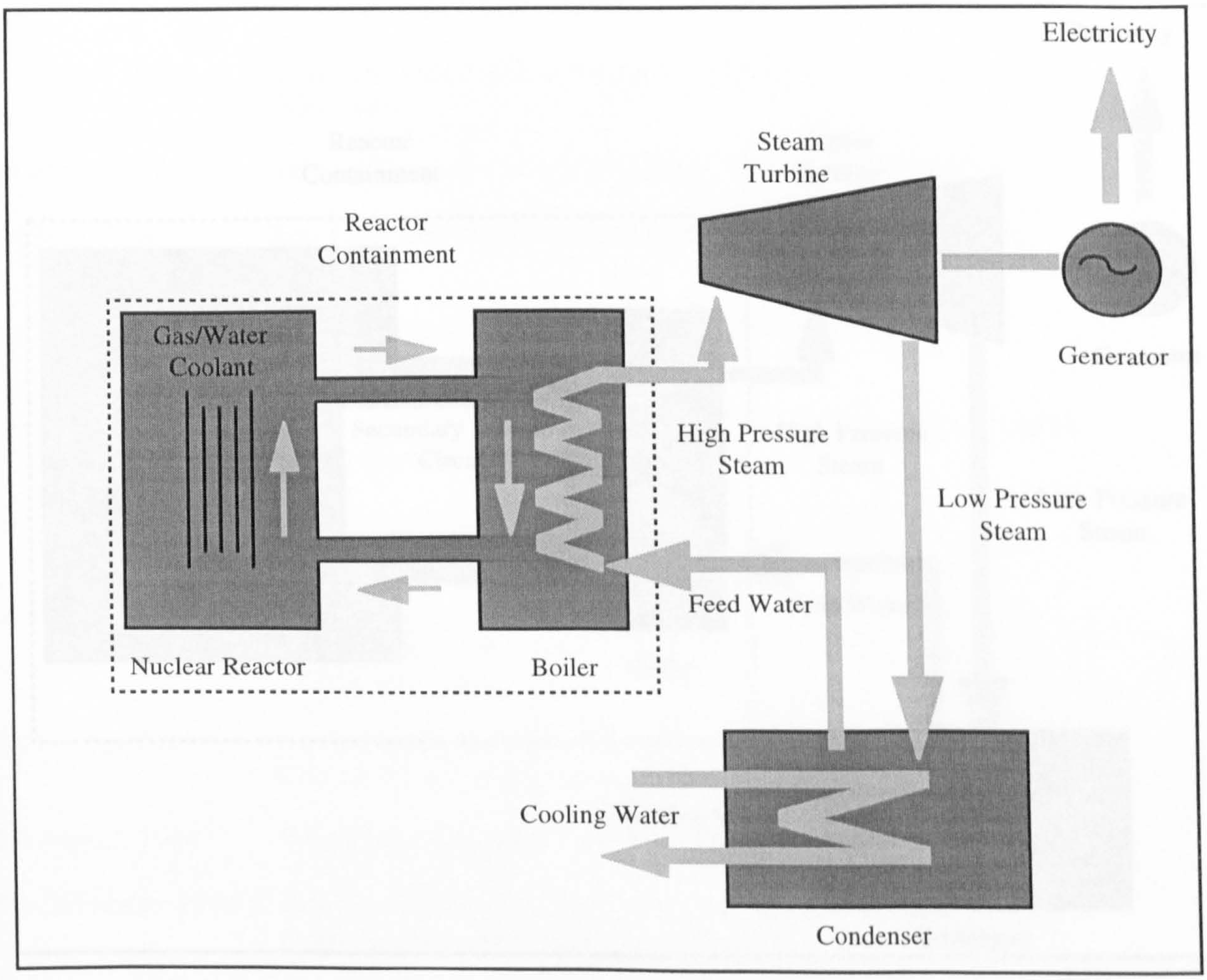
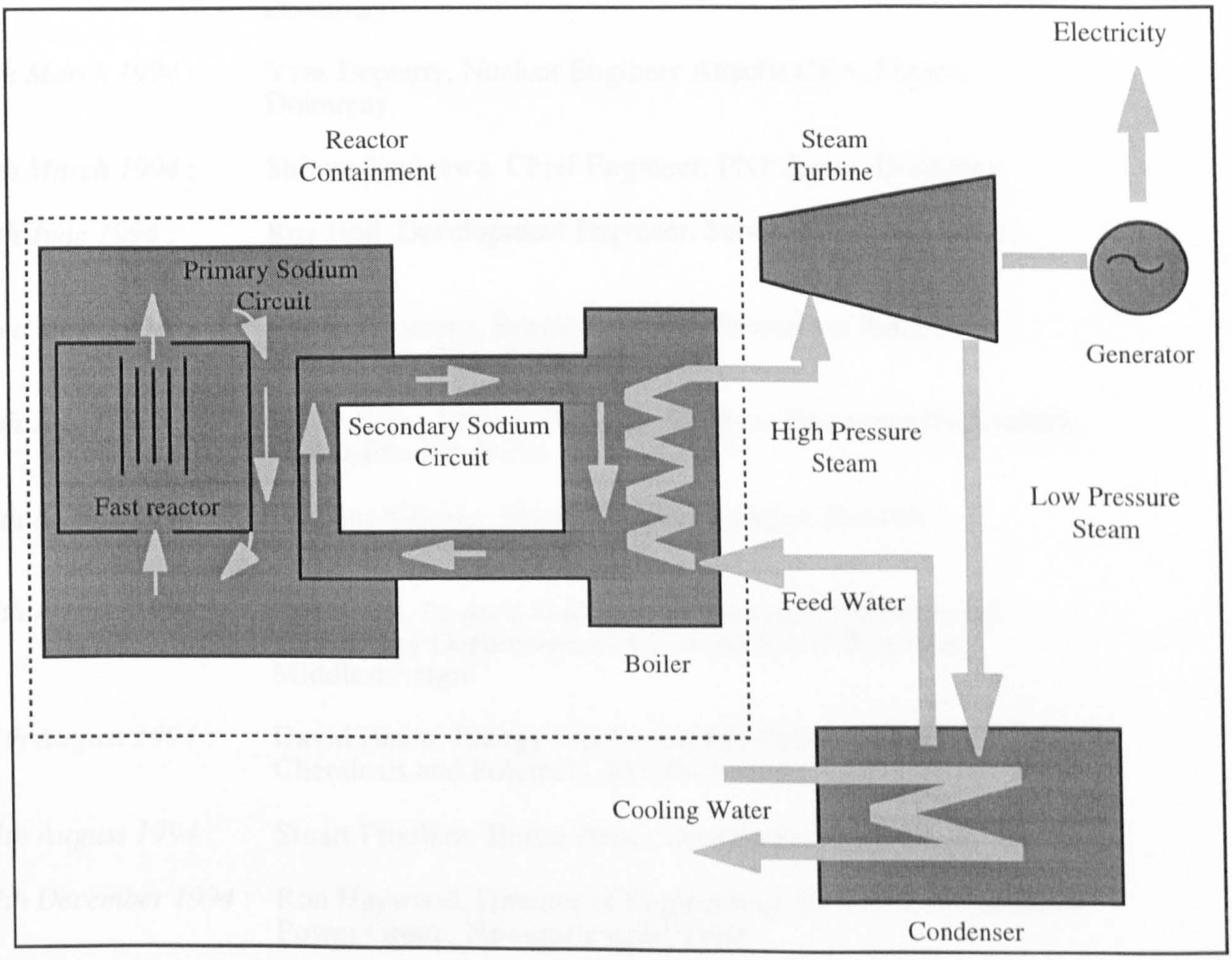


