

# COAL PURCHASE ANALYSIS IN THE ELECTRICITY SUPPLY INDUSTRY

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## ABSTRACT

The UK Electricity Supply Industry was sold into private ownership in 1990 and was followed by the floatation of the National Coal Board in 1994. Until this time successive Governments had ensured a market for the coal produced by the National Coal Board by prohibiting the Electricity Supply Industry from purchasing foreign coal and for decades the Electricity Supply Industry had been hostage to the fortunes of the coal industry. At the time of privatisation of the Electricity Supply Industry in 1990 the Government stated that it could no longer guarantee that all of the coal consumed by the new, privately owned Generators would be from British mines.

Since these changes, the conventional merit-order for the dispatch of generating plant in mixed-fuel systems has been superseded by scheduling of plant in response to commercial advantage. Gas-fired generation is now used to meet base-load demand, while coal-fired plant, traditionally a base-load generation source, is being forced to take an increasingly mid-merit position. While fuel for base-load generation is bought on long-term contracts, fuel for mid-merit generation is purchased more effectively on the medium-term market. It is therefore becoming more important for Generators to recognise the strategic issues encompassed in medium-term coal purchase and to respond accordingly.

The decision to buy coal can be followed through a number of stages from the initial identification of the requirement to make a purchase, through the tendering process to the final selection of suppliers. Understanding a supplier is essential to this process and to making effective organizational buying decisions.

Analysis of past performance of coal suppliers at each stage has led to the application of supplier assessment techniques to the development of a 'Coal Supplier Grading System'. Utilisation of this grading system benefits the Generator by assisting the purchaser to ensure that the best suppliers are selected while opportunities offered by new entrants into the market are not missed.

This thesis examines the factors which affect coal purchase on the medium-term market. The integration of these factors and the 'Coal Supplier Grading System' into the decision support system 'CoalMan' is described and, using realistic data, five examples of typical scenarios demonstrate the ranking of coal offers that successfully meet the requirements of the purchase.

## **DECLARATION OF ORIGINALITY**

The research recorded in this thesis, and the thesis itself, is the original and sole work of the author.

Gillian Margaret Bellhouse

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# CHAPTER 1

## INTRODUCTION

The UK Electricity Supply Industry (ESI) was sold into private ownership in 1990 and was followed by the floatation of the National Coal Board (NCB) in 1994. This chapter chronicles the events leading up to the eventual privatisation of the ESI and the NCB and some of the implications of further regulation in coming years. The effects of these changes on the use of coal for electricity generation in the current economic and regulatory climate are then discussed. Finally, fuel purchase for mixed fuel generation is introduced, with reference to coal purchase in particular.

### 1.1. Privatisation of the Electricity Supply Industry

The privatisation of the ESI in 1990 and 1991 brought many changes to operation planning and financial arrangements within the industry.

As in any supply industry consumers want a reliable, high quality service, at a reasonable price. This means that the ESI must endeavour to maintain supply to an adequate standard of reliability in a cost effective way. For all companies the advent of full competition at the time of the franchise-break in 1998 will make consumer satisfaction an even higher priority than at present. Privatisation and competition within the market place have made critical the need for utilities to become cost-effective.

#### 1.1.1. Structure of the ESI before Privatisation

The ESI originates from a collection of small, privately owned companies which were nationalised in 1947. By the time it was privatised in 1990 it had evolved into the Central Electricity Generating Board (CEGB), which generated 94%<sup>1</sup> of the total electrical energy requirement in England and Wales, and South of Scotland Electricity Board (SSEB) and North of Scotland Hydro-Electric Board (NSHEB) in Scotland.

The ESI could also receive electrical energy through the interconnection with France.

In England and Wales the electricity generated was transmitted by the CEGB to supply points from which the twelve area boards distributed it to consumers through local

networks. In Scotland, however, the two companies were vertically integrated and responsible for all transmission and distribution within their first-tier areas. Figure 1 shows how the UK ESI was structured before privatisation.

The Electricity Council (EC) regulated these companies as a whole and provided a link with the Government for the development of energy policy. The EC was also concerned with the setting of price levels within the ESI. There was therefore no openly competitive market for low cost sales since prices were fixed and area boards were restricted to selling their electricity within their own region.

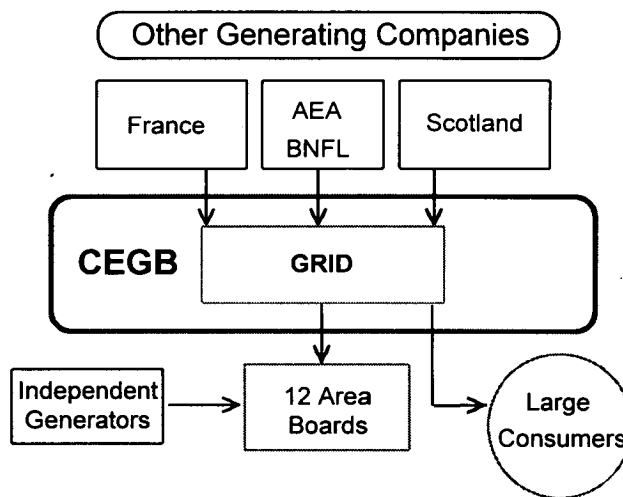


Figure 1. Structure of the UK ESI pre-privatisation

The problems associated with a closed market did not end with electricity sales. The Government prohibited the ESI from purchasing foreign coal<sup>2</sup> which was competitively priced. Indeed, coal purchased in the USA in the early 1960s would have cost around half that of British coal<sup>3</sup>. This meant that the ESI, with 82% of its capacity<sup>4</sup> at that time dependent on coal, was essentially hostage to the economics of the coal industry. As such it was highly susceptible to coal price fluctuations. In order to reduce the impact of variation in fuel price of any single source and increase price stability it was vital that supply was extended to include generating plant for a number of primary fuel types. Within ten years coal-fired capacity in the CEGB had dropped to 66%, with oil 22%, nuclear 10%, gas 1.5% and hydro 0.5%.

The merit-order for dispatch was set by cost of generation which meant that the cheapest stations were used first as base load and then the gradually more expensive stations used for mid-merit generation. Peak generation was met by stations designed to have a short lead-

time between start-up and full-load, for example diesel and small gas turbines. There was some flexibility for the CEGB to control costs through regulation of the merit-order, although the high dependence on a single fuel type meant that many of the benefits of this versatility were lost.

Throughout the 1960s and 70s demand increased quickly and was satisfied by the introduction of new, large power stations, including eight Magnox nuclear stations, which helped to broaden the generation mix of the CEGB. Table 1 shows how CEGB owned power stations, capacity and sales changed between 1960 and 1984.

<i>Year</i>	<i>Number of Stations</i>	<i>Capacity</i>	<i>Average Station Capacity</i>	<i>Annual Sales</i>
1960	262	24.34 GW	93 MW	40.3 TWh
1971	187	49.28 GW	264 MW	184 TWh
1981	131	60.03 GW	457 MW	data unavailable
1984	90	51.03 GW	567 MW	data unavailable

Table 1. CEGB development, 1960-84<sup>5</sup>

### 1.1.2. Structure of the ESI after Privatisation

In 1988 the government published its plans for privatising the ESI in England and Wales in the White Paper 'Privatising Electricity'<sup>6</sup>. This proposed the vertical and horizontal division of the highly integrated industry into sixteen companies. Privatised generation was divided between two companies; National Power (with 70% of generation) and PowerGen (with 30% of generation). The nuclear capacity was retained by the government as a third company, Nuclear Electric, until its privatisation in 1996 as part of British Energy.

The electricity generated by these companies, and the other companies which have entered the market since privatisation, is sold to suppliers through the Electricity Pool. The Pool is a trading agreement which is used to determine which generating sets are used to satisfy demand at any particular time<sup>7</sup>. The Pool also sets the spot purchase price for electricity during that time.

Electricity is transmitted through the grid by the fourth organisation, National Grid Company, which is responsible for its distribution to the 12 regional electricity companies

(RECs)<sup>8</sup> who supply their customers. Figure 2 shows the structure of the ESI post-privatisation. Table 5 shows a summary of the events leading up to privatisation of the ESI.

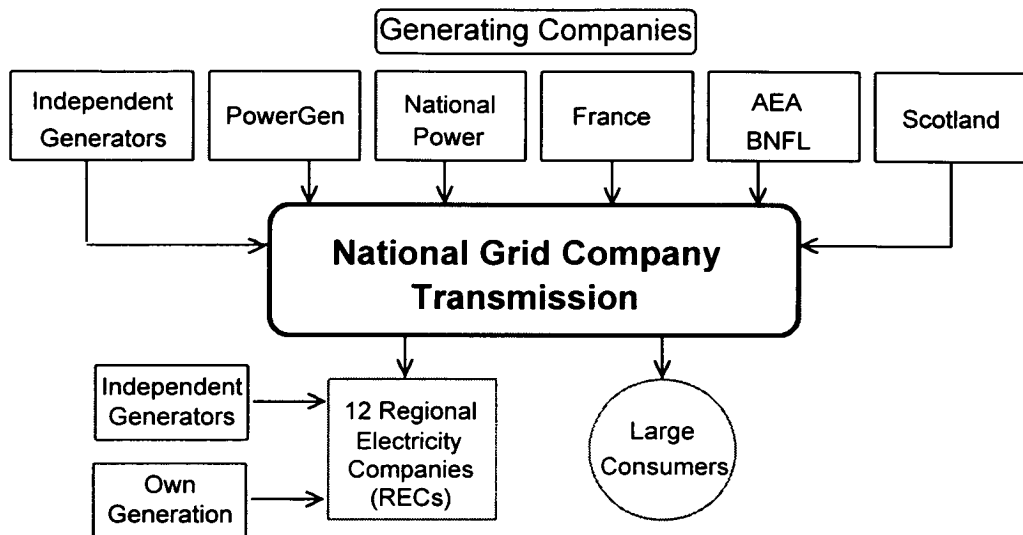


Figure 2. Structure of the UK ESI post-privatisation

May 1987	Conservative Party election manifesto announces commitment to privatisation of the ESI
December 1987	Select Committee on Energy starts enquiry into possible outcome of electricity supply in the private sector
February 1988	Publication of White Paper 'Privatising Electricity'
March 1988	Publication of White Paper 'Privatisation of the Scottish Electricity Industry'
July 1988	Select Committee on Energy publishes its report criticising many proposals published in the White Papers
November 1988	Companies to succeed the CEGB are named as National Power, PowerGen, and National Grid Company
December 1988	Second Reading of Electricity Bill in House of Commons
April 1989	Second Reading of Electricity Bill in House of Lords
July 1989	Electricity Act 1989 enacted
September 1989	Director General of Electricity Supply appointed - Stephen Littlechild
November 1989	Withdrawal of nuclear generation from sale and creation of Nuclear Electric and Scottish Nuclear
31st March 1990	Vesting Day: Transfer of CEGB and Area Board assets to successor companies. Licenses come into effect
December 1990	Sale of 12 Regional Electricity Companies and National Grid
March 1991	Sale of National Power and PowerGen
June 1991	Sale of Scottish Power and Scottish Hydro-Electric
July 1996	Sale of British Energy (Nuclear Electric and Scottish Nuclear Electric)

Table 2. Steps towards privatisation of the UK ESI<sup>9,10</sup>

The Secretary of State for Scotland also announced that the Scottish system would be privatised, but would be maintained as the two original vertically integrated companies. The SSEB became Scottish Power and NSHEB became Scottish Hydro-Electric. Both companies were responsible for generation, transmission, distribution and supply in their own first-tier areas. Figure 3 shows the first-tier areas for Scottish Power and Scottish Hydro-Electric at the time of privatisation. A third, government owned company was created; Scottish Nuclear Limited, responsible for the nuclear power stations at Hunterston and Torness. Generation from the Scottish Nuclear stations was to be sold directly to Scottish Power and Scottish Hydro-Electric for distribution to consumers. Scottish Nuclear was also privatised in 1996 as part of British Energy.

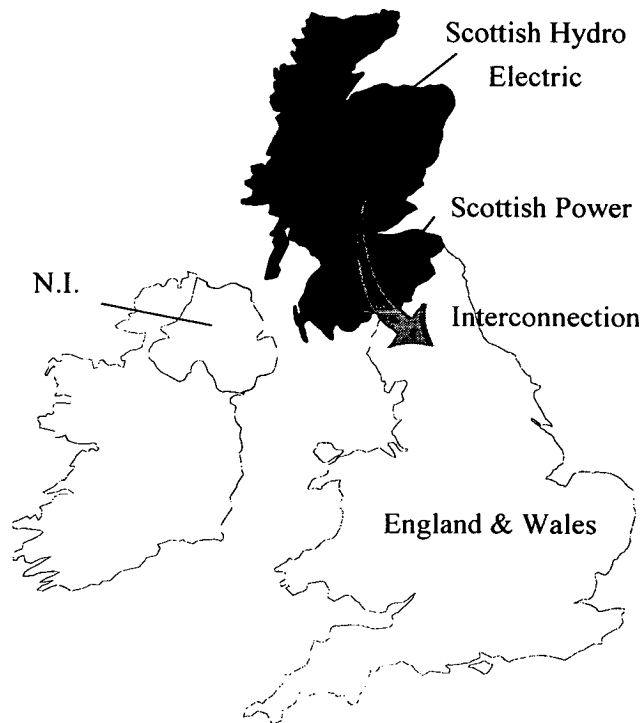


Figure 3. First-Tier areas in Scotland

With the approaching privatisation of the ESI the government stated that it would not be acceptable for the new privately owned companies to purchase solely from the British coal industry since this would effectively deny the ESI the benefits associated with greater choice of fuel supplier and the opportunity to maintain security of supply from multiple sources<sup>11</sup>. This policy brought about a reduction in the share of coal-fired generation.



In 1990 competition within the ESI was opened initially to those customers who had a peak demand of more than 1MW<sup>12</sup>. These customers could now choose to buy their electricity from whichever supplier they preferred.

Competition also emerged in fuel purchase. Generators who had originally purchased their fuel at a fixed market rate and without competition from other utilities found themselves in competition for the cheapest and highest quality resources. Coupled with this was shareholder pressure to maximise profits. Equation 1 below gives an example of a simplified calculation of the profit of any Generator.

$$\text{Profit} = \text{Income} - \text{Production Costs} - \text{Overheads} \quad (1)$$

Where:

Income = Income from Electricity Sales

Production Costs = Fuel + Operating Labour + Plant Control etc.

Overheads = Salaries + Pensions + Costs associated with Offices etc.

Income from electricity sales varies as demand varies. Overheads do not vary with demand since offices must still be maintained and pensions and salaries must be paid regardless. Variation in production costs is dependent on the price of fuel. Given that it is the largest single operating expenditure for an electricity generating company fuel purchase was an obvious area for improvements in cost-effectiveness.

## **1.2. Privatisation of the Coal Industry**

For many years the National Coal Board (NCB) was supported by successive governments who guaranteed that the majority of its output went directly to the state-owned electricity generator<sup>13</sup>. However, the NCB was required, under the 1980 Coal Industry Act, to break even by 1984-85 without any Government subsidy. The 1980s proved turbulent as the government began to increase pressure on the NCB to become more competitive by lowering operating costs and reducing stock levels. The only way in which this could be done was to schedule the closure of between 30 and 50 of the more expensive and less productive mines.

In 1984 the National Union of Mineworkers (NUM), headed by Arthur Scargill, called a strike over the proposed pit closures which was to last a year. During this time the CEGB strove to 'keep the lights on' and, against all the odds, they succeeded. Coal stocks at

stations had been increased as strike action began to look inevitable. Some coal-fired stations were converted to burn oil and the infrastructure required to support the increased demand was developed. Table 3 shows how generation was switched from coal to oil and other fuel sources during the strike.

The Conservative Government, under Margaret Thatcher, was determined not to be held to ransom by the miners as Edward Heath had been in the previous decade. It was a resolution which was to break the stronghold of the NUM and to prove that such a dependence on one fuel source left the ESI in a very vulnerable position.

The strike cost the British tax payer more than £2bn, largely due to the huge increase in generation from more expensive oil<sup>14</sup>. The strike brought an end to the power of the NUM<sup>15</sup>.

	<i>Consumption as a Percentage of Total</i>	
	<i>Actual</i>	<i>Expected Without Strike</i>
Coal	40	70
Oil	39	4
Gas	1	0
Nuclear Fuel	16	16
Purchases of Electricity	4	1

Table 3 . Fuel Consumption During the Miners Strike<sup>16</sup>

Almost a decade later in 1992 the Government announced another programme of pit closures. This time it intended to close 31 of the 50 remaining coal pits of which 12 were later reprieved, with 7 more mothballed<sup>17</sup>. It was apparent that British Coal was being made more attractive to potential buyers despite criticism that the government was being short-sighted. Fells and Lucas state in '*UK Energy Policy Post-Privatisation*':

*"If the domestic coal industry is brought to its knees by a combination of ruthless purchasing by the generators, low cost imports and privatisation, then when world prices of coal recover to levels commensurate with long-run marginal costs, then the costs of buying from abroad will be passed on to consumers"<sup>18</sup>.*

In August 1993 the government declared its plans to privatise British Coal and at the end of 1994 British Coal was finally privatised, with the pits being divided and sold as smaller

companies. Pit closures before privatisation and increasing imports of cheaper foreign coal meant that domestic stocks dropped dramatically as shown in Table 4.

	<i>Total UK Coal Stocks (kte)</i>
1992	47,207
1993	45,860
1994	26,572
1995	18,043

Table 4. UK coal stocks at end of period, 1992-95<sup>19</sup>

Table 5 shows a summary of events leading up to the privatisation of British Coal.

October 1992	British Coal announces 31 pit closures
October 1992	Trade and Industry Select Committee investigation of closures begins
October 1992	Government announces Coal Review into 21 of proposed pit closures
October 1992	Government commissions John T. Boyd Co to carry out analysis of 21 pits
November 1992	Government commissions Caminus Energy Ltd to carry out analysis of markets for coal
December 1992	High Court rules closures illegal, in breach of Modified Colliery Review Procedure, 1985
January 1993	Government commissions analysis of 10 pits not covered by Boyd Report
January 1993	Trade and Industry Select Committee report published. It recommends financial support for British Coal to build a competitive base and develop larger markets
January 1993	Caminus Report published. It suggests contraction in coal markets to 1997-98
January 1993	First Boyd Report (21 pits) suggests October closure programme reasonable
February 1993	Electricity Regulator reaffirms support for ESI 'dash-for-gas' strategy
March 1993	Government White Paper reprieves 12 pits, 7 more mothballed or under development. Reaffirms commitment to coal privatisation
June 1993	Rufford Colliery a reprieved pit, announces closure
June 1993	British Coal warns of threat to pits regarded as safe in 1992
July 1993	British Coal announces deep-mined losses for first quarter, 1993
August 1993	Pollution Inspectorate authorises PowerGen to burn Orimulsion
August 1993	Plans for early privatisation of coal, July 1994, reported

Table 5. Steps towards privatisation of British Coal<sup>20</sup>

Since privatisation of the ESI in 1990/91 and that of the NCB in 1994 the Generators have found themselves in competition with each other, not only for different fuel types, but also for the best sources of coal. Figure 4 shows the general trend of the power station coal purchase price, in real terms, since 1988 and compares it with other fuels for electricity generation.

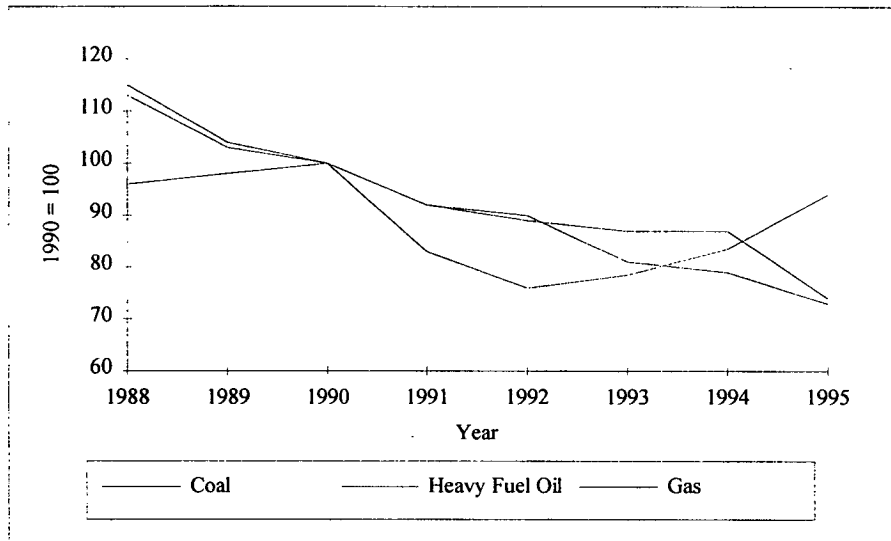


Figure 4. Fuel Prices in Real Terms 1988-95<sup>21,22</sup>

### 1.3. Future Changes for the ESI and Coal Generation

In 1998 competition within the domestic consumer market will open up. This will coincide with the completion of the present committed long-term coal purchasing agreements and the end of the nuclear fuel levy<sup>23</sup>. There is considerable uncertainty associated with these three changes and the fact that they coincide makes their consequences even more unpredictable.

Due to these forthcoming market upheavals companies on both sides of the fuel market must take advantage of the new opportunities open to them if they are to survive in the highly competitive industry.

### 1.4. Merit Order in Generation

Base-load generation is supplied by power stations which are most efficient and cost-effective if they are operated continuously. After deregulation in 1990 competition in UK

electricity generation was initially concentrated in the base load area of the generating market . This was largely due to new entrants building modern high efficiency gas fired power stations. The survival of these new entrants will be critically dependent on maintaining low cost generation. Being a base-load generator offers financial security in terms of economic generation and therefore shorter pay-back periods for capital investment of generation projects, however, in the increasingly competitive electricity market margins in base-load have been reduced to levels such that Utilities are now looking for opportunities to take advantage of mid-merit operation<sup>24</sup>. Operational reasons for being base-load generators include not having repeatedly to reduce output from stations, especially important for nuclear generation due to the risk of fuel poisoning (contamination of the fuel rods, rendering them unusable). Economics of generation and changes in the technology employed in the industry are gradually making these problems less significant.

With the projected increase in generation from gas, use of coal seems likely to decrease, moving from base-load generation to mid-merit generation. The consequences of this will be to increase the magnitude of variation in coal consumption relative to its total use. As a result, the planning of coal consumption and purchase will become increasingly critical to utilities, especially those who have a large dependency on coal.

Since 1990 the Government policy which favoured the use of coal in the generation of electricity within the UK has shifted towards the use of non-fossil fuels with the Non-Fossil Fuel Obligation (NFFO) and the Scottish Renewables Order (SRO). Under the NFFO and SRO the government objective is to have 1500 MW (declared net capacity) of new renewable energy sources commissioned in the UK by the year 2000<sup>25</sup>. Meanwhile, economics have encouraged the introduction of gas-fired generation and increasing oil prices have caused a reduction in generation from oil. This shift is illustrated in Figure 5. No new coal- or oil-fired stations have been built in the UK since 1989. PowerGen has, however, converted some of its oil-fired capacity to burn Orimulsion, a bitumen-based fuel. In recent years the majority of the growth has been in combined-cycle gas turbines (CCGTs) which have proved popular with the privatised electricity industry due to their higher thermal efficiency and environmental performance, coupled with their lower capital costs and the speed at which the plant can be constructed when compared with conventional fossil-fuel stations<sup>26</sup>. These factors have had a profound effect on the 'dash for gas' and the gradual reduction in market share for black fuel generation.

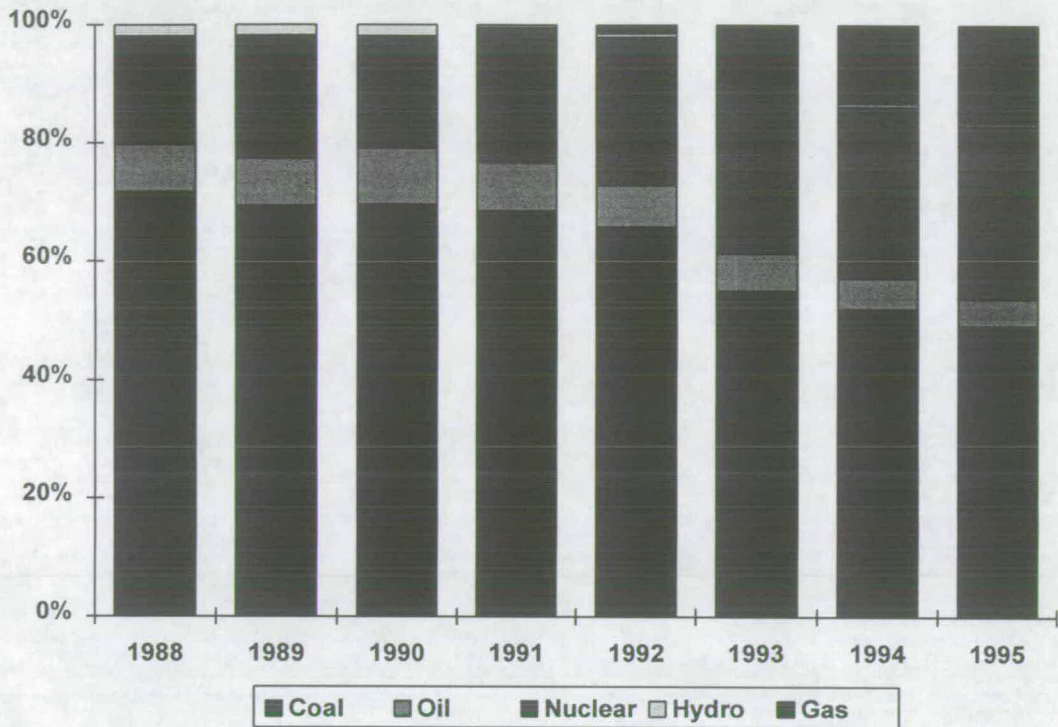


Figure 5 Breakdown of Electricity Generation, 1989-95<sup>27,28</sup>

Figure 6 shows a typical load duration curve for an electricity network supplied by a variety of fuel sources before the 'dash-for-gas'. Generators were positioned on the merit order according to their variable costs, flexibility and contractual obligations. Some types of generation occupied the lower 'base-load' element of the merit order. Nuclear and coal were positioned as base-load due to technical and economic constraints.

Figure 7 shows how this merit order has changed since the development of gas-fired generation. Coal has moved up the table, becoming increasingly mid-merit as it is replaced by the cheaper, more efficient alternative of gas. Nuclear and gas are now used as base load on the basis of both cost and contractual obligations.

Hydro generation, where available to the utility, is used to supplement the base load. Generation from hydro plant is small in the UK context, with 6% of total capacity<sup>29</sup>, although much more significant in Scotland. Hydro production has flexible and inflexible components which are a function of recent weather patterns. This determines its position in the merit order.

The difference, if any, between demand and generation is met by the combustion of black fuels<sup>30</sup>.

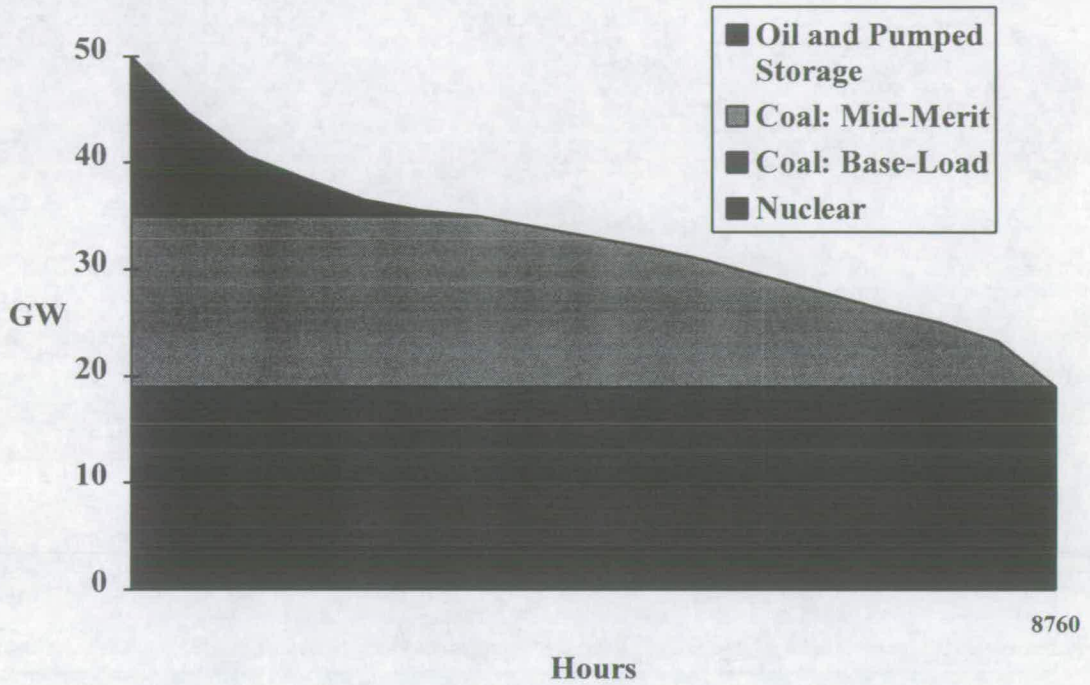


Figure 6 Typical Load Duration Curve before the 'dash-for-gas', 1988/89<sup>31</sup>

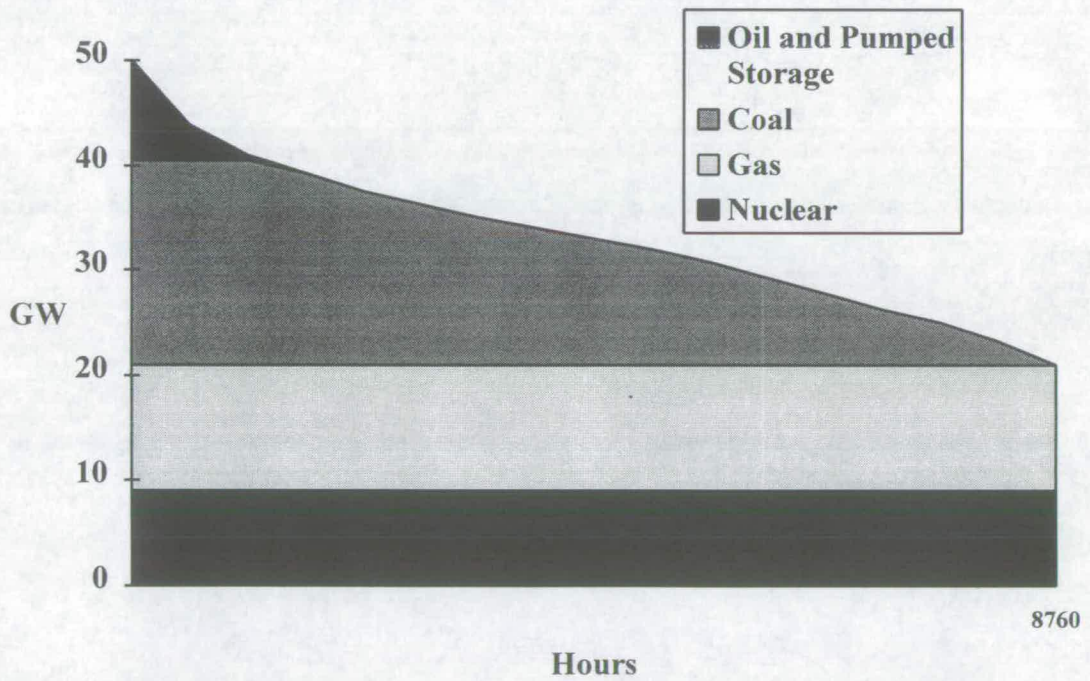


Figure 7 Predicted Load Duration Curve since the 'dash-for-gas', 1998/99<sup>32,33</sup>

## 1.5. Fuel Type Portfolio Management

In managing fuel purchase, decisions must be taken on types, timescales for purchase and quantities to buy. In Section 1.1.1. of this chapter it was stated that in order to reduce the impact of price fluctuations for individual fuels on Utilities a mix of generation sources should be maintained. Operating a portfolio of fuel types and suppliers offers the Generator a means of achieving more flexibility and, hence, more competitive solutions. However, each fuel type has particular uncertainties associated with it and, as coal takes an increasingly mid-merit position, so it inherits more of the planning variance associated with other forms of generation, for example, unplanned outages or, in the case of hydro generation, shortage of water, leading to a reduction in availability.

## 1.6. Planning Variance in Generation

All forms of generation have related production difficulties and unplanned outages, even base load. By comparing the actual generation from each source with the planned usage at the start of the selected period the major influences on coal use can be found. Further analysis of the figures gives an indication of what the differences between planned and actual generation mean in terms of black fuel stock required to meet a shortfall from another source, or extra reserves left due to an unexpected increase in output from elsewhere.

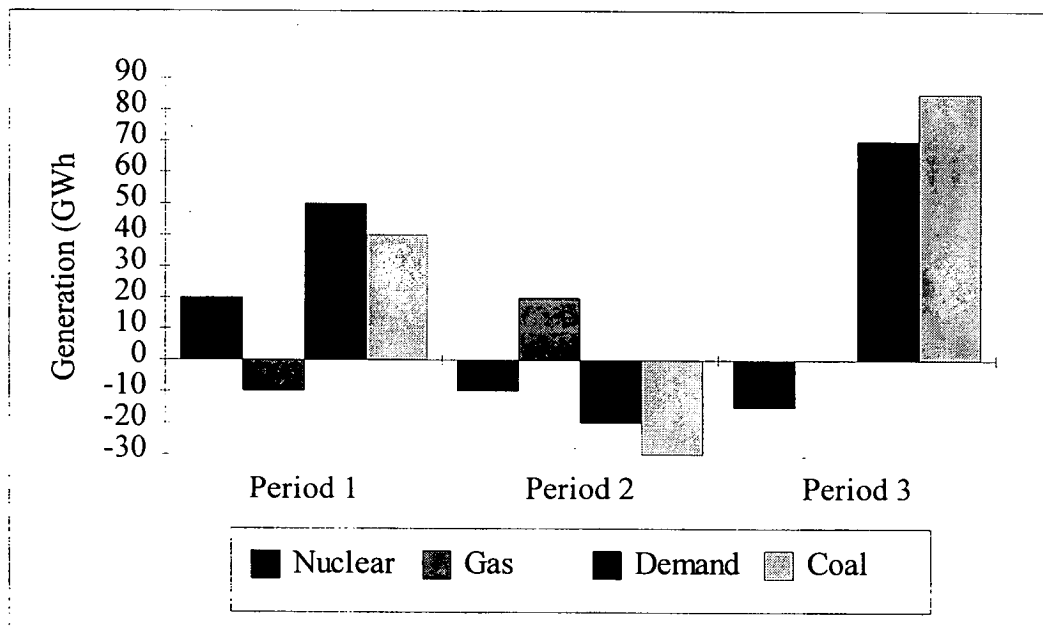


Figure 8. Graph of Differences Between Actual and Planned Generation and Demand.



A graph of the differences between actual output and planned output by fuel source is given in Figure 8. It can be seen from this that whenever the actual output from gas or nuclear is less than the planned schedule (a negative figure on the graph) the deficit in generating availability is made up by extra generation from coal. It can also be seen that whenever demand is higher than expected there is increased coal burn. Since coal-fired generation makes up the difference between base-load electricity supply (from gas and nuclear) and the demand it can be expected to reflect any variances between plan and actual use.