Figure 4: Fast Reactor Nuclear Plant



APPENDIX 3:

PERSONALLY-CONDUCTED INTERVIEWS

17th March 1994 :	Alistair Cruickshank, Special Projects Manager, AEA Technology, Dounreay.
17th March 1994 :	Evan Sutherland, PFR Power Plant Manager AEA Technology, Dounreay.
18th March 1994 :	Yves Depierre, Nuclear Engineer Attache CEA, France, Dounreay.
18th March 1994 :	Shingo Tanigawa, Chief Engineer, PNF Japan, Dounreay.
20th June 1994 :	Roy Hall, Development Engineer, Scottish Hydro-Electric, Perth.*
22nd June 1994 :	Roger Semmens, Senior Engineer, PowerGen Ratcliffe Technology Centre, Nottingham.*
27th July 1994 :	Phil Inskipp, Project Manager, Business Development,Scottish Hydro-Electric, Perth.
18th August 1994 :	Graham Wilman, Major Projects Manager, Norweb Generation, Manchester.
24th August 1994 :	Phil Smith, Projects and Services Manager, Research and Technology Department, ICI Chemicals and Polymers, Middlesbrough.
24th August 1994 :	David Hearn, Energy Purchasing and Policy Group ICI Chemicals and Polymers, Middlesbrough.
24th August 1994 :	Stuart Ffoulkes, Enron Power Operations, Stockton-on-Tees.
13th December 1994 :	Ron Haywood, Director of Engineering, Rolls-Royce Industrial Power Group, Newcastle upon Tyne

* Telephone Interviews

BIBLIOGRAPHY

General Bibliography

Alberry, P. J., Davidson, B. J., and Corey, M., 'Advanced Gas Turbine Power Generation', in *Energy for the 21st Century*, I.Mech.E. Seminar 1996-3, London, pp27-32

Andrews, D., 'Joining Forces', *International Power Generation*, March 1988, pp19-22

Armstrong, F. W., 'Gas Turbine Evolution', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference 1976-I, London, 4-5th February, 1976, pp1-15

Aveline, M., *European Utilites Yearbook 1993*, Oxford, Oxford Energy Research Associates, 1993

Aveline, M. and Mason, L., *Generation in Europe*, Oxford, Oxford Energy Research Associates, 1994

Aveline, M., Brough, M. and Sgori, D., *Generation in the 1990s: Electricity Capacity and New Power Projects: The 1996 Edition*, Oxford, Oxford Energy Research Associates, 1996

Awerbuch, S., et al., 'Capital Budgetting, Technological Innovation and the Emerging Competitive Environment of the Electric Power Industry, *Energy Policy*, Vol.24, No.2, pp195-202, February 1996

Barclay, C., *Electricity in the UK and Abroad*, London, House of Commons Library Research Papers, 95/130, 1995

Barnes, B., 'Review of Thomas Hughes' 'Networks of Power', *Social Studies of Science*, Vol.14, 309-314, 1984

Bijker, W. E., 'Do Not Despair: There is Life after Constructivism', *Science, Technology and Human Values*, Vol.18, No.1, pp113-138, Winter 1993

Bijker, W. E., *Of Bicycles, Bakelites and Bulbs: Toward a Theory of Sociotechnical Change*, Cambridge MA, MIT Press, 1995

Bijker, W. E., Hughes, T. P., and Pinch, T., (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987

Bijker W. E. and Law, J., (eds.) *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992

Bijker, W. E. and Law, J., 'General Introduction' in Bijker, W. E. and Law, J. (eds.), *Shaping Technology/Building Society,Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp1-14

Bishop M., Kay J., Mayer C., 'Introduction: Privatization in Performance' in Bishop M., Kay J., Mayer C., (eds.), *Privatization and Economic Performance*, Oxford, Oxford University Press, 1994, pp1-31

Bowers, B., *A History of Electric Light and Power*, Stevenage, Peter Peregrinus, 1982

Broadley, D. and Judd, A. M., 'The European Fast Reactor', *Atom*, Vol.396, pp25-31, October 1989

Broomfield, A. M., 'Fast Reactor Development Programme', *Atom*, Vol.395, pp6-9, September 1989

Broomfield, A. M., 'PFR Builds Firm Foundations for Fast Reactors', *Atom*, Vol.433, pp22-26, March/April 1994

Brown, Sir Stanley, *The Next 25 Years in the Electricity Supply Industry*, London, Institute of Electrical and Electronics Technician Engineers, London, November 1970

Bruce, A., 'Heseltine's 'Reprieved' Pits: Twelve Months On', *Energy Policy*, Vol.22, No.5, pp432-435, May 1994

Bruce, A., and Wright, M., ' Privatising British Coal: An Evolving Policy Problem', *Energy Policy*, Vol.22, No.1, pp57-67, January 1994

Burbridge, R. N., 'Development of 900MW Coal-Fired Generating Units', *Power Engineering Journal*, May 1988, pp147-154

Burdon, I. P., 'Competition, Control and the Common Good', *Power Engineering Journal*, November 1992, pp267-277

Byatt, I. C. R., *The British Electrical Industry 1875-1914: The Economic Returns to a New Technology*, Oxford, Oxford University Press, 1979

Callon, M., 'The Sociology of an Actor-Network: The Case of the Electric Vehicle', in Callon, M., Law J., and Rip, A., (eds.), *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World*, Basingstoke, MacMillan, 1986, pp19-34

Callon, M., 'Society in the Making: The Study of Technology as a Tool for Sociological Analysis', in Bijker, W. E., Hughes, T. P., and Pinch, T. (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge MA, MIT Press, 1987, pp83-103

Callon, M., Law J., and Rip A., (eds.), *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World*, Basingstoke, MacMillan, 1986

Carlson, W. Bernard, 'Artifact and Frames of Meaning: Thomas A. Edison, His Managers, and the Cultural Construction of Motion Pictures', in Bijker W. E. and Law J. (eds.), *Shaping Technology/Building Society:Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp175-198

Centre for the Study of Regulated Industries, *The UK Electricity Industry: Electricity Services and Costs 1992/93*, London, Chartered Institute of Public Finance Accounting, February 1994

Centre for the Study of Regulated Industries, *CRI Review of Electricity Services, Costs, and Financial Results 1995/96*, London, Chartered Institute of Public Finance Accounting, June 1997

Chappell, T. E. and Joyce, J. S., *The Environmental Aspects of the Killingholme Combined Cycle Power Plant*, I.Mech.E. Paper c410/056, International Conference on Power Generation and the Environment, London, November 13-14th, 1990

Chappell, T. E., 'The 900MW Combined Cycle Gas Turbine Power Station at Killingholme', *Proc. I. Mech. E., Part A, Journal of Power Energy*, Vol. 207, No. A3, pp147-155, 1993

Chappell, T. E. and Joyce, J. S., 'The Commissioning of PowerGen's Combined Cycle Stations at Killingholme and Rye House', in *Commissioning and Operation of Combined Cycle Plant,* I.Mech.E. Seminar 1994-9, London, 1st November 1994, pp69-77

Charles, D., 'In Search of Better Burn', *New Scientist,* 23rd January 1993, pp21-25

Clark, J. R., *Killingholme Powergen Combined Cycle Gas Turbine Power Station: Progress and Politics*, London, The Institution of Chemical Engineers, 1991

Chesshire, J., 'Why Nuclear Power Failed the Market Test in the UK', *Energy Policy*, Vol.20, No.8, August 1992, pp744-754

Clark, N., *The Political Economy of Science and Technology*, Oxford, Basil Blackwell, 1985

Cohen, H., Rogers, G. F. C., and Sarvanamuttoo, H. I. H., *Gas Turbine Theory*, 4th Edition, Harlow, Longman, 1996

Collingridge, D., *The Social Control of Technology*, London, Pinter, 1980

Collingridge, D., *The Management of Scale: Big Organisations, Big Decisions, Big Mistakes*, London, Routledge, 1992

Constant, E. W. II, *The Origins of the Turbojet Revolution*, Baltimore, The John Hopkins University Press, 1980

'Cooking with Gas', *International Power Generation*, September 1992, pp86-88

Coombs, R., Saviotti, P., and Walsh, V., *Economics and Technological Change*, Basingstoke, MacMillan, 1987

Coombs, R., Saviotti, P., and Walsh, V., (eds.), *Technological Change and Company Strategies: Economic and Sociological Perspectives*, London, Academic Press, 1992

Cooper, C., 'Excitement Returns to Electrical Power Engineering', *Power Engineering Journal*, August 1994, pp154-155

Coutard, O., 'Economics of Grid Systems in Reconfiguration: Competition in the Electricity Supply Industry' in Summerton, Jane (ed.),*Changing Large Technical Systems*, Boulder, Colorado, Westview Press, 1994, pp163-189

Cross, E. D., *Electric Utility Regulation in the European Union: A Country by Country Guide*, London, Wiley, 1996

Cross, M., 'A Very Dirty Business', *New Scientist,* 23rd January 1993, pp28-31

Cross, M., 'Nuclear Power on Britain's Back Burner', *New Scientist*, 6th November 1993, pp34-39

David, P. A., 'Heroes, Herds and Hysteresis in Technological History: Thomas Edison and 'The Battle of the Systems' Reconsidered', *Industrial and Corporate Change*, Vol.1, No.1, pp129-180, 1992

Davidson, B., 'Clean Coal Technologies for Electricity Generation', *Power Engineering Journal*, December 1993, pp257-263

Dettmer, R., 'A New Deal for Nuclear', *IEE Review*, September 1994, pp213-216

Doyle, G. and Maclaine, D., *Power as a Commodity: The Future of the UK Electricity Supply Industry*, London, FT Energy Publishing/Pearson, 1996

Edge, D., 'The Social Shaping of Technology', Edinburgh University Research Centre for Social Sciences, PICT Working Paper No.1, 1988

Edgerton, D., 'Essay Review: Tilting at Paper Tigers: Review of Donald MacKenzie's Inventing Accuracy', *British Journal for the History of Science*, Vol. 26, pp67-75, 1993

Edwards, P. N., 'From 'Impact' to Social Process: Computers in Society and Culture', in Jasanoff, S., et al., (eds.), *Handbook of Science and Technology Studies*, Thousand Oaks, California, Sage, 1985

Elliott, B., (ed.), *Technology and Social Process*, Edinburgh, Edinburgh University Press, 1988

Elliott, D. A., 'New Technology and Restructuring in the UK Energy Industry: The Case of Renewable Energy',*Technology Analysis and Strategic Management*, Vol.2, No.3, pp253-263, 1990

England, G., *The Gas Turbine – A Successful Developing Technology*, London, CEGB, 1978

'ESI is Ripe for Privatisation', *Electronics and Power*, August 1987, pp486-487

Fairney, W., 'Power Generation in the 1990s', *Power Engineering Journal*, December 1993, p239

Fells, I., 'What Price Coal Research?', *New Scientist*, 12th June 1993, p43

Fells I, 'Plus ca Change...?', *Science and Public Affairs*, Summer 1993, pp3-4

Fischer, F., *Technocracy and the Politics of Expertise*, Newbury Park CA, Sage, 1990

Flavin C. and Lenssen N., 'Reshaping the Electric Power Industry', *Energy Policy*, Vol.22, No.12, pp1029-1044, 1994

Ford, P. and Ford, G., *A Breviate of Parliamentary Papers, 1917-1939*, Oxford, Basil Blackwell, 1951

Forrest, J. S., *One Hundred Years of Public Electricity*, Egham, PE Consulting Group, 1975

Freeman, C., *The Economics of Industrial Innovation*, London, Frances Pinter, 1982

'Gas Expands into European Power', *Modern Power Systems*, February 1991, pp27-29

George, B. V., 'The Nuclear Programme', *Power Engineering Journal*, July 1989, pp199-202

Gordon, R., *One Hundred Years of Electricity Supply 1881-1981: A Brief Account of Some Aspects of Growth and Development over the Past Century*, Hove, South Eastern Electricity Board, 1981

Gowing, M., *Britain and Atomic Energy 1939-45*, London, Macmillan, 1964

Gowing, M. (assisted by Arnold, L.), *Independence and Deterrence: Britain and Atomic Energy, 1945-52; Volume 2: Policy Execution*, London, Macmillan, 1974

Gray P., Aveline M., Brough M., and Mason L., *Generation in the 1990s: Electricity Capacity and New Power Projects*, Oxford, Oxford Energy Research Associates, 1994

Greenhalgh, G., 'Do We Need an Energy Policy?', *Atom*, Vol.421, March 1992, pp25-26

Hadfield, A., 'Energy for People', *Power Enginering Journal*, February 1993, pp7-16

Haigh, I. T., 'Lighter Fuel: The Gas Turbine Comes of Age', *IEE Review*, Vol.37, No.3, pp97-102, 21st March 1991

Ham, C. and Hill, M., *The Policy Process in the Modern Capitalist State*, Harvester Wheatsheaf, Hemel Hempstead, 1984