For the example Utility described in Figure 8 it can be seen that given the relative reliability of the base-load sources, coal-fired generation mainly reflects variance in the demand. The following 'first-stage' analysis might be made:

***Period 1.***

- **Nuclear** - In this period there has been an unplanned increase in generation from nuclear fuel.
- **Gas** - Generation from gas is lower in this period than had been planned.
- **Demand** - Demand is greater than had been expected in this period, this may be due to cooler weather than was forecast.
- **Coal** - Coal generation has had to be increased in this period to counter the effects of variance in output from other fuels and demand.

***Period 2.***

- **Nuclear** - Nuclear generation has been less than planned in this period.
- **Gas** - Gas has shown an increase in output in this period.
- **Demand** - Reduced demand could be attributed to comparatively warm weather, reducing requirements for heating.
- **Coal** - The reduction in demand and the increase in gas generation has only been partly offset by the reduction in nuclear generation, hence coal has not significantly changed.

***Period 3.***

- **Nuclear** - Nuclear generation has again been below expected levels.
- **Gas** - Gas output has been exactly as expected.
- **Demand** - Large increase in demand possibly due to low temperatures and increased requirements for heating.
- **Coal** - Reduced nuclear output and high demand have combined to increase coal generation.

The consequences of large variations in output from other sources, and the fluctuations which can occur in demand, can result in substantial variation in coal use. Stock levels must be maintained such that enough is stored to meet this variation in coal-fired generation. However, unnecessarily high stock levels are expensive to maintain so a balance has to be found by operating long- and medium-term fuel purchase contracts.

## **1.7. Fuel Purchase within a Multi-Fuel Generating Company**

Fuel procurement is the largest single item in the operating expenditure of any electricity generator, and as such, is crucial to competition within the industry. In 1994 the UK electricity generating industry purchased 35.9 Mtoe (million tonnes oil equivalent) of coal and 3.58 Mt (million tonnes) of oil for the production of electricity<sup>34</sup>. In 1994/95 National Power alone spent £1,415 million on fuel and committed itself to spending a further £2.7 billion on long-term coal contracts<sup>35</sup>. With so much money invested in fuel purchase, and with cost-effectiveness important in every aspect of electricity generation the significance of analysis and appraisal of purchasing will increase.

The medium-term market for coal involves the utility going out to tender for supply for up to 12 months ahead. Coal producers respond with offers which have relatively stable prices. In contrast, long-term contracts (up to 15 years ahead) are subject to considerable price uncertainty. Coal can vary in quality depending on the source, therefore it is important to compare offers on more than simply a cost basis.

In the previous discussion of portfolio management, it was stated that uncertainty is an important influence in the organisation of contracts. The formalisation of the fuel purchasing decision process is therefore central to the co-ordination of coal contracts.

The long-term contracts which have supplied most of the coal burned in the past are being replaced, in part, with medium-term purchases (up to one year). Since medium-term purchases have made up a comparatively small percentage of the total coal purchased in the past there has been less experience in the field of medium-term contract organisation, for both purchasers and suppliers of coal. Contracts organised on this timescale are not popular with suppliers since they make long-term investment difficult. The consequence of no long-term investment will be that fewer coal sources will be developed and, in the future, there will be a reduced indigenous coal industry, leaving the ESI dependent on foreign supply. Hence, a complete shift towards these contract types may not realistically be possible. It is

therefore important that new methods of analysing medium-term coal requirements and organisation of contracts are explored.

## **1.8. Coal Purchase Decision Support Software**

Since the corporate changes in the Electricity Supply Industry the conventional merit-order for dispatch has been superseded. Release of the newly privatised Electricity Companies from binding contracts to purchase coal from the National Coal Board and the Industry Regulator's endorsement of the 'dash-for-gas' have advocated the commercial advantages of burning gas.

Gas-fired generation, traditionally employed to meet peak demand, is now used to meet base-load demand, while coal-fired plant, traditionally base-load, is taking an increasingly mid-merit position in the merit-order. Mid-merit generation is variable, depending on total demand and generation from other sources. Therefore, the quantities of fuel required to meet generation are also subject to a degree of variance. In order to take into account the move from base-load to mid-merit supply coal is now purchased more effectively on the medium-term market.

Experience of medium-term purchase is limited for both suppliers and purchasers of coal. Coal offers vary in quality of fuel, delivery rate and price. The fuel buyers need to be able to differentiate between suppliers and their offers when making a purchasing decision and must be able to identify the strategic merit of the purchases they make.

The need for a decision support system for medium-term coal purchasing was identified as part of a collaborative research project between the Department of Electrical Engineering at Edinburgh University and the Central Production Group at Scottish Hydro-Electric plc.

Crucial to successful progress in this project is an understanding of the critical factors which make up a 'good coal purchase'. Knowledge elicitation from experts at Scottish Hydro-Electric revealed that the criteria for a 'good purchase' are not necessarily constant and depend on a range of features such as the time of year when the purchase is being made, the circumstances of the purchase and the supply conditions.

The work carried out within this study has identified the main criteria for successfully purchasing coal, based on how requirements for coal change within the year and for

individual purchases. Suppliers' past performance has been analysed and the results have been used to evaluate which suppliers, of those that have tendered, will satisfy the particular demands of the next purchase. From this it is possible to draw up a 'purchase merit-order' which can be used to select which offers should be accepted. This study has led to the development of decision reduction techniques which have been incorporated into interactive decision support software.

## **1.9. Thesis Outline**

In the first section of Chapter 2 a detailed overview of the information required when making an informed fuel purchase decision is given and is followed by a description of contract organisation for mixed-fuel generation. Information requirements, contract organisation and their relevance to Scottish Hydro-Electric are then discussed in more detail. Finally, emissions legislation is presented and its effects on coal purchase decisions are discussed.

The first half of Chapter 3 examines the issues relating to strategic purchasing policies and proposes their integration into coal purchase for electricity generation. The complexities associated with organizational purchasing are then discussed and the buying decision models used in organizational purchase are then described. The second half of Chapter 3 discusses the application of these buying decision models to coal purchase and the resulting development of the 'Coal Supplier Grading System', the incorporation of which into a decision support system for coal purchase is then advocated.

Chapter 4 introduces the human decision making process and discusses how decision support systems, which encompass all or part of this process, have evolved. Following an overview of the structure of decision support systems, the application of the techniques used to coal purchase and coal supplier analysis is discussed. Finally, Chapter 4 discusses the software packages used in the development of the decision support system for coal purchase, 'CoalMan'.

Chapter 5 expands on the introduction to decision support systems in coal purchase and gives a detailed description of 'CoalMan', the decision support system developed in the course of this study. Examples and screen layouts are presented to illustrate the operation of the software. Each component of the software is shown and its associated calculations are given, along with concise explanations about what the software is doing at each stage.

In Chapter 6 results from running six typical scenarios, which represent the application of different criteria to the purchasing problem, are presented and the differences between the outcomes are compared. Detailed analysis of the results of each scenario is given.

Finally, Chapter 7 is a discussion of the work contained in this thesis. It also presents the conclusions and gives suggestions for further work in this field.

## CHAPTER 2

### FUEL SOURCES

The purchase of primary fuels for combustion is the largest single operating cost for all electricity utilities. Given that the production costs, and therefore the profit, of the company depends largely on the fuel it burns (see Section 1.1.2. of Chapter 1), fuel purchase is one of the most important functions carried out within the ESI.

When making a fuel purchase decision the decision maker must gather relevant information from a range of sources both internal and external to the organisation. This information has an impact on the contract types which the buyer will use in order to meet the Generator's requirements for fuel. Contract types and how they are used to purchase the available fuel sources are described in detail in this chapter.

Scottish Hydro-Electric and the company's relationship with ScottishPower is described. Fuel purchase as it is specifically related to Scottish Hydro-Electric is then introduced. Each fuel type available to Scottish Hydro-Electric and the constraints particular to the source and fuel itself are discussed in detail.

In recent years the introduction of more stringent legislative measures to control emissions has had an impact on generation from fossil fuels. These measures and those proposed for future implementation are summarised and their impact on fossil fuel generation in general is discussed.

#### **2.1. Information Required in Making a Fuel Purchase Decision**

Fuel purchase involves scheduling the fuel resources available to the electricity company in order that operational and supply security criteria are maintained while demand is met. This in turn involves optimisation of the purchase, distribution, storage and consumption of fuels<sup>36</sup> which must be carried out within the limits of a number of financial and technical constraints. These constraints range from contractual constraints, with their corresponding long-, medium- and short-term effects on the decision making process, through technical constraints, which cannot be altered except by long-term changes to generating plant, to generation constraints, including demand which cannot be precisely predicted.

To make decisions concerning which fuel(s) to purchase, and the quantities which will be needed, information is required from a number of sources as shown in Figure 9. From the diagram it can be seen that long-, medium- and short-term planning requires different sets of information.

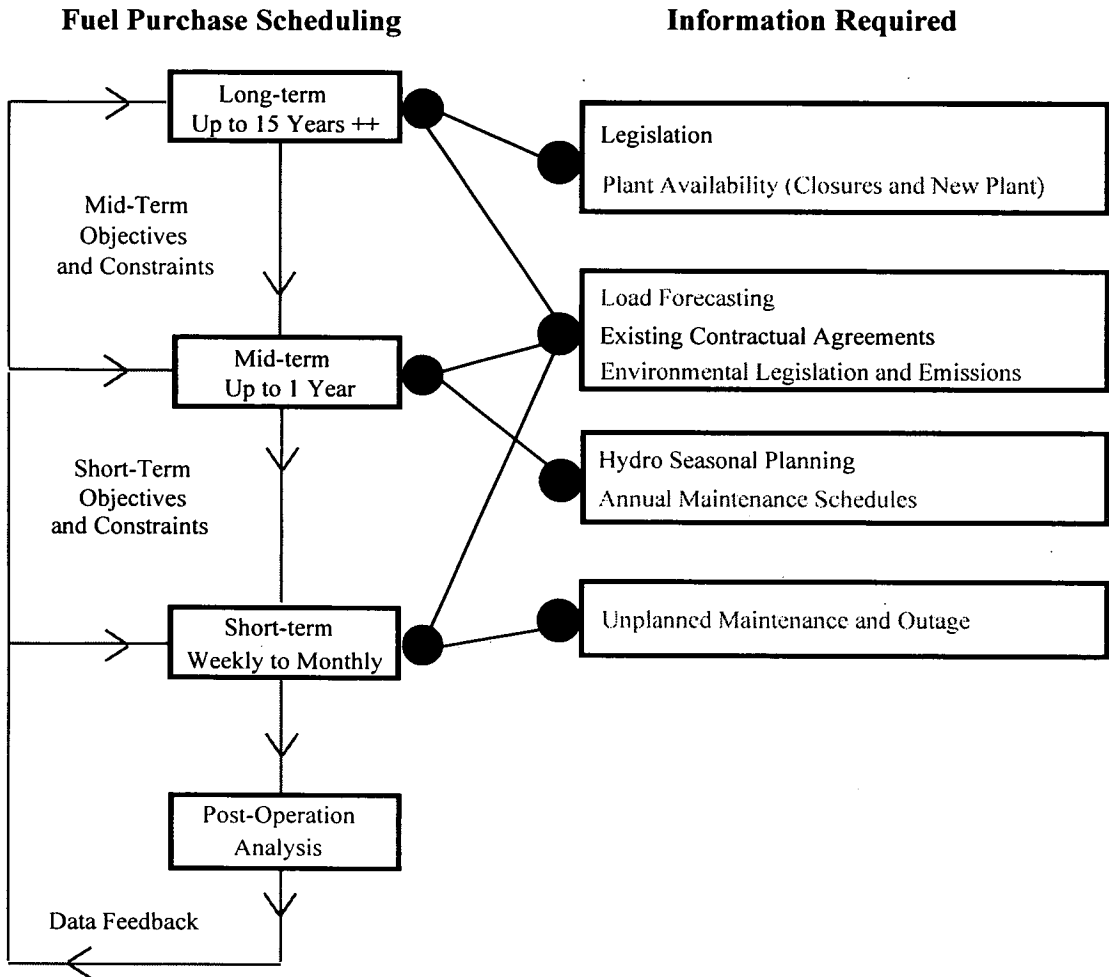


Figure 9. Information Required for Fuel Purchase

Long-term fuel purchase decisions are based predominantly on long-term load forecasts and other long-term contracts which have already been arranged. Commissioning of new generating plant and retirement of old plant will affect the period of time over which these contracts will run.

Medium-term decisions have additional input from maintenance schedules which, in the case of Scottish Nuclear, are agreed one year ahead. Unplanned maintenance or outage of plant has an impact on generation from other sources, in particular coal-fired generation which is increasingly becoming the mid-merit source which meets the difference between

demand and generation from base-load sources. In turn, this affects the purchase of fuel for mid-merit generation because its requirement cannot be exactly predicted. Coal-fired generation has associated environmental emissions which must also be taken into account in the fuel purchase decision. Emissions legislation is discussed in detail later in this chapter.

Short-term purchases are used to allow for changes in short-term maintenance, such as unplanned outages, and to take advantage of prices at the time of purchase. They also allow for variation in demand and supply forecasts.

The information required for fuel purchase scheduling decisions can be divided into 4 main areas of interest.

1. Demand: this has three categories; 1st Tier Demand, 2nd Tier Demand and Interconnector Sales (for ScottishPower and Scottish Hydro-Electric), each of which is forecast on all three timescales for purchase. Demand forecasts are central to any fuel purchase decision.
2. Fuel-specific information: this includes any existing contracts and their associated delivery rates. It is important that delivery allowances are not exceeded and that, in the case of coal and oil, additional purchases will not take stock levels over their maximum limits<sup>37</sup>. Purchases are also constrained by availability of the fuel in the timescale. This is described in more detail later in this chapter.
3. Market position: the position of the market and the actions of competitors within the market will affect the purchasing decision. This is discussed in detail in Chapter 3.
4. External legislation: this includes franchise breaks and emissions limits. The latter are discussed later in this chapter.

## **2.2. Contractual Agreements**

In managing fuel procurement, decisions must be taken on fuel types, timescales for purchase and quantities of fuel required. Operating a portfolio of fuel types and suppliers offers the Generator a means to achieve more flexibility in generation. It means that the Generator has no dependence on one particular fuel or supplier so that political issues, such



as the miner's strike of 1983 (see Section 1.2. of Chapter 1) have less impact on electricity generation.

Maintaining contracts with more than one supplier for each fuel type will allow the Generator to minimise fuel costs consistent with meeting contracts. This section considers the different contract types available to the Generators and how they complement each other.

Each fuel type used for electricity generation can be purchased in a number of ways, allowing the Generator to maintain secure fuel supply in order to guarantee generation. However, there are limits to the flexibility of supply that a Generator can achieve. While increasing the flexibility of a fuel mix can result in reduced risk for the Generator, its transfer to the supplier may incur a financial penalty.

The Generator can organise long-term fuel contracts with suppliers which vary in rate of energy delivery and, in some cases, change pricing during the period of the contract. One benefit of using long-term contracts is the creation of supply by giving the fuel supplier secure sales over an extended period. This allows the fuel supplier to raise capital and invest in further expansion, hence creating future secure supply for the Generator<sup>38</sup>.

Medium-term fuel contracts allow the Generator to purchase quantities of fuel for generation in the mid-merit region of the load-duration curve, as discussed in detail in Section 1.7. of Chapter 1.

The final option available to the Generator is to purchase fuel on the short-term or 'spot' market<sup>39</sup>. This is the market for prompt delivery of fuel at the station.

Each of these contract types has its associated risks and, because of the nature of the ESI, it is of benefit to the Generator to maintain a number of different types of contract and, where possible, to spread them over a range of fuel types. Figure 10 shows how, for a typical multi-fuel generator, the contracts would fit together to ensure flexibility in fuel supply.

An Electricity Utility can agree with any supplier to take a minimum amount of fuel at an agreed price and rate over a particular period. They must 'take-or-pay' for this energy in accordance with the contract<sup>40</sup>. The differences in contracts are the timescales over which they are arranged to run. These timescales are also associated with particular fuel types, as shown in Figure 10.

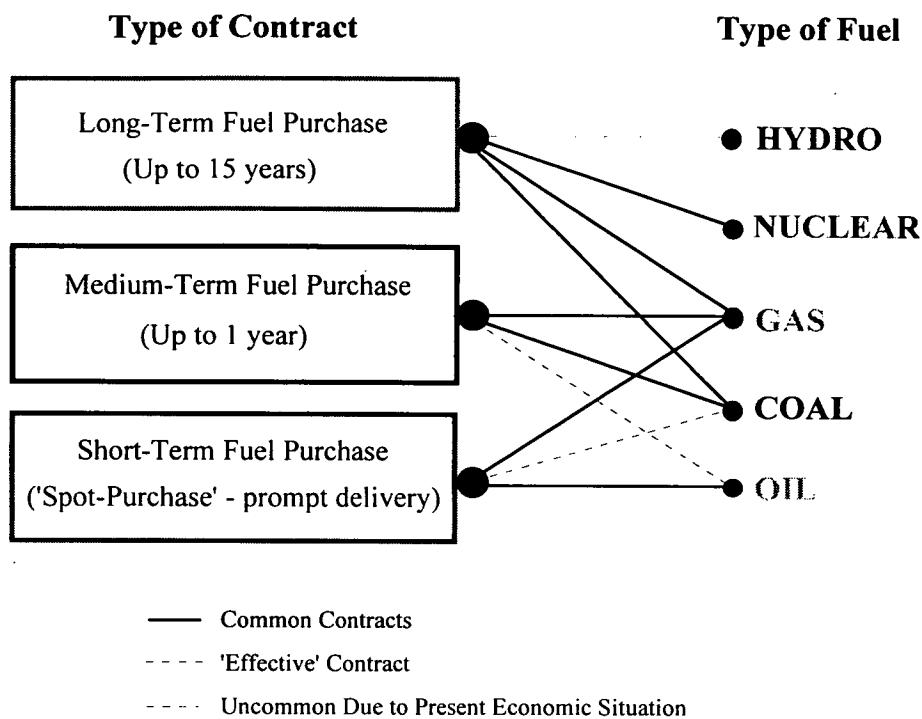


Figure 10. Fuel purchase contract types according to fuel

The types of contract under which each fuel is purchased is also dictated by its position in the merit order for generation. Fuel for base-load generation sources, such as coal, nuclear and gas, are purchased on long-term contracts. Fuel sources which supply mid-merit demand, such as coal and gas, will also be purchased on medium-term contracts in order to reflect some of the variance associated with being in this position in the merit order (see Chapter 1, Section 1.6).