Hammond, E., Helm, D., and Thompson, D., 'Competition in Electricity Supply: Has the Electricity Act Failed', in Helm, D., Kay, J. A., and Thompson, D., (eds.), *The Market for Energy*, Oxford, Oxford University Press, 1989, pp157-177

Hannah, L., *Electricity Before Nationalisation: A Study of the Development of the Electricity Supply Industry in Britain to 1948*, London, MacMillan/The Electricity Council, 1979

Hannah, L., *Engineers, Managers and Politicians: The First Fifteen Years of Nationalised Electricity Supply in Britain*, London, MacMillan/The Electricity Council, 1982

Hård, M., 'Beyond Harmony and Consensus: A Social Conflict Approach to Technology', *Science, Technology, and Human Values*, Vol.18, No.4, pp408-432, Autumn 1993

Hård, M., 'Technology as Practice: Local and Global Closure Processes in Diesel-Engine Design', *Social Studies of Science*, Vol.24, pp549-85, 1994

Harmon, R. A.,'The Keys to Cogeneration and Combined Cycles', *Mechanical Engineering*, February 1988, pp64-69

Hawley, Dr. R., 'The Nuclear Review', *Power Engineering Journal*, April 1995, pp61-68

Haywood R., 'New Technologies in Power Generation', *Rolls-Royce Magazine*, No.62, pp11-14, September 1994

Heilbroner, R. L., 'Do Machines Make History?' in Smith, Merrit Roe, and Marx, Leo, (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp53-65

Heilbroner, R. L., 'Technological Dterminism Revisted', in Smith, Merrit Roe, and Marx, Leo, (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp67-78

Helm, D., Kay, J. A., and Thompson, D., (eds.), *The Market for Energy*, Oxford, Oxford University Press, 1989

Helm, D., et al., 'Generation in the 1990s: Electricity Capacity and New Power Projects', Oxford, Oxford Economic Research Associates, 1993

Hennessey, R. A. S., *The Electric Revolution,* Newcastle, Oriel Press, 1971

Henney, A., *Privatise Power: Restructuring The Electricity Supply Industry*, Policy Study No.83, London, Centre for Policy Studies, March 1987

Henney, A., 'Energy Markets and Energy Policies after the White Paper', *Energy Policy,* January 1994, pp5-13

Henney, A., *A Study of the Privatisation of the Electricity Supply Industry in England and Wales,* London, EEE Ltd, 1994

Hickman, L. A., (ed.), *Technology as a Human Affair,* New York, McGraw Hill, 1990

Hirsh, R. F. and Serchuk, A. H., 'Momentum Shifts in the American Electric Utility System: Catastrophic Change – Or No Change at All?', *Technology and Culture,* Vol.37, No.2, pp280-311, April 1996

Hinton, Lord of Bankside (Christopher), *Heavy Current Electricity in the UK: History and Development,* Oxford, Pergamon Press, 1979

Hobsbawm, E. J., *Industry and Empire: An Economic History of Britain Since 1750,* London, Weidenfield and Nicolson, 1968

Holmes, A., *Electricity in Europe: Power and Profit,* FT Business Information, 1990

Holmes, A. and Plaskett, L., *The New British Electricity System,* FT Business Information, 1990

Holmes, A., *Electricity in Europe: The Triumph of Free Enterprise?,* FT Business Information, 1991

Holmes, A., Chesshire, J., and Thomas, S., *Power on the Market: Strategies for Privatising the UK Electricity Industry,* London, FT Business Information, 1987

Horlock, J. H., *Combined Power Plants: Including Combined Cycle Gas Turbine (CCGT) Plants,* Oxford, Pergamon Press, 1992

Hughes, T. P., *Networks of Power: Electrification in Western Society 1880-1930,* Baltimore, John Hopkins University Press, 1983

Hughes, T. P., *Edison and Electric Light* in MacKenzie, D., and Wajcman, J., (eds.),*The Social Shaping of Technology,* Milton Keynes, Open University Press, 1985, pp39-52

Hughes, T. P., 'The Seamless Web: Technology, Science, Etcetera, Etcetera', *Social Studies of Science,* Vol.16, pp281-292, 1986

Hughes, T. P., 'The Evolution of Large Technological Systems' in Bijker W. E., Hughes T. P., and Pinch T. (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology,* Cambridge MA, MIT Press, 1987, pp51-82

Hughes, T. P., *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970,* New York, Viking Penguin, 1989

Hughes, T. P., 'Technological Momentum', in Smith, Merrit Roe and Marx, Leo, (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism,* Cambridge MA, MIT Press, 1994, pp101-113

'Incentives for Innovation in Electric Power Utilities', *The IPTS Report*, No.4, pp14-17, European Commission Joint Research Centre, May 1996

Institute of Energy, *Energy for the Future* (2nd edition), London, Institute of Energy, 1986

Institution of Mechanical Engineers, *Gas Turbines – Status and Prospects*, I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976

Institution of Mechanical Engineers, 'Commissioning and Operation of Combined Cycle Plant', I.Mech.E. Seminar 1994-9, 1st November 1994

Institution of Mechanical Engineers, 'Energy for the 21st Century', I.Mech.E. Seminar 1996-3, 1996

International Energy Agency, *Energy Policies of the IEA Countries, 1992*, Paris, IEA, 1993

International Energy Agency, *Electricity Supply Industry: Structure, Ownership and Regulation in OECD Countries,* Paris, OECD/IEA, 1994

International Energy Agency, *Competition and New Technology in the Electric Power Sector*, Paris, OECD/IEA, 1996

International Energy Agency, *The Role of IEA Governments in Energy: 1996 Update*, Paris, OECD/IEA, 1996

'IPP at Keadby will use Frame 9F Technology', *Modern Power Systems*, June 1992, pp10-12

'Is There a Future for Coal R&D?', *Energy World*, No.247, March 1997, pp16-19

Jasanoff, S., et al., (eds.), *Handbook of Science and Technology Studies*, Thousand Oaks, California, Sage, 1985

Jeffs, E., 'Nuclear Delays Expected to Speed Comb. Cycle Growth', *Gas Turbine World*, July-August 1986, pp24-30

Jeffs, E., 'British Energy Situation after Privatisation', *Turbomachinery International*, May/June 1991, pp60-72

Jeffs, E., 'British Gas Turbine Industry Returns Experience to Home Market', *Turbomachinery International*, May/June 1991, pp74-77

'John Lyons' CEGB Entity Arguments Dismissed', *Electrical Review*, Vol.220, No.22, 16th-29th September 1987, p9-11

Johnson, R. S., *Natural Gas and its Role in Power Generation*, paper presented to the Institute of Mechanical Engineers, 12th December 1990

Judd, A. M., *Fast Breeder Reactors*, London, Pergamon Press, 1980

Karnøe, P. and Garud, R., 'Path Creation and Dependence in the Danish Wind Turbine Field', Institute of Organization and Industrial Sociology, Copenhagen Business School, Papers in Organization No. 26, 1998

Kenward, M., 'The Embers of Energy Research, *Director*, Vol.46, No.7, pp25-26, February 1993