### 2.2.1. Long-Term Contracts

Long-term contracts are those which run for more than one year and for up to 15 years, or even longer in certain cases. These contracts are used largely for fuel types used to supply base-load generating plant; hydro, nuclear, gas and coal.

#### 2.2.1.1. Hydro

Historical data on run-off within catchment areas is used to forecast available generation of electricity from hydroelectric plants. Since rainfall is not controllable, water appears at first sight to be inflexible. Pondage normally allows some degree of flexibility although this can

be lost if reservoirs are filled by a spell of heavy rainfall or reservoirs levels are reduced through drought.

Hydroelectric generation is, effectively, a long-term 'must-take' contract. When reservoirs are full the plant should be run, rather than risk spilling water and losing revenue. Since hydro generation is cheap it is always advantageous to generate electricity and sell it to the England and Wales Pool rather than spill water<sup>41</sup>.

#### **2.2.1.2. Nuclear**

Although, for technical reasons, nuclear generation may lack the ability to respond to rapid changes in system demand, it can respond to market conditions given more time. At the time of writing Scottish Nuclear, with a capacity of 2400 MW, has priority over other forms of generation when selling electricity into the Scottish Electricity Market. Scottish Nuclear have a 'must-take' contract which allows them guaranteed sales of all the electricity they produce; 74.9% going to ScottishPower and 25.1% to Scottish Hydro-Electric<sup>42</sup>. This contract will run until 2005.

Nuclear Electric, the second operating subsidiary of British Energy, generates electricity which is sold to the market through the England and Wales Pool. Its total capacity is approximately 7200 MW and its output in 1995/96 amounted to some 15% of total generation in England and Wales<sup>43</sup>.

#### **2.2.1.3. Gas**

In the UK between financial years 1992/93 and 1993/94 electricity generation from gas increased by more than 700%<sup>44</sup> due to the 'dash-for-gas'. At present approximately 21% of the UK's total electricity generation comes from gas<sup>45</sup>.

Electricity generation from gas tends to be inflexible due to contractual obligations. In some cases the supplier is an oil company, for whom gas is a by-product of oil recovery thus, in order to reduce gas supply, oil production must be reduced. Nevertheless, the commercial decision to 'turn-down' gas may be taken, despite the economic penalties which this attracts. Utilities can also increase their options through operating several gas-fired power stations and by having direct involvement in the gas market. For example, in a joint venture with

Marathon Gas, Scottish Hydro-Electric sell gas to consumers who spend over £1,140 annually on gas<sup>46</sup>.

Gas companies, most notably British Gas, have 'interruptible contracts' to supply to Utilities. These contracts allow the supplier to cut off the electricity companies at four hours notice at times when gas is required by higher priority customers, for example hospitals. In return the Utilities receive the fuel at a lower price. However, this means that back-up reserves of alternative fuels, such as propane, must be stored at the stations<sup>47</sup>.

#### **2.2.1.4. Coal**

By arranging long-term coal purchasing contracts the Utilities attempt to ensure that the mining companies have the financial security they need to invest in the development of new mines<sup>48</sup>.

Since some Utilities have long-term agreements to supply electricity to their consumers, this method of ensuring the availability of future fuel sources and secure fuel prices is of benefit to the Generator. By tying in a percentage of their expected coal purchases with long-term contracts they guarantee supplies for several years. The financial risks associated with purchasing large quantities of coal on the spot market make long- and medium-term contracts a favourable option for ensuring steady supply at known terms.

### **2.2.2. Medium-Term Contracts**

A fuel supplier can tender for contracts to supply a specified amount of fuel within a set time period at some time in the future, from a few months up to several years. Such contracts usually apply to coal, oil and gas.

#### **2.2.2.1. Coal**

As previously mentioned, in Chapter 1, coal is increasingly taking a mid-merit role in the UK electricity generating industry. It now tends to occupy the position between less flexible generation and demand.

Before privatisation Government legislation guaranteed the demand for coal and forced the CEGB to maintain large stock-piles of fuel at their stations. However, in the post-

privatisation, 'dash-for-gas' market, coal suppliers are increasingly being forced to compete for medium-term contracts and can no longer enjoy the security of long-term guaranteed sales.

Mines usually have some capacity to increase production over their medium-term sales contracts. Generators can therefore purchase additional tonnages at close to the marginal cost of producing the coal. This lowers the average price and introduces some of the benefits associated with a spot market, as described in Section 2.2.3.1.

#### **2.2.2.2. Oil**

Oil may be purchased through 'Hedging' contracts. The Generator may choose to arrange a contract for the supply of oil at some future date at the present oil price plus a fixed premium. The benefit of this hedging method is the reduction of price risk by ensuring that the terms of purchase at a future date are known. If the spot price of the fuel rises in the meantime then the Generator has successfully overcome some of the price risk associated with spot market purchases. If the spot price for oil drops then the Generator need not purchase the fuel but will be required to pay the fixed premium<sup>49,50</sup>.

For example, a buyer might arrange a hedging contract for oil at a cost of \$55/tonne plus a fixed premium of \$5/tonne. If, by the time the oil is due for delivery, the oil price has risen to \$70/tonne then the buyer has saved \$10/tonne. However, if the price has dropped to \$40/tonne then the buyer can choose to pay the fixed premium of \$5/tonne and then purchase the oil required at the cheaper price available on the World market.

Hedging is an investment strategy and energy risk management tool<sup>51</sup>. It should not be seen as a method of off-setting potential losses<sup>52</sup>.

#### **2.2.3. Spot Purchases**

Spot purchases are short-term agreements where energy is supplied quickly and at a price close to marginal cost. The fuel is traded for immediate delivery, as distinct from the delivery timescales associated with standard contracts.

### **2.2.3.1. Coal**

Generators operate a portfolio of coal supply contracts over a range of time periods, from a matter of months to a number of years. Usually only a proportion is committed to long- and medium-term arrangements, the rest is left to shorter-term (less than one year) purchases.

Before privatisation of the National Coal Board in 1994 there were large quantities of coal stocked at UK pit heads, as shown in Table 4 in Chapter 1. It was, therefore, possible to purchase large quantities of UK coal on short timescales. However, the expense associated with maintaining these stocks coupled with the requirements of the new coal companies to be cost-effective has meant a reduction in the coal available for purchase on the UK spot market. There is a spot market for coal in the rest of Europe, and in the USA it is reported that up to 15% of coal traded is through spot sales<sup>53</sup>.

### **2.2.3.2. Oil**

In terms of fuel purchase, oil is generally bought as required on the spot market. Since privatisation electricity generation from oil has fallen by a quarter and by 1993 it represented only 8% of fuel used for generation in the UK<sup>54</sup>. Oil is now largely a stand-by source of fuel for generation.

## **2.3. Scottish Hydro-Electric**

Scottish Hydro-Electric supplies electricity to customers throughout Great Britain. Its first tier licence area covers all of Scotland North of a line running between the Clyde and Tay estuaries, amounting to approximately 25% of the total land area and 3% of the population of Great Britain<sup>55</sup>. The first tier area accounts for approximately 65% of its electricity sales and all of its transmission and distribution business<sup>56</sup>. The rest of its electricity sales are to industrial customers and regional electricity companies (RECs) in England and Wales.

Scottish Hydro-Electric has a generation business which has access to several types of fuel for electricity production. Since the company uses fossil fuel generation fuel purchase is an important facet of daily operations. Every day Planning Engineers at Scottish Hydro-Electric make decisions on which fuel(s) to buy and the quantities and timescales in which to buy them.

Scottish Hydro-Electric and ScottishPower are both vertically integrated companies. The hydro capacity and Peterhead gas-fired station are in Scottish Hydro-Electric's first tier area, while the coal generation at Longannet and Cogenzie is in that of ScottishPower. The two nuclear stations, Hunterston and Torness, are also in ScottishPower's first-tier area.

Figure 11 shows the percentages of total generating capacity supplied by each station type, including the nuclear component which is only sold through ScottishPower and Scottish Hydro-Electric, and not directly onto the grid.

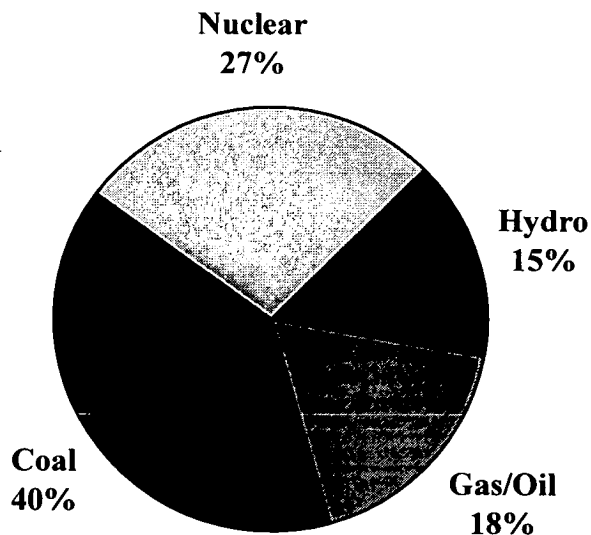


Figure 11. Generating Capacity shared between ScottishPower and Scottish Hydro-Electric

The breakdown of plant allowance for Scottish Hydro-Electric and ScottishPower is shown in Table 6. Capacity available to Scottish Hydro-Electric is then shown in percentage terms in Figure 12.

<i>Declared Net Capacity (MW)</i>	<i>Scottish Hydro-Electric</i>	<i>ScottishPower</i>
Nuclear Capacity (2400)	25.1%	74.9%
Peterhead Gas (230)	30%	70%
Peterhead Oil (1320)	50%	50%
Coal Capacity (3456)	576MW	
Hydro Capacity (1050)		200MW (up to 400GWh/year)

Table 6. Breakdown of Plant Allowance for ScottishPower and Scottish Hydro-Electric.

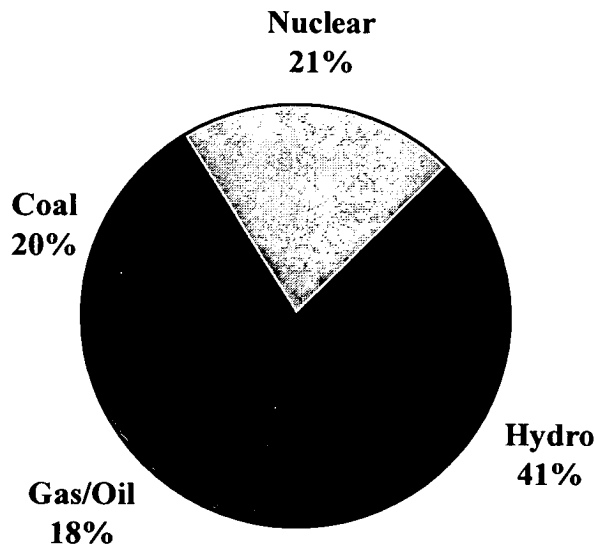


Figure 12. Capacity Available to Scottish Hydro-Electric plc

Figure 13 shows how this capacity was utilised over the last two years, giving an indication of how availability of hydro generation changed from relatively high availability in 1994/95 to a relatively low one in 1995/96. This was due to a reduction in rainfall which led to a drop in generation from hydro plant and, hence, an increase in the uptake of coal. The decrease in nuclear generation and the availability of other sources also had an impact on the use of coal for generation. The increase in generation from gas is due to development of new capacity in England<sup>57</sup>.

Recent episodes which have led to increased use of coal include:

- Low rainfall and reduction in availability of hydro generation.
- Unplanned nuclear outages.

In order to meet the resulting additional requirement for coal the Scottish Electricity companies have purchased extra coal on the medium-term market. However, supply problems at the Longannet Complex Mines, used to supply Longannet Power Station, have meant a further reduction in available coal in Scotland. In total, the additional coal requirements due to outages of other electricity sources and coal supply problems have meant that ScottishPower have had to make coal purchases on the world market in order to meet demand.



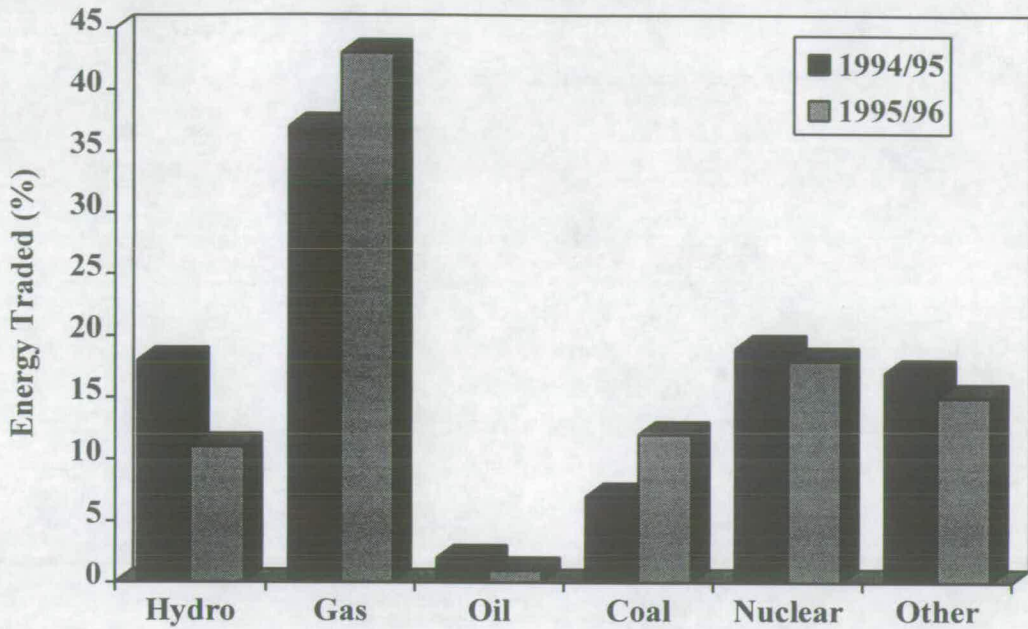


Figure 13. Sources of Electricity Traded by Scottish Hydro-Electric<sup>58</sup>

For Scottish Hydro-Electric fuel purchase is a major component of the cost of production and carries substantial business risk. Decisions are based on information containing uncertainty and must also consider legislative and technical obligations.

#### 2.4. Coal

Before, and for some years after, privatisation ScottishPower and Scottish Hydro-Electric had joint purchasing agreements: ScottishPower purchased coal on behalf of Scottish Hydro-Electric for delivery to Longannet and Cogenzie and Scottish Hydro-Electric purchased all gas and oil for use in the Peterhead power station. However, it was recognised that this left two monopsonies in Scotland and in April 1995 independent fuel purchasing was introduced<sup>59</sup>. Scottish Hydro-Electric took over purchase of their own requirements for coal, while maintaining the long-term contracts set up on their behalf by ScottishPower under the coal agreement. ScottishPower now buys all of the gas and oil it requires at Peterhead power station in addition to the existing long-term purchases arranged as joint purchase agreements.

Prior to the introduction of their own fuel purchase, Scottish Hydro-Electric would contact ScottishPower with instructions to purchase a particular amount of coal for delivery within a

period. ScottishPower would then contact suppliers and give Scottish Hydro-Electric details of the lowest cost offers received which satisfied the tendering criteria and the technical requirements of the stations. When the offers were combined they would meet Scottish Hydro-Electric's consumption requirements within emissions limits. Scottish Hydro-Electric could then choose to accept or reject the package.

The method by which this was carried out meant that Scottish Hydro-Electric had little, if any, direct contact with coal suppliers. The offers received were also filtered before they reached Scottish Hydro-Electric so they had no experience and limited knowledge of what constituted a suitable candidate. For this reason, over the first eighteen months of HEs own coal purchase the company has had to come to terms with being placed on a steep learning curve. The fact that this is also a crucial factor in the success of the business has meant that the curve has felt all the steeper. Currently Scottish Hydro-Electric spend in the region of £35 million per year on coal for electricity generation<sup>60</sup>.

#### **2.4.1. Coal Contract Portfolios**

Generators operate a portfolio of coal supply contracts over a range of time periods, from a matter of months to a number of years. Usually only a proportion is committed to longer term arrangements, the rest is left to medium-term (less than one year) purchases.

Within Scottish Hydro-Electric's fuel purchase group two complementary activities can be distinguished:

- Long-term and medium-term fuel supply management
- Short-term spot fuel purchase

Longer term contracts are designed to minimise the risk of price fluctuations in the spot-fuel markets, while short-term spot fuel purchases reap the rewards of price movements. Spot purchases are associated with fuel destined for marginal electricity production and are therefore central to profit maximisation strategies. Risk is managed by striking a balance between long- and short-term contracts.

Apart from the price benefit, some of the coal demand is left to medium- and short-term purchases because of uncertainty in coal requirements in the developing market.

The balance between the volumes of coal committed to long-, medium- and short-term purchases is set by the confidence the fuel buyers have in the forecast requirements for fuel. For base-load generation a large proportion of the requirement will be predictable, but for mid-merit generation it will be harder to predict precisely the quantities of fuel which will be required. The cost and availability of marginal supplies will also affect the levels of fuel requirement which buyers will leave to short-term purchasing. Buyers must therefore rationalise the benefits of security of fuel supply with the uncertainty associated with variation in supply from other sources.

Experience gained from dealing with the practicalities of coal purchasing, for example transport and processing, suggest a lead time of approximately three months from initially identifying a need to purchase coal to first deliveries. Scottish Hydro-Electric must therefore ensure sufficient coal is stocked to cover uncertainty in consumption over this lead time.

#### 2.4.2. Station Requirements

Fuel for Longannet and Cockerzie coal-fired power stations is subject to strict quality controls. For each delivery there are maximum and minimum accepted values which are shown in Table 7. The table also shows the additional limits imposed either by the station itself, or by Scottish Hydro-Electric with reasons behind these restrictions.

	<i>Accepted at Station (per delivery)</i>	<i>Limits on Average of Deliveries</i>	<i>Reason for Limits on Deliveries</i>
Calorific Value	21.4 GJ/Te min	21.4 GJ/Te min	minimum heat input to the boiler required to achieve maximum continuous rating of the station
Sulphur	2% max	<1.1%	to stay within stack rate (maximum sulphur emissions)
Moisture	20% max	<17%	to allow for rain increasing moisture content of coal
Inerts (Moisture + Ash)	28% max	28% max	reduce heat output

Table 7. Specification Requirements at Longannet and Cockerzie

### 2.4.3. Stock Management

Once it arrives at Cockenzie or Longannet Power Station the coal stock is managed by ScottishPower. Each delivery is first analysed for specification and its quality and quantity is logged such that the total energy input to the coal stock can be recorded. For Scottish Hydro-Electric, a log of the stock-weighted averages for sulphur, CV, moisture, ash and other constituents is kept.

For Scottish Hydro-Electric's own purchase sub stock there is no fuel cost charged by ScottishPower. However, for purchases arranged jointly under the coal agreement there is a charge which is calculated using Equation 2.

$$\text{Stock Weighted Average Cost (Gross)} = \frac{A+B}{C+D} \text{ £/GJ} \quad (2)$$

Where:

A = total price (£) of ordinary purchase sub-stock at beginning of contract year

B = total price (£) of coal delivered into stations for contract year

C = total energy (GJ) gross as received of ordinary purchase sub-stock at beginning of contract year

D = total energy (GJ) gross as received of coal delivered into stations for contract year

Fuel Usage (GJ gross) is calculated half-hourly in accordance with the following formula:

$$\text{Fuel Usage (GJ gross)} = \frac{(E+(F \times G))}{(1-H)} \times 1.026 \times 1.055 \quad (3)$$

Where:

E = no load heat consumption per half-hour

F = number of units of electricity (MWh) required to be dispatched by purchaser in half-hour

G = incremental heat rate (net GJ/MWh) in respect of the dedicated unit

H = agreed transmission loss factor of 0.03

1.026 = agreed fuel stock deterioration factor

1.055 = agreed conversion factor for net to gross GJs for coal based on historical data and following formula for conversion of gross to net calorific value:

$$\text{Net C.V.} = (0.964 * \text{gross C.V.}) - (13.9 * \text{Volatiles}) - (7.87 * \text{Ash}) + (0.766 * \text{Sulphur}) - (30.6 * \text{Moisture}) + 613.1 \quad (4)$$

## 2.4.4. Delivery Schedules

### 2.4.4.1. Road

Delivery of coal by road is the cheapest transport method available to the generator. One reason for this is that the fewer number of times the coal has to be handled the fewer additional charges are incurred. The coal requires less handling when it is transported by road than by rail and therefore incurs less extra cost. However, there is not an unlimited allowance of road delivery to the Scottish stations. This is due to local environmentally acceptable limits, both in terms of dust and from the noise and nuisance factor of hundreds of coal trucks travelling to and from the station. Table 8 shows the maximum number of road deliveries available to Scottish Hydro-Electric both weekly and annually. Within the overall limits there may be some spare road capacity within the Summer months.

<i>Station</i>	<i>Weekly Maximum</i>	<i>Daily Maximum</i>	<i>Approximate Daily Rate (trucks)</i>
Longannet	12.5 kte	2500 te	approx. 110
Cockenzie	5.5 kte	1100 te	approx. 50

Table 8. Road Delivery Scheduling

### 2.4.4.2. Rail

It is more expensive to transport coal by rail than by road. Where mines do not have their own rail system the coal must first be loaded onto trucks and then transported to the rail depot where it will be transferred to rail. This means that it must be handled more often than that which goes directly onto trucks and then to the station. Rail charges are also higher and increase as the distance of the mine from the station increases. Table 9 shows the maximum number of deliveries which Scottish Hydro-Electric can have made to Longannet and Cockenzie.

<i>Station</i>	<i>Annual Fixed Rate</i>	<i>Approximate Weekly Rate (tonnes)</i>
Longannet	unlimited	7,000
Cockenzie	unlimited	4,000

Table 9. Rail Delivery Scheduling

Since rail privatisation, however, the freight company TransRail has been working to reduce the costs of transporting coal by train<sup>61</sup>. By reducing the costs of rail transportation the Utilities will be encouraged to move some road deliveries on to rail. This will have the additional benefit of removing coal related traffic from the roads.

## 2.5. Oil

The price of oil is used to dictate its purchase; what to buy, how much to buy and when to buy it. Cost forecasts can be used but since the price is unpredictable they are largely not reliable. Purchases made up to one month ahead allow the buyer to gain a better 'feel' for the direction the market is moving in so more cost effective purchases can be made.

A spot purchase of oil can be delivered to Peterhead oil-fired station in as short a time as a week, depending on how urgently it is required at the station. It is brought in on ocean tankers, containing up to 50,000 tonnes, and put into storage at the station.

In recent years Scottish Hydro-Electric has purchased oil on the spot market alone. This is due to high world oil prices and the advantage that Scottish Hydro-Electric has no absolute dependence on oil for generation. However, Scottish Hydro-Electric maintains around 20,000 tonnes to cover for loss of gas supply at Peterhead gas-fired station.

## 2.6. Gas

As a power station fuel gas has many attractive properties. It is cleaner than coal generation, since gas has negligible sulphur content and produces no ash, and the stations take less time to build with lower capital costs. Table 10 shows comparison with other generating plant.

<i>Fuel</i>	<i>Construction Time (Years)</i>	<i>Unit Capital Cost (£/kW)</i>
Gas	2	750
Oil	4	800
Coal	6	900

Table 10. Typical Construction Times and Unit Capital Costs<sup>62,63</sup>

Although the fuel is more expensive than coal, for these reasons, electricity from gas is cheaper than from coal. It does not fluctuate in the way that oil and coal price can. It is also not easily influenced by other economic factors, although it will respond in some way to variation in the price of other fuels and the Retail Price Index.

### **2.6.1. Supply Constraints**

Scottish Hydro-Electric 'must-take' a *minimum* of 1,715 TJ per week of Miller Plateau gas, although this can be scheduled according to demand. Hydro generally take up to 275 TJ per day through the working week and reduce it to around 205 TJ per day at the weekend.

There are also upper and lower limits within which the company must stay for technical reasons. The lower limit of 260 MW is set by the gas turbines in the station which will not run any lower, although they can be switched off. The upper limit of 1200 MW is set by the total capacity of the generating plant.

Although gas cannot be stored at Peterhead it is possible to increase the pressure in the pipes for short periods. The acceptable pressure in the pipes is 114 → 170 bar, although it is maintained at around 130 bar for the majority of the time. This flexibility in pressure is used to increase storage of gas over night when demand is low and then to allow increased supply during the day when demand is high.

### **2.6.2. Miller Gas Plateau**

The Miller Plateau at Peterhead will come to an end in 1998. This will mean that replacement economic fuel supplies must be sought. The consequences of not finding replacement gas will be increased generation from coal or oil or purchases from the pool.

Increasing coal burn will require the fitting of Flue Gas Desulphurisation (FGD) to remove the additional sulphur emissions, as described in detail in Section 2.10. of this chapter. This will be expensive but must be considered as part of the total economic appraisal of long-term fuel purchases. 1% sulphur fuel oil is also likely to become more expensive on World Markets as demand increases. Since more than 40% of electricity traded by Scottish Hydro-Electric in 1995/96 was from gas generation, an increase in pool purchases to meet this reduction would leave the company highly dependent on contracts from other Generators and prove more expensive.

The solution will require a detailed economic appraisal of each of Scottish Hydro-Electric's generation options and any offers of fuel supply that may be made.

## **2.7. Hydro**

Scottish Hydro-Electric have approximately 1300 MW of hydro powered capacity divided into the Northern and Southern Hydro Groups. Northern Hydro Group has five hydro schemes; Shin, Conon, Affric/Beaully, Garry/Morrison and Foyers. Southern Hydro Group has three hydro schemes; Tummel, Breadalbane and Sloy/Awe.

Generation is forecast using a ten year moving average for each month and is then predicted one week ahead based on rainfall forecasts from the Met. Office. This dependence on weather patterns means that hydro generation exhibits more variation from its generation forecast than the other fuel sources available to Scottish Hydro-Electric. For this reason these fluctuations have the greatest impact on coal burn. The graph in Figure 13 shows how a drop in hydro generation affected the use of coal between the years 1994/95 and 1995/96.

## **2.8. Nuclear**

Scottish Nuclear cannot sell their electricity directly to the E&W Pool; instead all of their output must go to ScottishPower and Scottish Hydro-Electric for distribution to their customers. ScottishPower and Scottish Hydro-Electric take a 74.9/25.1% share, respectively, of Scottish Nuclear's output.

Annual trade with Scottish Nuclear amounts to approximately £120M of which only a small percentage can be directly influenced by Scottish Hydro-Electric. The cost does not include transmission loss or the payment of transmission costs to ScottishPower for use of their capacity.

### **2.8.1. Maintenance**

Maintenance is planned annually, with the outage plan agreed in October of the previous year. Planned maintenance is scheduled for the Summer months when electricity demand is lower. Until 1995 each reactor was required to have full maintenance every two years, meaning that of the four reactors in Scotland two would be off for six weeks each during the



Summer months every year. However, maintenance is now carried out on each reactor on a three year cycle<sup>64</sup>, with an interim partial shutdown for approximately two weeks. Table 11 shows how this pattern works for the four reactors. Once every three years two reactors will be shutdown for maintenance, but for two years only one will be closed for the full six week maintenance programme.

Reactor	Year 1	Year 2	Year 3	Year 4	Year 5
Torness: Reactor 1	•			•	
Torness: Reactor 2		•			•
Hunterston: Reactor 1			•		
Hunterston: Reactor 2	•			•	

Table 11. Maintenance Scheduling

Scottish Hydro-Electric and ScottishPower would find it preferable if Scottish Nuclear were to plan routine maintenance, and therefore reduce generation, at times when demand is low or when the interconnector is not operational. Generally this preference is satisfied by planning major outages for the Summer months.

### 2.8.2. Reduction in Output

Should Scottish Hydro-Electric or ScottishPower decide that they will require a reduction in nuclear generation they must order a 'ramp down' one day in advance. Scottish Nuclear will then reduce the output from the reactors as necessary. For this service Scottish Hydro-Electric or ScottishPower must pay Scottish Nuclear compensation, and may only make such a request four times annually. This carries the penalty of 'sustained factor', that is, should something happen to Scottish Nuclear's generating equipment during the reduction, the utility which ordered the ramp down will be liable for costs incurred by the resulting outage. When this happens their only recourse is to prove 'force majeure', or 'act of God or nature'.

In cases of over capacity it is generally accepted that Scottish Nuclear should be turned down before Miller Gas. If Miller is reduced then Scottish Hydro-Electric becomes liable for compensation for reduction in oil production, of which the gas supply is a by-product.

### 2.8.3. Nuclear Fuel Limitations

Nuclear stations cannot ramp-up or ramp-down very quickly. Dropping control rods in, or moving them out too quickly, poisons the fuel by producing xenon. Therefore Scottish Nuclear cannot load follow. The nuclear reactor is the controlling factor in the speed with which the output may be varied.

### 2.9. Cost of Emissions

In 1988 the European Council adopted the Large Combustion Plant Directive (LCPD) which required each Member State in the EC to reduce emissions of SO<sub>2</sub> and NO<sub>x</sub>. The reductions required in the UK are given in Table 12 below<sup>65</sup>.

<i>Target Date</i>	<i>Percentage Reduction Required from 1980 levels</i>	
	<i>in SO<sub>2</sub></i>	<i>in NO<sub>x</sub></i>
1993	20	15
1998	40	30
2003	60	no target set

Table 12. Percentage Reduction in Emissions Required Under LCPD

Limits are now applied to sulphur and nitrogen emissions and a landfill tax is proposed for the disposal of ash. These emissions charges mean that the full cost of generation from coal-fired plant is no longer restricted to production costs.

In order to carry out an accurate assessment of the value of a coal purchase the costs of emissions must be included as part of a full-cost analysis. The next sections of this chapter consider some of the legislation being used, or proposed, to reduce emissions and how this legislation affects the use of different fuels for generation, with special reference to coal purchase.

### 2.10. Emissions Legislation

Concern over potential environmental changes caused by enhanced global warming and acid deposition has focused on their cause. One of the main contributors to the emission of the

gases thought to be responsible for these effects is the Electricity Supply Industry (ESI), through the use of fossil-fired power stations. Calls for limits on present levels have led to emissions legislation in, for example, the UK and in the wider European Union, with the European Environment Protection Act.

As mankind became increasingly aware of the potential effects of gaseous emissions, legislation was introduced in an attempt to control or limit their level. Early legislation was (and still is in many instances) based on a command/control model, where pre-set levels were agreed and any emissions above these levels attracted a fine by the authorities<sup>66</sup>.

This form of legislation is somewhat crude and limited in effectiveness. Governments are now addressing the question of which form of legislation should replace it. Should countries be forced to reduce their overall emissions, regardless of the type of industry they support, or should any restrictions be introduced with the national economies of the countries involved and their position in supplying World markets in mind? Legislators, policy makers and engineers must now rationalise the rising demand for electricity with the desire to be more energy efficient and to protect the environment. Two options are carbon taxation and tradeable emission permits<sup>67</sup>.

### **2.10.1. Carbon Taxation**

Carbon taxation first gained widespread attention in 1989. The idea was that by applying a tax to gaseous emissions of the oxides of carbon such emissions would be discouraged and the economic standing of low-carbon processes would be improved. In June 1990, the EU heads of state agreed to limit the emissions of greenhouse gases as part of an action for 'sustainable development' and within a few months the Energy/Environment Council had undertaken to stabilise CO<sub>2</sub> emissions in the EC at 1990 levels by the year 2000. Without this action, it is forecast that levels of CO<sub>2</sub> could rise by about 14%<sup>68</sup>. The European Commission has developed a strategy for achieving this target which includes:-

- R&D programmes and technical measures.
- Measures to help member states who have the greatest problems of abating emissions or economic constraints.
- Tax measures, including the possibility of a specific CO<sub>2</sub> energy tax.

The tax is not intended as the sole measure against increasing emissions but as part of a strategy to increase energy efficiency. In a broader sense this tax is seen as part of a policy

for protecting the environment that deals with air acidification, transport, nature protection and other relevant issues. The energy, or carbon, tax should be offset by tax incentives for firms and individuals, the aim being to promote new investment in improving the efficient use of energy and limiting CO<sub>2</sub> emissions.

The EC Environment Commissioner suggested that the money raised from the taxation should be used to finance research and development programmes into reducing carbon emissions<sup>69</sup>. Such a tax is a politically convenient way of raising money for environmental research because the source is directly linked to the problems being addressed. It is not a tool for affecting fuel choice or encouraging fuel efficiency. Table 13 shows the revenue which would be raised by a tax of 0.4\$/tC (dollars per tonne of carbon) applied to all fossil fuels. The figures amount to more than \$300M/yr in Western Europe and over \$2bn/yr if applied world-wide. [\$ = US dollars]

So far, unilateral introduction of a carbon tax has been rejected because of the increased burden of higher energy prices that it would impose on national industries. To meet this complaint the draft directive explicitly includes a clause stating that the tax arrangements cannot be applied in the member states until other countries of the OECD (Organisation for Economic Co-operation and Development) have introduced a similar tax, or measures which would have an equivalent financial impact. The EC Economic Policy Committee has agreed that the proposals are compatible with the objectives pursued and with economic efficiency.

Fuel	Carbon Content	Western Europe Consumption		World Consumption	
		Mtoe	MtC	Mtoe	MtC
	MtC <sup>a</sup> /Mtoe <sup>b</sup>				
Coal	1.07	263	281	2428	2600
Oil <sup>c</sup>	0.81	594	481	3038	2460
Gas	0.61	199	121	1631	984
Total (MtC):			883		6044
Revenue @0.4\$/tC (\$M):			353		2417

<sup>a</sup>MtC = million tonnes of carbon.

<sup>b</sup>Mtoe = million tonnes of oil equivalent.

<sup>c</sup>Oil figures allow for non-energy applications.

Table 13. Revenue raised by 'fund raiser' carbon tax<sup>70</sup>.

An international agreement on domestic carbon taxes would not involve handing over resources to international control. However, such an agreement would not address the question of resource/technology transfer to developing countries. The fixing of a domestic rate would need to take into account the fact that certain economies depend on more energy intensive industries than others. Domestic subsidies could also offset the tax burden.

### **2.10.2. Tradeable Emissions Permits**

An alternative to carbon taxes is marketable emission permits, already in limited use in the United States. The idea is that emissions are controlled through a system of permits, which can be interchanged between various parties without central direction. The approach seems to offer many attractions, but whether the benefits are realised will depend partly on the form the system takes.

First, governments would need to negotiate a global target for emissions. The arduous process of allocating emission restrictions among countries would be replaced by the allocation of permits. Allocations based on current emissions, GNP and land area have all been suggested but the most practical basis would be a capacity-based one, as implemented in the USA.

Secondly, the question of whether the permits should be tradeable or leasable would need to be agreed upon. One suggestion is that permits be periodically 're-issued' according to the initial allocation system. This would amount to a system in which permits are leased but never sold, overcoming many of the objections associated with the overall question.

Finally, the currency of trading would need to be agreed upon, although most economists are likely to argue that it should be unrestricted.

In the United States tradeable emissions permits have already been introduced to help the electricity Utilities halve their annual emissions of sulphur dioxide. The Environmental Protection Agency (EPA) has distributed 5.3 million one year permits, each corresponding to an allowance to emit 1 ton (imperial) of sulphur dioxide into the atmosphere, to the 110 worst polluters<sup>71</sup>. By the year 2000 it is planned that a total of 9.5 million permits will be available to all Utilities. In March 1993 some 150 thousand tons of pollution rights were auctioned by the Chicago Board of Trade for around \$21 million<sup>72</sup>. Since then the purchase price for emissions permits has fluctuated between \$125 and \$450 each. Like all other

stocks, pollution can now be bought, sold and auctioned by anyone who is interested in it. Indeed, some environmental groups have purchased permits and shelved them with a view to reducing atmospheric pollution.