Knott, M., 'The Dash for Gas', *Process Engineering*, January 1991, pp82-83

Landes, D., *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present,* Cambridge, Cambridge University Press, 1969

Law, J., (ed.), *A Sociology of Monsters: Essays on Power, Technology and Domination,* London, Routledge, 1991

Law, J. and Callon, M., 'The Life and Death of an Aircraft: A Network Analysis of Technical Change', in Bijker, W. E. and Law, J. (eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp21-52

Law, J., and Bijker, W. E., 'Postscript: Technology, Stability, and Social Theory' in Bijker, W. E. and Law, J. (eds.) *Shaping Technology/Building Society: Studies in Sociotechnical Change*, Cambridge MA, MIT Press, 1992, pp291-312

Lenssen, N. and Flavin, C., 'Sustainable Energy for Tomorrow's World: The Case for an Optimistic View of the Future', *Energy Policy,* Vol.24, No.9, pp769-781, 1996

Lewis, R., 'Interview with Neil Clarke', *Business & Technology Magazine*, May 1994, pp21-23

Livingstone, R., 'Meeting Future Electricity Demand', *Electronics and Power*, October 1987, pp645-648

Lyons, J., 'Privatising Electricity Supply Cannot Be Justified', *Energy Policy,* Vol.17, No.2, pp149-154, April 1989

McGowan, F. and Thomas, S. D., 'Electricity in Europe: Inside the Utilities', London, *FT Business Information*, 1992

McGowan, F., 'Energy Policy in the UK to 1992' in McGowan, F., et al., *Energy Policy: An agenda for the 1990s*, Brighton, University of Sussex, May 1993, pp1-14

MacKenzie, D., "Micro' versus 'Macro' Sociologies of Science and Technology', Edinburgh University Research Centre for Social Sciences, PICT Working Paper No.2, 1988

MacKenzie, D., 'Towards a Historical Sociology of Nuclear Weapons Technologies' in Gleditsch, N. P., and Njolstad, O., (eds.), *Arms Races: Technological and Political Dynamics*, Oslo, Prio and Sage, 1990

MacKenzie, D., *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, Cambridge MA, MIT Press, 1990

MacKenzie, D., 'Economic and Sociological Explanation of Technical Change', in *Technological Change and Company Strategies: Economic and Sociological Perspectives*, by Coombs, R., Saviotti, P., and Walsh, V., (eds.) London, Academic Press, 1992

MacKenzie, D., *Knowing Machines: Essays on Technical Change*, Cambridge MA, MIT Press, 1996

MacKenzie, D., and Wajcman, J., (eds.), *The Social Shaping of Technology*, Milton Keynes, Open University Press, 1985

MacKerron, G., 'The Role of Gas in the Future of European Electricity Generation', unpublished paper presented to conference, 'Gas Powered Electricity Generation', London, Feb 24th-25th, 1993

MacKerron, G., 'Regulation and the Economic Outcomes of Privatisation', unpublished paper prepared for seminar, 'New Structure of the British Supply Industry', Bath, 16th April 1993

MacKerron, G, 'Innovation in Energy Supply: The Case of Electricity', unpublished paper prepared for inclusion in *Handbook of Industrial Innovation*, by Dodgson, M. and Rothwell, R. (eds.), Cheltenham, Elgar, 1994

MacKerron, G., 'Nuclear Power Under Review', in Surrey, J., (ed.), *The British Electricity Experiment: Privatisation: The Record, The Issues, The Lessons*, London, Earthscan, 1996, pp138-163

MacKerron, G. and Pearson P., (eds.) *The UK Energy Experience: a Model or a Warning?*, London, Imperial College Press, 1996

Marcus, Alfred A., *Controversial Issues in Energy Policy*, Newbury Park CA, Sage, 1992

Marshall, Lord (Walter), 'The Future for Nuclear Power', *Atom*, Vol.400, pp5-13, February 1990

Maude, C. W. and Kirchner, A. T., *Gas Turbine Developments*, London, IEA Coal Research, September 1995

Misa, T. J., 'How Machines Make History, and How Historians (and Others) Help Them to Do So', *Science, Technology, and Human Values*, Vol.13, Nos.3&4, pp308-331, Summer and Autumn 1988

Misa, T. J., 'Theories of Technological Change: Parameters and Purposes', *Science, Technology, and Human Values*, Vol.17, No.1, pp3-12, Winter 1992

Misa, T. J., 'Retrieving Sociotechnical Change from Technological Determinism', in Smith, Merrit Roe and Marx, Leo, (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp115-141

Melvin, A., 'Gas Taps its Natural Flare', *New Scientist*, 7th October 1989, pp59-61

Midttun, A., (ed.), *European Electricity Systems in Transition: A Comparative Analysis of Policy and Regulation in Western Europe*, Oxford, Elsevier Science Ltd., 1997

Morone, J. G. and Woodhouse E. J., *The Demise of Nuclear Energy?: Lessons for the Democratic Control of Technology*, New Haven, Yale University Press, 1989

Nelkin, D., 'The Political Impact of Technical Expertise', in Boyle, G., Elliott, D., and Roy, R. (eds.), *The Politics of Technology*, London, Longman/The Open University, 1977, pp189-205

Noble, D. F., *America by Design: Science, Technology, and the Rise of Corporate Capitalism*, New York, Alfred A. Knopf, 1977

Odell, P. R., 'The West European Gas Market', *Energy Policy*, Vol.16, No.5, pp480-493, October 1988

Pacey, A., *The Culture of Technology*, Oxford, Basil Blackwell, 1983

Parker, M., 'Effects on Demands for Fossil Fuels', in Surrey, J. (ed.), *The British Electricity Experiment: Privatisation: The Record, The Issues, The Lessons,* London, Earthscan, 1996, pp120-137

Parker, M. and Surrey, J., 'Contrasting British Policies for Coal and Nuclear Power, 1979-92', *Energy Policy*, Vol.23, No.9, pp821-850, September 1995

Pfenninger, H., 'Combined Steam and Gas Turbine Power Stations', *Brown Boveri Review*, Vol.60, No.9, pp389-397, September 1973

Pinch, T. J. and Bijker, W. E., 'The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other', *Social Studies of Science*, Vol.14, pp399-441, 1984

Pjipker, B. B. and Keppel, W. E., 'Amsterdam to have First 140MWe Gas Turbine', *Modern Power Systems*, pp28-33, May 1986

Potts, K., (ed.), Keynote Market Report: Electricity, Hampton, Keynote, 1996

Ridley, M., 'Cleaning up with Cheap Technology', *New Scientist*, 23rd January 1993

Riley, J. R., et al., 'Can Manufacturing Capacity Keep Up with New Orders for CTs?', *Power Engineering*, April 1990, pp45-47

Riley, S. and Taylor, M., 'The UK Generation Market', *Power Engineering Journal*, Vol.7, No.6, pp240-246, December 1993