A programme for the application of a similar tradeable emissions permit scheme has also been proposed by the UN's Commission on Sustainable Development. It would be based loosely on the existing one for trading SO<sub>2</sub> and would be applied first in the US, European Union and Japan, covering an estimated 40% of total global emissions of CO<sub>2</sub><sup>73</sup>. If the programme proves successful it will be extended to include other countries.

### **2.10.3. Land-Fill Taxation**

A third taxation has recently been introduced in the UK, that of landfill. The tax is aimed at reducing all waste disposal and encouraging the recycling of bottles, paper and other household waste. However, it affects all forms of waste, including the disposal of ash from coal-fired generating plant, which directly affects the cost of generation from coal.

The costs of disposal can be up to £7 per tonne but, while it is still under negotiation, the proposed tax for disposal of Power Station ash is £2/tonne of ash produced. Introduction of this tax in the Electricity Supply Industry could have devastating effects on the coal industry.

## **2.11. Emissions Abatement Techniques**

There are a number of ways to reduce the emissions from power stations to meet these legislative measures. A few of those which are in large scale commercial operation are covered here.

### **2.11.1. Sulphur Control**

The emission of sulphur dioxide is dependent on the sulphur content of the fuel and on any post-combustion emissions control. Three methods for the reduction of SO<sub>2</sub> emitted during combustion are available:<sup>74</sup>

- Treatment of coal before combustion to reduce sulphur content.
- Design of combustion processes such that sulphur is collected in the ash.

- Removal of SO<sub>2</sub> from combustion gases before their emission into the atmosphere.

Removal of SO<sub>2</sub> from combustion gases is called Flue Gas Desulphurisation (FGD) and yields products such as gypsum, sulphuric acid and sulphur, which can be sold for use in other applications. FGD is, however, expensive. For example a 2GW installation has a capital cost of around £300M, and it reduces the efficiency of the station by about 1.5%<sup>75</sup>.

### 2.11.2. Nitrogen Control

During combustion NO<sub>x</sub> is formed from nitrogen in the fuel and from the oxidisation of air bound nitrogen. Use of 'low NO<sub>x</sub> burners' optimises the fuel and air mix so a lower flame temperature can be achieved reducing the production of NO<sub>x</sub> by up to 50%<sup>76</sup>.

Selective Catalytic Reduction (SCR) is used to remove 80-90%<sup>77</sup> of NO<sub>x</sub> from the flue gas and involves passing the gases over a catalytic bed of platinum with ammonia to reduce the NO<sub>x</sub> to nitrogen. Concerns over the possible release of unreacted ammonia and the cost and lifetime of the catalyst have meant that SCR is not presently considered to be good economic and technical practice in the UK.

### 2.11.3. Carbon Dioxide Control

As yet no method for the practical removal of CO<sub>2</sub> from flue gases on a large scale has been developed, although research is ongoing. Until techniques are proven to be technically and economically viable, the main approach to limiting carbon dioxide emissions will have to be through more efficient energy conversion systems or the increased use of less carbon intensive sources. More efficient systems include the use of Combined Cycle Gas Turbines (CCGTs), while less carbon intensive sources include gas. Nuclear power plants and renewable generators are negligible emitters of carbon dioxide.

Sequestration of carbon dioxide in the deep ocean has been under investigation for many years. Until recently it has not been tested in practice, however, in September 1996 a group of scientists on a North Sea oil rig began experiments to pump liquefied CO<sub>2</sub> through a 1000 metre pipeline into sandstone repositories 1 km beneath the sea, with apparent success<sup>78</sup>.

While still in the early stages of testing this method of waste gas disposal may find popularity with some of the larger producers of the waste gas. The drawback of the system is, of course, financial. Since waste gases from power generation are not purely CO<sub>2</sub> the most expensive part in the process is the removal of the CO<sub>2</sub> from the other gases. This requires energy and that costs money. Estimates suggest that the introduction of these processes could add around 30% to the price of electricity, an increase which the Utilities may find hard to absorb.

One concern associated with these measures is that the CO<sub>2</sub> stored in this way will be released into the atmosphere at a later date. More research into the possible environmental effects of such methods is therefore required<sup>79</sup>.

#### **2.11.4. Ash Control**

When a coal type is analysed it gives a percentage ash content. All ash contained in the coal goes straight through the boiler of the generating set and is either emitted into the atmosphere or is precipitated off at the end of the combustion process. No additional ash is formed in the combustion process.

The best way to reduce ash emissions is to reduce the amount of ash that goes into the combustion process, that is, through the use of a low ash coal. However, this may impact on other aspects of the coal specification and may require to be traded off against moisture content, calorific value and other important factors in the coal selection process.

### **2.12. Emissions Management for Scottish Hydro-Electric**

#### **2.12.1. Sulphur Control**

At present there is no flue gas desulphurisation (FGD) equipment installed at either Longannet or Cogenzie Power Stations. There are no immediate plans to add any since the financial cost of installation would increase the costs of generation at stations which have a relatively low sulphur output anyway. However, ScottishPower have now finalised the evaluation of adding sea water scrubbing FGD at Longannet Power Station, a system which they may take steps to introduce as emissions legislation becomes tighter.



Scottish coal is largely high grade, low sulphur coal and the stations have strict rules about the maximum levels of sulphur allowed in any coal delivery, as discussed in Section 2.4.2. of this chapter. This ensures that SO<sub>2</sub> emissions are kept lower than average output levels for other stations, as mentioned. SO<sub>2</sub> emissions from Longannet Power Station are approximately one third of the UK average emissions from coal-fired plant<sup>80</sup>.

The formula given by Equation 5, for calculating SO<sub>2</sub> emissions, is the agreed basis for compliance with emissions reductions under the Large Combustion Plant Directive (see Section 2.9).

$$1 \text{ tonne Sulphur in coal} \rightarrow 1.9 \text{ tonnes Sulphur Dioxide out} \quad (5)$$

This formula could be re-evaluated and changed in time if modifications are made to the plant or with more information and research by Environmental groups.

### 2.12.2. Nitrogen

Under the Large Combustion Plant Directive the formulae for calculating NO<sub>x</sub> emissions from Longannet and Cockerzie Power Stations are given by Equations 6 and 7.

Low NO<sub>x</sub> burners have been fitted at Longannet giving the output rate for NO<sub>x</sub> as shown in Equation 6.

$$\text{Longannet: } 1 \text{te coal in} \rightarrow 7 \text{kg NO}_x \text{ out} \quad (6)$$

Work has now started on the installation of a 'gas-reburn' process at Longannet, a pioneering project which will be used to demonstrate further reductions in NO<sub>x</sub> emissions. This process involves the injection of natural gas, at high velocity, into the combustion chamber above the coal flame<sup>81</sup>. Nitrogen oxides are converted into nitrogen and water. This project will be the first of its kind in Europe<sup>82</sup>. Figure 14 shows the effects of low NO<sub>x</sub> burners and gas-reburn on nitrous oxide emissions at Longannet Power Station.

At present low NO<sub>x</sub> burners have yet to be installed at Cockerzie Power Station, however, ScottishPower plan to add this process to one unit.

The formula for nitrogen oxide output at Cockerzie Power Station is shown in Equation 7.

$$\text{Cockerzie: } 1 \text{te coal in} \rightarrow 9 \text{kg NO}_x \text{ out} \quad (7)$$

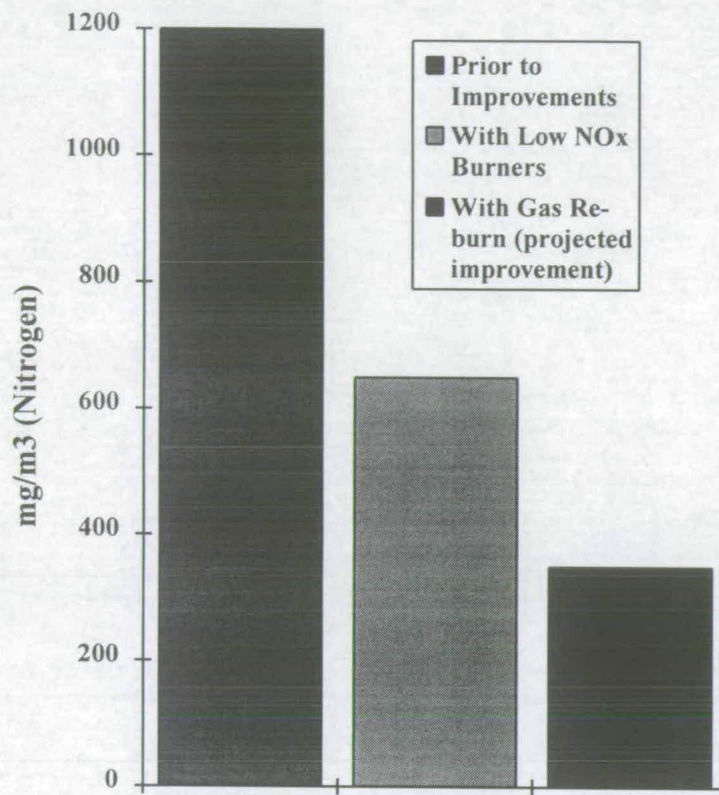


Figure 14. Longannet NOx Emission Limit<sup>83</sup>

### 2.12.3. Ash Reduction

At Longannet and Cockerzie Power Stations electrostatic precipitators<sup>84</sup>, for dust abatement, have been installed to remove ash from the flue gases before release into the atmosphere.

ScottishPower own a Pulverised Fuel Ash sales business through which it sells the ash collected by this equipment, both in its raw state and as a blended cement. The introduction of the Landfill Tax of £2/te of ash means that its disposal must be paid for. Development of the Pulverised Fuel Ash market will reduce the amount of ash produced and the costs associated with its disposal.

Since the quantity of ash created by the combustion process is dependent on the amount of ash in the coal the purchase of low ash content coal is also employed to ensure that ash emissions are reduced.

## 2.13. Chapter Summary

In the first section of this chapter a detailed overview of the information required when making an informed fuel purchase decision was given. The information required for coal purchase decision making falls into six categories:

1. **Electricity Demand:** demand is forecast on three timescales; short-, medium- and long-term. Demand forecasts are central to any fuel purchase decision.
2. **Supply from Other Sources:** in order to purchase the correct amount of coal the buyer has to know how much electricity each fuel source is forecast to supply during the period of the purchase.
3. **Fuel-specific information:** includes quality constraints, delivery rates and limits, existing contracts and their associated delivery rates.
4. **Emissions Legislation:** this includes limits on sulphur and nitrogen emissions and the landfill tax levied on ash produced.
5. **Coal Offer Details:** these include the specification, quantity, delivery rate, transport method and price of the fuel being offered.
6. **Contractual Knowledge:** the buyer will have a thorough understanding of the differences between various contract types and how they fit together to give a purchasing portfolio to meet long-, medium- and short-term requirements.

Since all of the information discussed must be considered in fuel purchase the process of analysis is long and involved. This indicates that the complexity and quantity of the information which must be taken into account effectively prohibits the buyer from investigating the effects of variation in other sources or demand on requirements for coal.

The application of computer technology to this field would successfully reduce the time spent on supplier selection and enhance the scope for making the purchase decision. Incorporating all of the issues which affect coal purchase into a piece of software will also allow the buyer to test scenarios for the impacts of variation of other sources on the use of coal.

## CHAPTER 3

### STRATEGIC PURCHASING AND SUPPLIER ASSESSMENT

As shown in Chapters 1 and 2, privatisation of both the Electricity Supply Industry and the National Coal Board, coupled with increased generation from gas-fired power stations, have meant that the process of purchasing coal has changed significantly in recent years.

The government no longer guarantees that the majority of coal from British mines will be consumed by state-owned power stations. In addition, since the 1960s the amount of coal-fired plant has dropped from 84% to approximately 50% of total installed capacity and has been forced from base-load to mid-merit generation. It has therefore become increasingly important for Utilities to recognise the strategic issues encompassed in medium-term coal purchase and to respond accordingly. This chapter considers strategic purchasing policies and proposes their integration into coal purchase for electricity generation.

The chapter then describes the complexities associated with organisational buying, in particular the motivation that drives the organisational buyer and the processes involved when making a purchasing decision. The methods used to model the stages of these processes are then presented. The criteria used to distinguish between suppliers are then explained and Supplier Appraisal is discussed on the basis of these criteria.

The chapter continues with an application of these methods to the purchase of coal. A novel approach to 'Coal Supplier Analysis', based on the models presented in the first section is then introduced. The conclusions of this work are used as the basis of 'Coal Supplier Analysis'.

#### **3.1. Strategic Purchasing**

Strategies employed in purchasing vary depending on the company making the purchase and the supply market from which the purchase is being made. Some companies include little strategic planning in their purchasing, instead treating it as a clerical task; placing orders on a short-term basis and reacting to any situations affecting purchasing as they arise. On the other hand, many companies are taking a longer-term, more proactive approach to their purchasing requirements, making strategy a driving force in the procurement process.

Saunders (1994) divides purchasing strategies into three categories that are driven primarily by competition in the supply markets:<sup>85</sup>

1. *Traditional:* The traditional strategy for purchasing involves obtaining competitive quotations or tenders, then using negotiating tactics to obtain the lowest price available for the item being purchased. Typically the supply market is competitive and a hands-off, price driven relationship with bidders is appropriate.
2. *Co-operative:* A second strategy involves the fostering of long-term, co-operative relationships with suppliers. This collaborative approach is based on mutual trust and interest in supply and demand, rather than solely on contractual agreements, and allows both the supplier and the company to work together to improve performance.
3. *Vertical Integration:* Instead of buying supplies from independent suppliers some companies choose vertical integration, that is, maintaining and controlling supply through ownership of a facility which produces the required goods. This strategy is applied in areas where supply is critical to business and the company cannot rely on competition in supply markets to guarantee cost-effective supply.

In recent years companies have recognised that in many cases purchasing can no longer be simply treated as an operational function, but has associated strategic issues. Management of supply is important in any situation where the supply market is complex and/or the items being purchased are critical for successful operation<sup>86</sup>. As supplier relationships and availability of supply become more uncertain, so supply management becomes increasingly important.

An important aspect of co-operative strategic purchasing is that of selection of suppliers and supply base management<sup>87</sup>. The management of relationships between suppliers and purchasers is central to this process.

### **3.2. Strategic Implications of Purchasing Portfolio Positioning**

Kraljic (1983) uses a 'purchasing portfolio matrix' to describe how the position of the company relative to that of the supply market can be used to suggest strategic purchasing measures. In the purchasing portfolio matrix, shown in Figure 15, company buying strength is plotted against the strength of the supply market. The shaded areas are divided into 3

sections where either the company or supplier are in a position of strength, or there is a balance between the two. These are called 'exploit', 'diversify' and 'balance', respectively<sup>88</sup>.

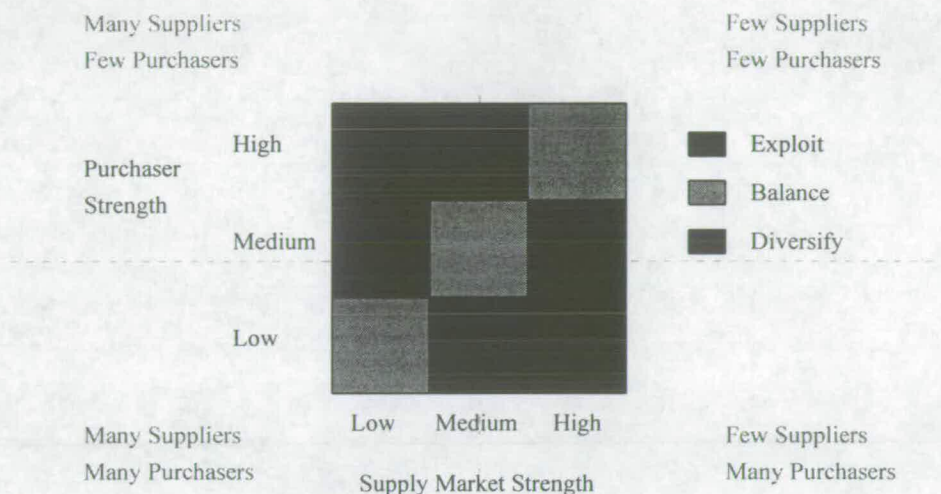


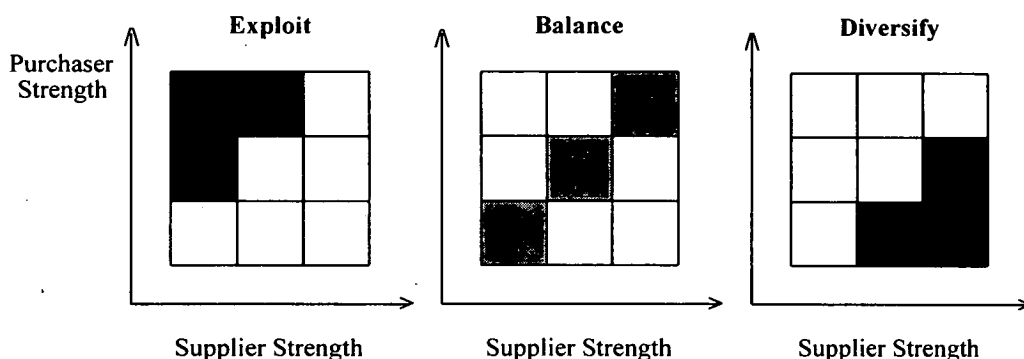
Figure 15. The Purchasing Portfolio Matrix

- *Exploit:* In the 'exploit' region of the matrix the purchasing company takes the dominant role. When the company is in this position it may adopt an aggressive strategy to maximise the benefits of achieving favourable prices and contracts. At the same time it is important that the company does not behave too aggressively and, in the process, put long-term supplier relationships at risk.
- *Diversify:* In this region of the matrix suppliers take a dominant position. In this situation the company should take a defensive role by looking for new suppliers to supplement their supply base.
- *Balance:* In this situation, where neither the supply market nor the company is in a dominant position, the company must maintain a balanced intermediate strategy. By responding with unnecessary aggressiveness the company may damage the long-term supplier relationship, while being defensive could prove costly to the company.

When the company is in a position of strength it should capitalise on the situation to secure preferential treatment, within limits. However, when negotiating from a position of

weakness the company may have to offer the supplier some form of incentive, such as longer-term contracts or higher prices.

Table 13 shows a number of policy issues which may affect a particular supply market and suggests courses of action suitable to aid the return to the balanced situation, or position of company strength. These are the strategic implications of using purchasing portfolio positioning.



<i>Policy Issues</i>	<i>Exploit</i>	<i>Balance</i>	<i>Diversify</i>
Volume	Spread	Keep or Shift Carefully	Centralise
Price	Press for reductions	Negotiate opportunistically	Keep low profile
Contractual Coverage	Buy Spot	Balance contracts and spot	Ensure supply through contracts
New Suppliers	Stay in touch	Selected vendors	Search vigorously
Inventories	Keep own	Use stocks as 'buffer'	Bolster stocks
Own Production	Reduce or don't enter	Decide selectively	Build up or enter
Substitution	Stay in touch	Pursue good opportunities	Search actively
Logistics	Minimise cost	Optimise selectively	Secure sufficient stocks

Table 13. Strategic Implications of Purchasing Portfolio Positioning<sup>89</sup>

The policy issues introduced in Table 13 fall into five areas of interest<sup>90</sup> relevant to coal purchase and the issues raised in Chapters 1 and 2.

1. *Supplier Selection:* The important task of coal supplier selection, from both known and new suppliers, will be covered in detail later in this Chapter.
2. *Contract Duration:* In coal purchase issues relating to contract duration include;
  - a. contractual coverage for fuel sources making up the portfolio
  - b. the availability of new, or substitute, sources of supply.
3. *Value Analysis:* The value of the fuel used for generation will depend on the coal price, prices of other fuels and the value of the energy in the electricity market.
4. *Inventory Management:* Inventory management is influenced by the logistics and costs of transporting coal to the station by the mix of road or rail deliveries. Coal production constraints (including local authority planning constraints) also affect inventory management. Coal production cannot be increased and decreased at the will of the utility, instead stocks must be used to meet annual fluctuations in demand, such as the increase expected during the Winter. Stock levels at the station must be maintained within specific quality limits and this will also affect coal purchase.
5. *Multinational Sourcing:* At times when domestic sources of coal cannot meet the requirements of the Utility it may employ this strategy and import foreign coal to meet demand. At other times multinational sourcing may be more economically viable than domestic purchasing.

### **3.3. Purchasing Motives**

Organisational buying behaviour is a phrase which is ascribed to a range of purchasing situations. Parkinson and Baker, in *Organisational Buying Behaviour*<sup>91</sup>, define it in its most general form as follows:

*"Organisational Buying Behaviour is the purchase of a product or service to satisfy organisational rather than individual goals".*

Therefore, an organisational buyer makes purchases on behalf of the organisation he works for and has the motives of the company to drive him and its hierarchy to account to. His decisions are made with respect to the objectives of the company rather than to satisfy his



personal needs and, as such, it is his responsibility to make judgements about all aspects of the purchase.

In some cases the buyer must also decide who should make the purchase decisions<sup>92</sup> as he is likely to be working as part of a team. The buyer must also be able to justify the purchasing decision in terms of the corporate governance standards such that it will meet statutory audit.

Company objectives which the buyer must seek to achieve are termed 'Buying Motives' and are directly associated with the decision to purchase a particular type of product over others. Since 'Buying Motives' are derived from limits set by the company it is possible to evaluate how close a supplier comes to meeting all of the constraints on the purchase.

The buyer will have reasons for choosing one supplier over all others which are known as 'Patronage Motives'. These motives, such as the reliability of the supplier, are based on the purchaser's perception of the supplier's performance compared with other suppliers. They can be affected by the emotions of the purchaser on the day of, or in the lead up to, the final decision and are therefore difficult to formally evaluate.

Copeland's review of Industrial Purchasing Motives is shown in Table 14 below. He lists each of the Buying and Patronage Motives associated with industrial purchase.

<i>Buying Motives</i>	<i>Patronage Motives</i>
Economical in use	Reliability of supplier
Improved plant productivity	Punctuality of delivery
Flexible	Exact fulfilment of specification requested
Durable	Variety of selection
Safe-guarding employee welfare	Dependability of repair service

Table 14. Copeland's review of industrial purchasing motives<sup>93</sup>

It can be seen from Table 14 that 'Buying Motives' include tangible benefits, such as reduced cost or improvements in plant productivity. 'Buying Motives' will influence the process of identifying that a purchase is necessary. The less discernible benefits derived from the 'Patronage Motives' include the purchaser's perception of how reliable or punctual the supplier will be, which may encourage selection of a supplier who is known to perform

well in these areas. 'Patronage Motives' are dominant when selecting a supplier to satisfy the requirements of the purchase.

### 3.4. The Buying Decision Process

Once the initial identification of a requirement to purchase has been made an organisational buying decision can be followed through 4 stages, each with a distinct outcome. Figure 16 shows each of these stages and their results.

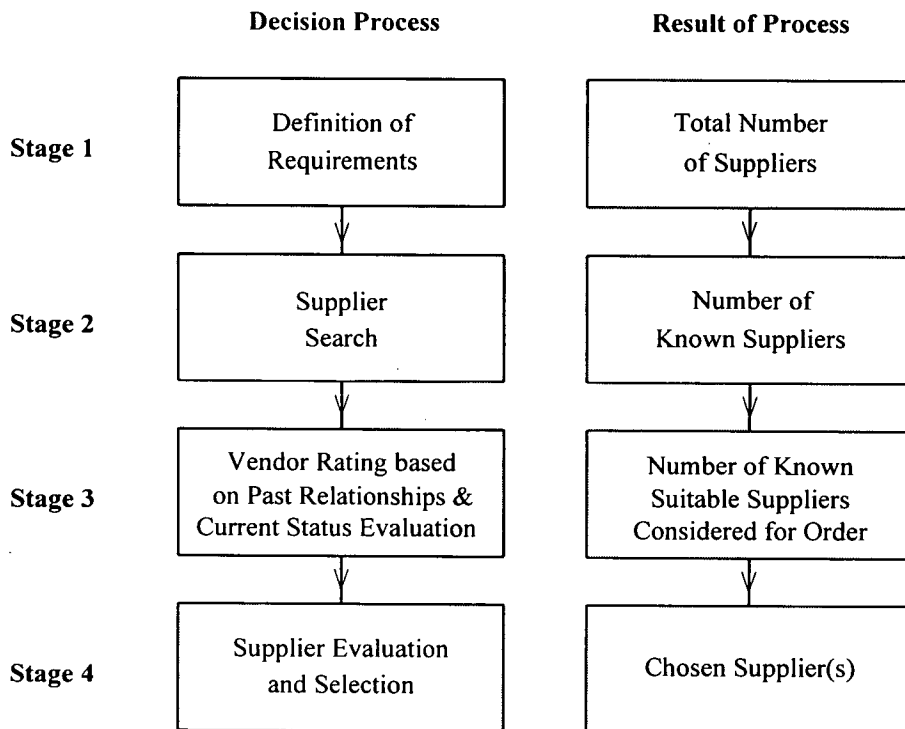


Figure 16. Simplified Model of the Buying Decision Process<sup>94</sup>

Each stage in the process has its own associated set of 'Key Decision Criteria'. Suppliers must satisfy these criteria if they are to be accepted to the next stage of the buying decision process.

The first stage calls on the purchaser to define the requirements of the purchase. These will be determined within the company itself and will place an overall limit on the total number of suppliers who can be investigated. Criteria evaluated at this stage will include:

- Product Characteristics
- Cost Tolerances

- Demand for own Products
- Competitive Environment

The second stage, tender pre-qualification, is the search for all suppliers who, it is believed, can potentially meet the requirements identified in Stage 1. This requires the application of some limits to the area of enquiry for capable suppliers, for example, restricting the search to local vendors.

The third stage has two aspects; historical analysis of each supplier and the current status of the supplier.

If a supplier has been used before then the buyer will have some expectations about his performance in the future. Where his performance has been satisfactory in the past a supplier's record will work in his favour and his chances of being selected again will be increased. Conversely, if he has a bad track record it will be less likely that he will be selected again. Suppliers who have no track record with the company will fall between these groups.

The three past performance criteria most commonly evaluated at this stage are:

- Delivery Performance
- Price Performance
- Quality Performance

It is also essential at this stage to evaluate the current status of the suppliers through discussion with them. This will allow suppliers who are perceived to have an unacceptable history to redeem themselves and for those that are untried to sell the benefits to be gained from their product or service.

Finally, the results of the preceding stages will give a shortlist of suppliers whose product will meet the requirements of the purchase and, it is believed, will perform well throughout the purchase period. They satisfy all of the 'Key Decision Criteria' associated with the purchase decision. They can now be compared with each other and ranked to give the 'best fitting' supplier(s) for the purchase.

The suppliers will be compared on the basis of their individual offer or service. This will include price, quality, delivery considerations and bonuses offered by the suppliers for purchasing their product.

### 3.5. Buying Decision Models

This section will consider two types of Buying Decision Models. The first model is that of the 'multiattribute model' which can be applied to coal purchase. The second is the 'perceived risk model', the most commonly used of the 'dominant dimension models'. It is shown in this Chapter that each of these models has particular relevance in coal purchase.

#### 3.5.1. Multiattribute Models

It is the final stage of the decision process that poses the greatest problem for the organisational buyer. The suppliers which have reached this stage of the process have met the purchase requirements set in Stage 1 and are also thought to be able to supply the product or service to the standards desired by the company, as defined in Stage 3. Therefore, in order to select the best of this group of 'good' suppliers it is necessary to rank them according to how well they fit the purchase criteria.

Kelly<sup>95</sup> advocates the use of a 'Supplier Appraisal Form' to establish this ranking. With this approach the 'Key Decision Criteria' determined for Stages 1 & 3 of the Buyer Decision Process [see Section 3.4.] are developed into a series of questions that can be organised in such a way as to give an insight into the potential supplier.

Kelly suggests that the supplier's response to each question be given a graded value as follows:

5. Exceptional
4. Very Good
3. Good
2. Fair
1. Lowest Acceptable
0. Unacceptable

Once each feature on the list has been evaluated the buyer should add the figures up and then divide by the total number of features on the list, giving an overall grade for the supplier<sup>96</sup>. In this way all potential suppliers can be compared.

One limitation of this method is that the features are not weighted<sup>97</sup> and so a false rating may be given if, for instance, a supplier scores well on communication and delivery but

unacceptably on quality. It would therefore be possible to select a supplier who would not meet quality expectations simply because he was rated highly for communication. This supplier would not satisfy the requirements of the purchase, but the shortcomings of his selection would not become apparent until the first deliveries were made.

A second limitation is that this grading system is based on the supplier's own responses to the questions and on the purchaser's impressions of those responses. It may be desirable for more than one buyer to complete a 'Supplier Appraisal Form' for each supplier and then base the ratings on a collection of responses. However, this does not fully address the inconsistencies which can be associated with methods such as this.

Webster and Wind<sup>98</sup> state that the 'Key Decision Criteria' are used by the organisational buyer in a variety of ways, which may change throughout the course of the purchase and between different purchases.

This implies that a straightforward ranking of all acceptable suppliers does not fully represent the decision processes of the buyer. Instead, there are four identifiable ways in which these criteria may be used, all of which are based on heuristics or 'rules of thumb' employed by the buyer. As such, it is beneficial to the buyer to become aware of these models and know when to use them to best effect. The four decision models are:

1. *Conjunctive Model:* The buyer will select a supplier if it meets minimum standards across a range of predetermined criteria.
2. *Disjunctive Model:* The buyer will select a supplier if it meets a single criterion from those analysed in the 'Supplier Appraisal Form'.
3. *Lexicographic Model:* These more complex models assign a relative importance to the different attributes of the product and supplier. Each of the suppliers is compared on what is deemed to be the most important attribute and the selection is made. However, if more than one supplier satisfies this criterion then they will be compared on the next most important attribute, and so on until the required number of suppliers remain.
4. *Compensatory Model:* Using this model the buyer may compromise if the supplier cannot meet the requirements of one attribute, but performs significantly better on other attributes.

Webster and Wind suggest that a combination of any of these models may be used at any time. How they are applied in coal purchase is covered in Section 3.11 of this chapter.

### **3.5.2. Perceived Risk Models**

One of the fundamental aspects of industrial purchasing is perceived risk - that is, the uncertainty which the buyer associates with the consequences of his actions. There are two broad areas where risk-reduction techniques are commonly used by organisational buyers<sup>99</sup>:

- Uncertainty
- Consequences

#### **3.5.2.1. Uncertainty**

Uncertainty in purchasing falls into two categories; external and internal.

External uncertainties are those associated with the performance of the suppliers or their products. They may be reduced by increasing knowledge about the suppliers through discussion and collaboration. The development, completion and analysis of an Supplier Appraisal Form is one method employed to fulfil this need for knowledge. Further knowledge elicitation methods, such as visits to the supplier's plant, can also reduce uncertainty and perceived risk associated with the purchase.

Internal uncertainties can include a buyer's apprehensions about how others in the company will react to his decisions. These are known as the 'psychosocial' consequences of his actions. Uncertainty in this area can be reduced by discussing buying expectation with other buyers or those affected by his decision within the organisation. Understanding the company's expectation of his performance as a whole can also help the purchaser to rationalise internal uncertainty.

#### **3.5.2.2. Consequences**

When making a purchasing decision which may have profound consequences for the company it may be in the interests of the purchaser not to take risks with new, untested suppliers for fear of 'getting it wrong' and damaging his reputation or even losing his job. Choosing a known, reliable supplier over an unknown but cheaper supplier can be seen as a rational decision for the individual purchaser, however, this course of action may effectively

prohibit the company from exploiting good financial options and new entrants from breaking into the buying decision process. On the grounds that the buyer may be 'keeping his neck in' by purchasing safely, he may actually be making irrational purchasing decisions in the eyes of the company.

The importance of the consequences of a purchase increases as the importance of the purchase to the company and/or the buyer increases. This is proportional to the amount of time, money and effort that either are willing to invest in the purchase. To reduce the perceived risk associated with the consequences of the purchase it may be useful, where possible, to reduce the importance of the decision. One method of achieving this is to select more than one supplier for the purchase (multiple sourcing) which will reduce some of the perceived risk associated with an individual supplier's performance by 'spreading' the risk. Again, a decision to stay only with known, dependable suppliers reduces the time invested in making the purchase decision and, hence, reduces this aspect of the perceived risk.

Webster and Wind state in '*Organisational Buying Behaviour*' that<sup>100</sup>:

*"Information search and analysis reduce performance and psychosocial risk by helping to clarify goals and assess the ability of alternative courses of action to achieve these goals."*

However, if this information is to reduce risk successfully then its source must have reasonable credibility with the purchaser<sup>101</sup>. For this reason past personal experience of the supplier is often seen as the most credible source of information. It is likely that a relationship will have formed between the supplier and buyer which will give credence to any further information exchanged between them. Hence, this is another barrier to new entrants in the market.

### **3.6. Analysis of Coal Purchase**

The generation of electrical energy is a process which involves the conversion of raw materials (fuel) into a usable, saleable product (electricity). Therefore, fuel supplies are crucial to maintain reliable supplies of electricity to customers at economic prices and to achieve the sales objectives of electricity producers. It is for this reason that a portfolio of supply sources must be managed, as explained in Chapter 2 on contract types. However, within a particular fuel type a range of suppliers and lengths of contracts must be maintained if electricity supply from that source is to be guaranteed.

Section 1.4. of Chapter 1 explained how coal generation is used to make up the difference between electricity demand and generation from other sources. The circumstances that trigger a requirement to purchase coal can therefore be divided into these two areas.

### **3.6.1. Electricity Demand**

For Scottish Hydro-Electric, demand forecasts are divided into three categories, 1st Tier sales, 2nd Tier sales and Interconnector sales (see Chapter 2). Consumer demand depends inversely on temperature. Thus, in Winter demand is expected to rise. Unexpected temperature changes can affect the amount of coal-fired generation which is required to meet customer demands and can result in either an increase in coal stock stored at the station, or initiate the purchase of further coal supplies.

Potential sales to the England and Wales Pool are affected by the availability of the Interconnector and the price of electricity in the Pool. If the interconnector capacity is reduced due to maintenance, or the Pool price drops below a generators marginal cost, then sales to the England and Wales Pool will drop. This will reduce the generation required in Scotland for export South of the border.

### **3.6.2. Generation from other sources**

Other sources of generation available to Scottish Hydro-Electric are:

- Hydro
- Nuclear
- Gas

Generation from each of these sources is forecast up to eighteen months ahead. The buyer compares the total estimated generation with the total forecast demand over the same period and then calculates how much coal will be required to make up the difference. He will then start the 'Buying Decision Process' covered in further detail in the Section 3.7.

However, if any of the alternative generation sources produces less than forecast then coal is used to make up the shortfall: as a consequence, coal stocks will drop below planned levels. This will necessitate further purchase of coal and the coal purchasing process will be instigated. Low rainfall, and therefore a drop in available hydro-electric generation, is one



of the circumstances under which coal uptake will increase, requiring additional coal purchase<sup>102</sup>.

### 3.7. Decision Modelling in Coal Purchase

As discussed in Chapter 2 there is a lead time of approximately 3 months between initial identification of a need to purchase coal and the first deliveries at the station. Part of this lead time is attributed to making the final decision about the coal companies from which to purchase. Figure 17 shows how coal purchase fits the buying decision process introduced in Figure 16 earlier in this chapter.