Rip, A. and Kemp, R., 'Towards a Theory of Socio-Technical Change', limited circulation monograph, School of Philosophy and Social Science, University of Twente and MERIT, University of Limburg, May 1996

Roberts, J., 'Privatisation, Pluralism and PWRs: Looking Beyond Market Forces', *Technology Analysis and Strategic Management*, Vol.2, No.3, pp237-251, 1990

Roberts, J., Elliot, D. and Houghton, T., *Privatising Electricity: The Politics of Power*, London, Bellhaven Press, 1991

Robinson, C., *Making a Market in Energy*, Institute of Economic Affairs, London, 1992

Robinson, C., *Energy Policy: Errors, Illusions and Market Realities*, IEA Occasional Paper 90, London, IEA, 1993

Robinson, C., *Electricity Privatisation in England and Wales: Progress and Problems*, Surrey, Surrey University Energy Economics Discussion Paper No. 82, 1995

Rochlin, G. I., 'Broken Plowshare: System Failure and the Nuclear Power Industry', in Summerton, J. (ed.),*Changing Large Technical Systems*, Boulder, Colorado, Westview Press, 1994, pp231-261

Rogner, H-H., 'Technology and the Prospects for Natural Gas', *Energy Policy*, Vol.16, No.1, pp9-26, February 1988

Roland, A, V., 'Status Report on the US Natural Gas Industry', *Energy Policy*, Vol.16, No.3, pp226-229, June 1988

Rost, P., 'Towards a Competitive Market-Related Energy Policy', *Energy Policy*, Vol.16, No.5, pp450-452, October 1988

Rudig, W., 'Towards a New Political Science of Technology', Strathclyde University Department of Politics Paper, 1990

Russell, S., 'The Social Construction of Artefacts: A Response to Pinch and Bijker', *Social Studies of Science*, Vol. 16, 331-346, 1986

Russell, S., 'Power Politics: Explaining the Introduction – or Absence – of Energy Technologies', University of Wollongong Department of Science and Technology Studies, Working Paper No. 2, April 1991

Russell, S., Interests and the Shaping of Technology: An Unresolved Debate Reappears, University of Wollongong Department of Science and Technology Studies Working Paper No. 4, April 1991

Russell, S., 'Writing Energy History: Explaining the Neglect of CHP/DH in Britain', *British Journal of the History of Science*,Vol.26, pp33-54, 1993

Salsbury, S. M., 'The Australian Electric Power Industry and the Politics of Radical Reconfiguration', in Summerton, Jane (ed.), *Changing Large Technical Systems* , Boulder, Colorado, Westview Press, 1994, pp141-162

Self, Sir A. H., and Watson, E. M., *Electricity Supply in Great Britain: Its Development and Organisation*, London, Allen and Unwin, 1952

Shorthouse, N. L., 'Designing Gas Turbines for the Industrial and Marine Field', in *Gas Turbines – Status and Prospects*, I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp27-34

Skeer, J., 'How is Electric Power Technology Development Affected by Growing Power Sector Competition ?, in *Competition and New Technology in the Electric Power Sector*, Paris, IEA/OECD, 1996, pp7-12

Smith A. R. and Sharpe M., 'Rye House – a Further Step in the Use of Gas for Power Generation', *Power Engineering Journal*, Vol.9, No.1, pp33-40, February 1995

Smith, M. R. and Marx, L., (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994

Smith, M. R., 'Technological Determinism in American Culture', in Smith, Merrit Roe, and Marx, Leo, (eds.), *Does Technology Drive History?: The Dilemma of Technological Determinism*, Cambridge MA, MIT Press, 1994, pp2-35

Smock, R., 'Gas Turbines Dominate New Capapcity Ordering', *Power Engineering*, August 1989, pp23-28

Smock, R., 'Need Seen for New Utlity Capapcity in '90s', *Power Engineering*, April 1990, pp29-31

Smock, R., 'Gas-Turbine, Combined Cycle Orders Continue', *Power Engineering*, May 1991, pp17-22

Sørensen, K. H., *Technology in Use:Two Essays on the Domestification of Artifacts* , University of Trondheim Centre for Technology and Society, STS-arbeidsnotat 2/94

Sørensen, K. H., *Trials and Transformations: The Consumption of Technology* ,public lecture delivered at Edinburgh University, February 1995

Sørensen K. H. and Levold N., 'Tacit Networks, Heterogeneous Engineers, and Embodied Technology', *Science, Technology, and Human Values,* Vol.17, No.1, pp13-35, Winter 1992

Spinks, L. J., 'Some Observations on the Selection of Gas Turbine Generating Plant', in *Gas Turbines – Status and Prospects,* I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp147-156

Stokes, P. A., 'Developments in Combined Cycle Power Technology', in *Energy for the 21st Century,* I.Mech.E. Seminar 1996-3, London, pp19-23

Street, J., *Politics and Technology,* Basingstoke, MacMillan, 1992

Sullivan, R., et al., 'Electricity from Coal and Gas – a Cost Comparison', *Power Engineering Journal,* pp 275-278, December 1993

Summerton J., *District Heating Comes to Town: The Social Shaping of an Energy System,* Linköping University Studies in Arts and Sciences No.80, Linköping, Sweden, 1992

Summerton, J., (ed.),*Changing Large Technical Systems* , Boulder, Colorado, Westview Press, 1994

Surrey J., 'Energy Policy in the European Community: Conflicts Between the Objectives of the Unified Single Market, Supply Security, and a Clean Environment',*The Energy Journal,* Vol. 13, No. 3, 1993

Surrey, J. (ed.),*The British Electricity Experiment: Privatisation: The Record, The Issues, The Lessons,* London, Earthscan, 1996

Swann, D.,*The Retreat of the State: Deregulation and Privatisation in the UK and the US,* Hemel Hempstead, Harvester Wheatsheaf, 1988

Sweet, C., (ed.), *The Fast Breeder Reactor: Need? Cost? Risk?,* London, MacMillan, 1980

Thomas, S., 'Energy Policy – A New Agenda', in McGowan, F., et al. *Energy Policy: An Agenda for the 1990s,* Brighton, University of Sussex, May 1993, pp147-158

Thomas, S., 'The British Market Reform: A Central Capitalistic Approach', in Midttun, Atle, (ed.), *European Electricity Systems in Transition: A Comparative Analysis of Policy and Regulation in Western Europe,* Oxford, Elsevier Science Ltd., 1997, pp41-87

Thorén, T. E., 'A New Maintenance Concept Applied in the Design of a New Industrial Gas Turbine in the 100MW Class', in *Gas Turbines – Status and Prospects,* I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp81-90

Tyler, J. R., 'The Industrial Gas Turbine – Its Status and Prospects', in *Gas Turbines – Status and Prospects,* I. Mech. E. Conference Publications 1976-I, London, 4-5th February, 1976, pp65-74

'UK Government pulls out of EFR ...', *Atom,* Vol.425, p2, November/December 1992

Valenti, M., 'Combined-Cycle Plants: Burning Cleaner and Saving Fuel', *Mechanical Engineering,* September 1991, pp46-50

Valenti, M., 'Breaking the Thermal Efficiency Barrier', *Mechanical Engineering*, July 1995, pp86-89

Valentine, J., *Atomic Crossroads: Before and After Sizewell*, Merlin Press, London, 1985

Vergragt, P. J., 'The Social Shaping of Industrial Innovations', *Social Studies of Science*, Vol.18, pp483-513, 1988

Vickers J. and Yarrow G., 'The British Electricity Experiment', *Economic Policy*, Vol.6, pp187-232, 1991

Vincenti, W. G., 'The Technical Shaping of Technology: Real-World Constraints and Technical Logic in Edison's Electrical Lighting System', *Social Studies of Science*, Vol.25, No.3, pp 553-574, August 1995

Watson, J., 'The Technology that Drove the 'Dash for Gas'', *Power Engineering Journal*, February 1997, pp11-19

Weaving, A. H., 'Electrical Power System in the UK', *Power Engineering Journal*, September 1988, pp245-247

Webb, J. S., 'Power Plant Procurement in the 1990s', *Power Engineering Journal*, December 1996, pp262-267

Weber, K. M., 'Political Control and Diffusion of New Technologies in the Energy Sector: Conceptual Issues and Empirical Evidence', paper presented to the Third International ASEAT Conference, Manchester, 6th-8th September 1995

Webster, A. *Science, Technology and Society: New Directions*, Basingstoke, Macmillan, 1991

Wharmby, B., *Competition and Prices in Electricity Supply*, London, IEE, 1995

White, N., 'The Future for Natural Gas in European Power Generation', paper presented to the Institute of Mechanical Engineers, 12th October 1990, pp5-21

Williams, R., *Politics and Technology*, London, MacMillan, 1971

Williams, R., *The Nuclear Power Decisions: British Politics 1953-1978*, London, Croom Helm, 1980

Williams, R. and Edge, D., *Social Shaping Reviewed: Research Concepts and Findings in the UK*, Edinburgh University Research Centre for Social Sciences, PICT Working Paper No.41, 1992

Williams, R. and Edge, D., 'The Social Shaping of Technology', *Research Policy*, Vol.25, pp865-899, 1996

Williams, R. and Russell, S., 'Opening the Black-Box and Closing it Behind You: On Microsociology in the Social Analysis of Technology', Edinburgh University Research Centre for Social Sciences, PICT Working Paper No.3, 1988

Williams, R. H. and Larson, E. D., 'Aeroderivative Turbines for Stationary Power', *Annual Review of Energy*, Vol. 13, pp429-489, 1988

Winner, L., *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, Cambridge MA, MIT Press, 1977

Winner, L., 'Do Artifacts Have Politics?' in MacKenzie, D., and Wajcman, J., (eds.), *The Social Shaping of Technology*, Milton Keynes, Open University Press, 1985, pp26-38

Winner, L., *The Whale and the Reactor: A Search for Limits in an Age of High Technology*, Chicago, University of Chicago Press, 1986

Winner, L., 'Social Constructivism: Opening the Black Box and Finding it Empty', *Science as Culture*, Vol.3, Pt.3, No.16, pp427-452, 1993

Winskel, M., *Theoretical and Practical Aspects of Cash-Flow Discounting: The Case of the British Energy Sector*, unpublished M.Sc. dissertation, Imperial College of Science, Technology and Medicine, University of London, October 1987

Witton, J., 'Gas Turbines - Present and Future', *Process Engineering*, August 1984, pp18-21

Wood, B., 'Gas Turbine Developments', in *Diesel Engineers and Users Association*, Publication 336, September 1970

Woolgar, S., 'The Turn to Technology in Social Studies of Science', *Science, Technology, and Human Values*, Vol.16, No.1, pp20-50, Winter 1991

Yarrow, G., 'Privatization, Restructuring, and Regulatory Reform in Electricity Supply', in *Privatization and Economic Performance*, Bishop, M., Kay, J., and Mayer, C., Oxford, Oxford University Press, 1995, pp62-88

Zeltmann, E. W., 'Opportunities for the Power-Plant Industry: A Ten-year Perspective', *TMI Handbook*, pp34-40, 1992

Corporate Literature

Central Electricity Generating Board, *Annual Report,* various years

'Dounreay', UKAEA, 1988

'Power Plans Steam Ahead', *ICI C&P News*, August 1995, pp1-2

'The Prototype Fast Reactor', UKAEA, 1986

'Roosecote: Britain's First Combined Cycle Power Station', Manchester, Norweb, September 1991

Wilkinson, P., 'Building on Experience at Keadby', *Hydro-Electric Business*, Spring/Summer 1994, pp14-17

Newspapers

Baxter, A., 'Generating a New Alliance', *Financial Times*, 18th May 1993, p10

Baxter, A., 'The Millenium Looks Bright', *Financial Times*, 16th May 1995, p1

Beavis S. and King, I., 'Nuclear Dream Turns to Dust', *The Guardian*, December 12th 1995, p18

Beavis S. and Barrie C., 'Blow to Nuclear Sell-off', *The Guardian*, 14th December 1995, p1

Buckley, C., 'Shaft of Light that could be merely a Stay of Execution', *The Times*, 29th December 1997, p46

Fishlock, D., 'Power Sell-Off 'Could Threaten Fast Reactor Plan'', *Financial Times*, 5th April 1988, p8

Fishlock, D., 'Funding is at the Core of a Nuclear Future', *Financial Times*, 6th May 1988, p6

Garnett, G., 'Confusion for Equipment Makers', *Financial Times*, 29th March 1990, FT Survey of the Electricity Industry, pII

Gribben, R., 'New threat to coal as dash for gas gathers pace', *Daily Telegraph*, 19th May 1997

Hollinger, P., 'RJB ends 48 years of Nationalised Coal', *Financial Times*, 30th December 1994, p17

Lascelles, D., 'Plug Pulled on More Nuclear Power', *Financial Times*, 12th December 1995, p9

Samuelson, M., 'Private Players Plan for the Power Game', *Financial Times*, 29th April 1988, p10

Samuelson, M., 'Gas Power Station Approved', *Financial Times*, 11th May 1988, p8

Samuelson, M., 'ICI Plans Gas-Fired Power Stations', *Financial Times*, 19th October 1989, p9

Samuelson, M., and Garnett, N., 'Coal-Fired Power Station Plans Hit by Privatisation', *Financial Times*, 27th October 1988, p1

Samuelson, M., 'Electricity Contracts Safeguard Coal Jobs', *Financial Times*, 5th December 1989, p20

Samuelson, M., 'A Dramatic Comeback', *Financial Times*, 20th April 1990, FT Survey of the Gas Industry, p9

Samuelson, M., 'Cheap Natural Gas Threat to green Power Station', *Financial Times*, 12th May 1990

'Siemens buys Ailing R-R Power Generation Plant', *The Times*, 10th April 1997, p26

Thomas, D., 'Pioneers Under Siege', *Financial Times*, 6th September 1990, p25

British Official Publications

(all published in London by HMSO)

Department of Energy, *Energy: The Key Resource*, (Sir Jack Rampton), Energy Paper 4, July 1975

Department of Energy, *Energy Research and Development in the United Kingdom*, Energy Paper 11, 1976

Department of Energy, *National Energy Conference, June 22nd 1976, London; Volume 1: Report of Proceedings; Written Contributions*, Energy Paper 13, 1976

Department of Energy, *The Structure of the Electricity Supply Industry in England and Wales*, Cmnd 6388, 1976

Department of Energy, *Energy Policy Review*, Energy Paper 22, 1977

Department of Energy, *Energy Policy : A Consultative Document*, Cmnd 7101, 1978

Department of Energy, *Re-organisation of the ESI in England and Wales*, Cmnd 7134, 1978

Department of Energy, *Energy Technologies for the UK: An Appraisal for Research, Development and Demonstration Planning*, Energy Paper 39, June 1979

Department of Energy, *Speech on Energy Policy*, (Nigel Lawson), Energy Paper 51, 1982

Department of Energy, *Energy Research and Development in the UK*, Energy Paper 11, 1986

Department of Energy, *Sizewell B Public Inquiries*, (Sir Frank Layfield), January 1987

Department of Energy, *Energy Technologies for the UK: 1986 Appraisal of Research, Development and Demonstration*, Energy Paper 54, February 1987

Department of Energy/ Energy Technology Support Unit, *Background Papers Relevant to the 1986 Appraisal of UK Energy Research, Development and Demonstration*, ETSU R-43, February 1987

Department of Energy, *Privatising Electricity: The Government's Proposals for the Privatisation of the Electricity Supply Industry in England and Wales*, Cmnd 322, February 1988

Department of Energy, *Prospects for the Use of Advanced Coal Based Power Generation Plant in the United Kingdom*, Energy Paper 56, July 1988

Department of Energy, *Hinkley Point C Public Inquiries*, (Michael Barnes), 1990

Department of Trade and Industry, *Energy Related Carbon Emmissions in Possible Future Scenarios for the United Kingdom*, Energy Paper 59, 1992

Department of Trade and Industry, *The Prospects for Coal: Conclusions of the Government's Coal Review*, Cmnd 2235, March 1993

Department of Trade and Industry, *Energy Technologies for the UK: An Appraisal of UK Energy Research, Development, Demonstration and Dissemination*, Energy Paper 61, May 1994

Department of Trade and Industry, *Clean Coal Technologies: A Strategy for the Coal R&D Programme*, Energy Paper 63, 1994

Department of Trade and Industry and the Scottish Office, *The Prospects for Nuclear Power in the UK: Conclusions of the Government's Nuclear Review*, Cmnd 2860, May 1995

Department of Trade and Industry, *Government Observations on the Second Report from the Trade and Industry Committee on Nuclear Privatisation*, HC 383, 1995-96

Department of Trade and Industry, *The Energy Report Vol.1: Change and Opportunity*, May 1996

Department of Trade and Industry, *Digest of United Kingdom Energy Statistics*, 1997

Department of Trade and Industry, *Energy Trends* (Monthly);various issues

House of Commons Energy Committee, *The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector*, 3rd Report, HC 307, 1987-88

House of Commons Energy Committee, *Government Observations on the 3rd Report from the Committee, The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector*, HC 701, 1987-88

House of Commons Energy Committee, *Third Report from the Energy Committee (1987-88) on The Structure, Regulation, and Economic Consequences of Electricity Supply in the Private Sector: Follow-up*, HC 152, 1988-89

House of Commons Energy Committee, *The Flue Gas Desulphurisation Programme*, 3rd Report, HC 371, 1989-90

House of Commons Energy Committee, *The Cost of Nuclear Power*, 4th Report, HC 205, 1989-90

House of Commons Energy Committee, *The Fast Breeder Reactor*, 5th Report, HC 119, 1989-90

House of Commons Energy Committee, *Government Observations on the Fifth Report from the Committee (session 1989-90) on the Fast Breeder Reactor*, 1st Special Report, HC 31, 1990-91

House of Commons Energy Committee, *Clean Coal Technology and the Coal Market after 1993*,
5th Report, HC 208, 1990-91

House of Commons Energy Committee, *Consequences of Electricity Privatisation*, 2nd Report, HC 113, 1991-92

House of Commons Energy Committee, *House of Commons Scrutiny of Energy Matters*, 5th Report HC 313 1991-92

House of Commons Select Committee on Nationalised Industries, *The Electricity Supply Industry*, HC 236, 1962-63

House of Commons Select Committee on Nationalised Industries, *Gas, Electricity and Coal Industries*, HC 77, 1965-66

House of Commons Select Committee on Nationalised Industries, *Re-organisation of the Electricity Supply Industry, Prelegislative Hearings*, HC 636, 1977-78

House of Commons Standing Committee E, *Minutes of Proceedings of (Electricity) Bill*, HC 271, 1988-89

House of Commons Standing Committee D, *Minutes of Proceedings of (Coal Industry) Bill*, HC 283, 1993-4

House of Commons Trade and Industry Committee, *Government Response to the Second Report from the Energy Committee (1991-92) on the Consequences of Electricity Privatisation*, HC 222, 1991-92

House of Commons Trade and Industry Committee, *British Energy Policy and the Market for Coal*, 1st Report, HC 237, 1992-93

House of Commons Trade and Industry Committee, *British Energy Policy and the Market for Coal: Follow-up*, HC 188, 1993-94

House of Commons Trade and Industry Committee, *Aspects of the Electricty Supply Industry*, 11th Report, HC 481, 1994-95

House of Commons Trade and Industry Committee, *Nuclear Privatisation: Minutes of Evidence*, HC 795, 1994-95

House of Commons Trade and Industry Committee, *Nuclear Privatisation*, 2nd Report, HC 43, 1995-96

House of Commons Trade and Industry Committee, *Energy Regulation*, 1st Report, HC 50, 1996-97

House of Commons Trade and Industry Committee, *Liberalisation of the Electricity Market*, 2nd Report, HC 279, 1996-97

Industry Department for Scotland, *Privatisation of the Scottish Electricity Industry*, Cmnd 327, 1988

Ministry of Fuel and Power, *Report of the Committee of Inquiry into the Electricity Supply Industry*, Cmnd 9672, 1956

Ministry of Power, *Fuel Policy*, Cmnd 2798, October 1965

Ministry of Power, *Fuel Policy*, Cmnd 3438, November 1967

Monopolies and Mergers Commission, *Central Electricity Generating Board*, HC 315, 1980-81

Monopolies and Mergers Commission, *Gas*, Cmnd 500, October 1988

Office of Electricity Regulation (OFFER), *Annual Reports*, 1993: HC 352 1993-94; 1994: HC 432 1994-95; 1995: HC 348 1995-96

-END-