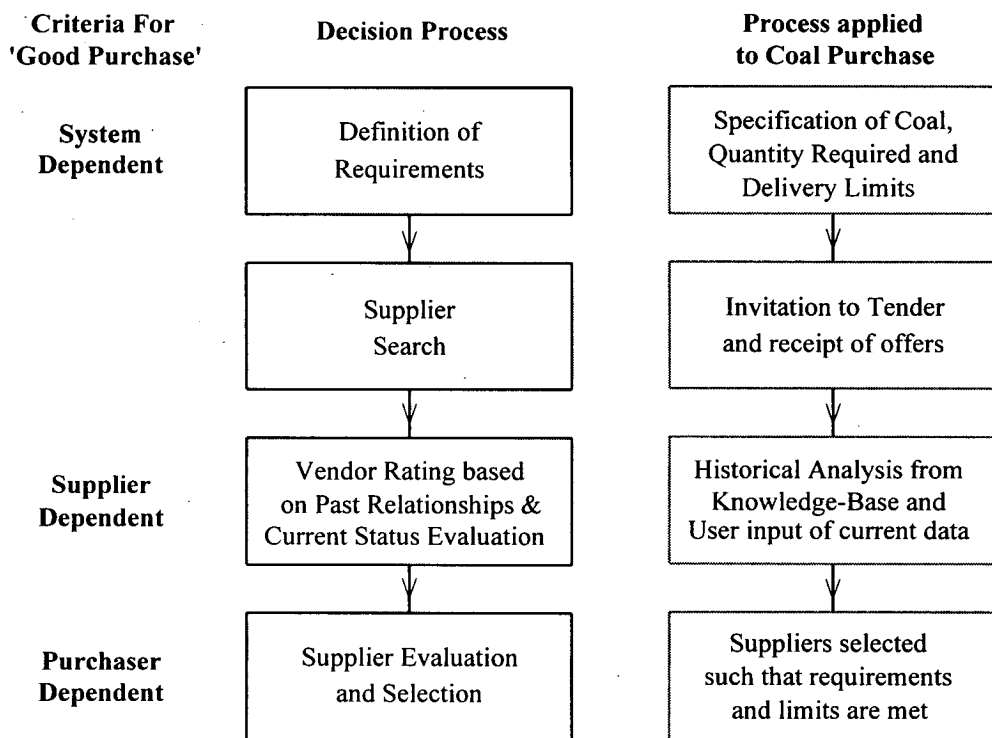


Figure 17. Simplified Model of the Buying Decision Process applied to Coal Purchase

Interviews with purchasers and planners at Scottish Hydro-Electric plc have shown that the criteria for a 'good purchase' that carry a measure of perceived risk can be divided into three groups; System Dependent, Supplier Dependent and Purchaser Dependent criteria. The groups correspond with the stages of the decision process identified in Figure 17. They can then be broken down into separate attributes, each of which will have different relative importance depending on circumstances affecting the purchase.

*System Dependent Criteria:*

- Power station minimum/maximum specifications for coal delivered.
- Availability forecasts for other fuel types.
- Demand forecasts.
- Recommended stock levels.
- Emissions limits and cumulative emissions levels for this calendar year.
- Cumulative Road and Rail deliveries for this financial year.

These are the 'Buying Motives' introduced in Section 3.3 of this chapter. They are derived from technical, financial and legislative limits imposed internally by the company and the power station or externally by Government and local authority. A supplier's compliance with these limits is therefore easily established.

Some of these motives form the 'Definition of Requirements' and are then incorporated into an invitation to tender which is sent to all prospective suppliers.

*Supplier Dependent Criteria:*

- Delivery Reliability.
- Quality of Coal Supplied.
- Handling of Queries.

These are the 'Patronage Motives' used to select particular suppliers over others. Since the fundamental requirements of any coal purchase are that it meets the coal quality specification and is delivered on time to satisfy electricity production, then suppliers who have a good record of performing satisfactorily will be viewed more favourably than those who have not.

*Purchaser Dependent Criteria:*

- Cost (Tender Cost, Transport Cost and Emissions Cost).
- Time allocated to purchasing decision.

This stage covers the final selection of suppliers for purchase. Those that have been deemed 'acceptable' in the preceding stages are now ranked according to ability to meet the requirements of the purchase. At this stage there may be additional information about the offers taken into consideration.

As discussed in Section 3.5.2 of this Chapter it is advantageous for the buyer to find methods by which he can reduce the risks involved in making a decision to purchase coal. The next sections address techniques developed to do this for coal purchase, based on the criteria introduced above.

The selection criteria used in the 'Supplier Dependent' stage of the decision process can be further expanded into categories which define where a delivery ceases to meet the requirements of a purchase or when the quality of the coal is no longer acceptable. These are discussed in the next sections.

### **3.8. Delivery**

If coal is not delivered to a given station when it is required, coal stocks will be reduced and electricity production could be jeopardised. In such circumstances the unplanned shortfall of coal supplies will have to be made up from other coal suppliers or other fuel sources. A coal supplier's ability to deliver can be broken down into four categories for analysis:

- i. Ability to start supplies when agreed.
- ii. Ability to complete contract within deadline.
- iii. Ability to optimise use of power station access limitations.
- iv. Confidence of purchaser in coal company's ability to supply.

These are the most important aspects of delivery scheduling and the overall 'ability to supply', which is calculated as a function of these aspects, varies in importance depending on the circumstances surrounding each individual purchase decision.

#### **3.8.1. Ability to Start Supplies When Agreed.**

A supplier's ability to meet the start of the contract varies in importance with the quantity of fuel which he is supplying. It is also a function of how quickly the purchaser requires the coal to be delivered. Generally, the circumstances of the purchase dictate that the contract starts on time, or close to time, so it is in the interests of the purchaser to avoid selecting suppliers who have a history of delayed first deliveries.

The Utility will look less favourably on a delay in meeting the start of a contract for a small quantity of coal. If the supplier is to deliver a large quantity of coal over, say, a year then a

delay of three weeks may be less crucial and have less impact on the total delivery schedule than a supplier who was to have made deliveries over a four week timescale but was three weeks late with the first delivery. This area of analysis varies with the quantity of fuel that is being delivered and how important it is to the Utility to have it at the station on time. In general, being unable to start supplying coal when agreed creates problems later in the contract when pressure on limited access increases as other contracts are scheduled to start. The consequences of unplanned reduction in stock levels can also jeopardise generation at times when the rate of coal use is high.

Discussions with experts at Scottish Hydro-Electric plc have led to the following proposed method of grading suppliers with respect to their performance at meeting the start of the contract.

- Grade A: Consistently meet start of contract.
- Grade B: Miss contract start occasionally.
- Grade C: Consistently miss contract start.

### **3.8.2. Ability to Complete Contract Within Deadline.**

A supplier's ability to meet the contract start is directly related to this next aspect of supplier analysis. The supplier may miss his starting time but may find it possible to make up his delivery schedule such that he can successfully complete the tender within the agreed time limit. This is more likely if the purchase is a large one, scheduled over a significant period of time.

Three weeks of late deliveries may be added to the rest of a six-month purchase by phasing larger deliveries, subject to them being acceptable to the Utility. However, short or small purchases are unlikely to 'catch up'. It is less likely that a three week delay in supply for a four week delivery phase will be 'caught up' in the final week.

- Grade A: Consistently meet delivery deadlines.
- Grade B: Occasional contract overrun.
- Grade C: Consistently fail to supply.

### 3.8.3. Optimum Use of Limited Access to Power Stations.

Unless the mine is situated at the Power Station, the lowest cost way to deliver coal is by road since it must be handled fewer times after it leaves the mine. However, due to the environmental impact of coal trucks travelling in the local area, restrictions are placed on the numbers of trucks that can deliver to power stations. In Chapter 2 the annual and weekly limits for Longannet and Cockenzie power stations were discussed. These limits and the additional costs of bringing coal in by rail mean that each road delivery day has a financial benefit associated with it.

After a coal company has been selected for road deliveries and the contract has been drawn up the supplier will be allocated certain days on which he must deliver a specified amount of coal. If the supplier does not fill a daily allocation of road deliveries then the costs incurred are two-fold. The days road deliveries and their value are effectively lost since the weekly maximum cannot be met by increasing deliveries over the daily maximum. This means that the coal must be re-scheduled for delivery by road at another time, either using up more of Scottish Hydro-Electric's road allowance, or at the discretion of ScottishPower who may have additional road capacity available. If neither of these options are available then the coal must be delivered by rail instead which will be more expensive than the original road delivery would have been. The alternative is to remove the delivery from the schedule entirely. An example of a cost calculation for the switch of one road delivery day to rail is shown below.

*Example:* The following contract has been agreed:

<i>Company</i>	<i>Quantity</i>	<i>Road</i>	<i>Rail</i>	<i>Calorific Value</i>
Mining Company A	50,000 tonnes	115 p/GJ	125 p/GJ	24 GJ/tonne
<i>Where: p/GJ = pence per Gigajoule; GJ/tonne = Gigajoules per tonne</i>				

*Statistics for each daily road delivery slot:*

approx. 100 trucks per day; equivalent to 2100 tonnes of coal per day

50,000 tonnes  $\approx$  24 delivery days

*To deliver by road:*

Cost per tonne =  $(115 \text{ p/GJ} * 24 \text{ GJ/tonne})/100 = \text{£ } 27.60 \text{ per tonne}$

Total cost by road =  $2100 \text{ te} * \text{£}27.60 = \text{£ } 57,960/\text{day}$

To deliver by rail:

Cost per tonne =  $(125 \text{ p/GJ} * 24 \text{ GJ/tonne})/100 = \text{£ } 30.00 \text{ per tonne}$

Total cost by rail =  $2100 \text{ te} * \text{£}30.00 = \text{£ } 63,000/\text{day}$

Cost to transfer each missed road delivery to rail =  $\text{£ } 63,000 - \text{£ } 57,960 = \text{£ } 5040/\text{day}$

The costs of missing a road delivery slot are considerable, amounting to some 8.5% of the total cost of purchasing the coal. Paying for a missed delivery to the Power Station will be negotiated between the Generator and the coal company, and will depend on the reasons for the delivery being missed. If the fault lies with the mining company then it is in their interests to respond to problems they may be having and to help make an early recovery.

The following grading system has been developed for categorising suppliers with respect to their ability to utilise delivery slots.

Grade A: Above expectations of utilising delivery slots.

Grade B: Consistently meet expectations of utilisation.

Grade C: Disappointed at past utilisation.

A Grade C supplier is unlikely to be selected since delivery slots missed or not fully utilised will cost the Generator significantly in time and resources, as well as the direct costs calculated for rescheduling each delivery. The minimum estimated cost incurred by re-scheduling each delivery would amount to approximately £5040 per day as shown in the calculation.

#### **3.8.4. Confidence in Supply**

The purchaser may have particular reasons for having high or low confidence in the supplier being able to meet the delivery constraints. Reasons for low confidence would be the opening of a new mine for supply, or a history of problems at the pit or elsewhere in the supply chain. Large companies which own well established mines will be less likely to have problems with supply. Likewise, companies with a number of mines will be able to switch production to another mine should they have problems at one location. This means that suppliers who own, say, one relatively new mine or seek a contract to open a new mine have the additional problem that there are greater risks to the purchaser (see earlier analysis).

A buyer is only likely to purchase from a new source when they perceive a need to diversify supply, or when the market is restricted and the increasing cost of coal justifies taking the risk of using an untried source. The following grading system has been developed to reflect the buyer's confidence in the supplier:

- Grade A: Supplier has large portfolio of sites, so purchaser highly confident in supply.
- Grade B: No reason to doubt ability to supply.
- Grade C: Supplier has history of problems, or proposes supply from an untested site.

### **3.9. Quality of Supply**

There are two defining factors in how a supplier is graded for the quality of his coal. The first is based on past performance and the analysis of the coal he is offering to the purchaser. The second is a measure of how he manages the quality of his coal on site.

#### **3.9.1. Meet Specification**

The owners of a coal-fired power station fix a range of acceptable values for the calorific value and the sulphur and moisture content of the coal delivered (see Section 2.4.2. of Chapter 2). There are also limits set on the coal held in stock at the station, which are wider than the maximum values set for each individual delivery. They can be met in a number of ways.

The average values can be calculated for a number of deliveries, as long as any one delivery does not fall outwith the acceptable quality parameters, or specification, i.e. coal with a high percentage of constituent sulphur may be mixed with coal of a lower sulphur content to give an average value which is accepted at the station.

The minimum calorific value must be adhered to strictly. However, individual deliveries with a lower calorific value may be accepted as part of a package of deliveries whose average calorific value is above the limit. At the station the calorific value of the coal which is in stock is calculated and the new delivery will only be accepted if it will not take the average of the stock below the acceptable limit (within cost-effective limits of blending required).

Suppliers have different ways of meeting some of the elements of the specification in the tender: for example, the moisture content of the coal can be adjusted during the sorting and cleaning processes. All of the limits on the specification must be met by the coal supplied, or should be close enough to satisfy the power station chemist who is responsible for boiler performance. The reasons are given in Section 2.4.2. of Chapter 2.

The following scheme has been created to denote how well a supplier meets the specification he has been contracted to meet.

- Grade A: Never disappointed. The coal delivered is always within the specification.
- Grade B: Generally meet contract specification. Almost always within delivery specification.
- Grade C: Poor record. Best deliveries required action and expense on the part of the purchaser.

### **3.9.2. Quality Control**

Each mine should have its own test facilities for checking the coal before it is despatched to the power station. If the coal arriving at the station yields test parameters which consistently prove to be different from those which the supplier measured there may be problems supplier testing facilities. Problems with testing facilities at the station will be revealed by discrepancies for all deliveries from all suppliers.

It is expected that the power station will have the best test facilities since it benefits from economies of scale where there are many suppliers competing for business. High quality test facilities are an additional overhead and so, instead of having a large number of expensive facilities dispersed around the country, each mine will have limited test facilities. The coal will be tested both at the mine and at the higher quality facilities at the station.

The grading system developed for Quality control at mines is categorised as follows:

- Grade A: Demonstrated excellence. Coal delivered always matches coal dispatched.
- Grade B: Some deviation in quality measurements. Quality control methods in doubt.
- Grade C: No satisfactory quality control and problems experienced in past.



At the station samples amounting to approximately 80kg of coal are taken randomly from the suppliers delivery. These samples are combined and crushed and resampled until only 1kg of coal is left (the rest is returned to the stock). Of the remaining quantity 500g is kept for the supplier, 250g is stored for the purchaser (in case of dispute with supplier over quality) and 250g is tested for quality.

### **3.10. Query Handling**

The query handling grade is determined by two aspects of supplier behaviour. The first is based on how the coal supplier responds to queries from the purchaser. The second is ascertained by how he has performed in the past when problems have arisen.

#### **3.10.1. Dealing with Queries**

How a supplier handles queries about the progress of a contract, or problems which are affecting it, will determine how he is graded in this section. He will be judged on how he behaves when he has to be contacted about problems with his supply and, thereafter, how he acts to remedy the issue. The following grades have been designed to allow the buyer to categorise suppliers responses to queries:

- Grade A: Supplier works to help purchaser.
- Grade B: Variable in discussion and action.
- Grade C: Don't discuss problems, may even deny there are any.

#### **3.10.2. Notification of Problems**

At times when the purchaser is in a position of strength, for instance when there are many suppliers and few purchasers, it is in the best interests of the supplier to inform the purchaser of any problems which may affect his ability to meet the requirements of the purchase. If he thinks he won't be able to utilise his delivery slots then it may be possible for the purchaser to schedule another company to deliver coal at that time and reduce loss. The following grades have been defined to reflect how each supplier communicates problems with supply.

- Grade A: Immediate, voluntary notification of any problem.
- Grade B: Variable in notification of problems.
- Grade C: Leaves it to the purchaser to identify and raise problems.

### **3.11. Multiattribute Decision Models Applied to Coal Purchase**

#### **3.11.1. Conjunctive Models in Coal Purchase**

*Supplier must meet minimum standards across a range of criteria.*

In coal purchase the conjunctive model is directly applied to the 'System Dependent' stage of the decision process and the specification of the fuel (see Figure 17). Since there are limits set at the stations for ash, sulphur and moisture content which no delivery should be outside any supplier unable to meet these limits will be rejected when evaluated at the 'Supplier Dependent' stage of the decision process.

#### **3.11.2. Disjunctive Models in Coal Purchase**

*Supplier must meet a single criterion.*

In some cases there is an immediate requirement for delivery of, say, coal with a low sulphur content, termed here low-sulphur coal. If the suppliers who can satisfy these demands are limited then the purchasers may make the decision to buy the fuel, regardless of performance in other areas such as query handling (quality constraints must always be met).

#### **3.11.3. Lexicographic Models in Coal Purchase**

*Each attribute is assigned a relative importance and the performance of each supplier is compared for each of them in order.*

Discussion with Scottish Hydro-Electric revealed that use of this model is apparent in coal purchase during the 'Supplier Dependent' stage of the decision process. A group of suppliers may meet the criteria set by the purchaser, but some will be a 'better fit' than

others and will be ranked accordingly. The criteria which come under scrutiny in this stage are those evaluated for delivery reliability, quality of coal supplied and handling of queries.

#### **3.11.4. Compensatory Models in Coal Purchase**

*Buyer compromises between different suppliers who meet different desired attributes.*

Suppliers which reach the compensatory stage of the model must first have met the standards set in the conjunctive, disjunctive and lexicographic models.

The purchaser will 'trade-off' between suppliers to create a 'portfolio' of purchases which complement each other. For example, a number of fuels may be purchased of which one may have a low calorific value. This can be accepted if it is complemented with a high calorific value fuel such that the aggregate specification of all of the fuels arriving at the station do not exceed the fuel stock limits.

There may also be some cases where a coal company offers 'options to buy' at a later date. In some cases these will offer the purchaser some flexibility and allow the risks associated with the forecasts in demand and supply from other sources to be reduced.

Figure 18 shows how these models are used to complement each other in coal purchase. The diagram also illustrates some of the aspects which are covered by each model, although there is some overlap which does not appear.

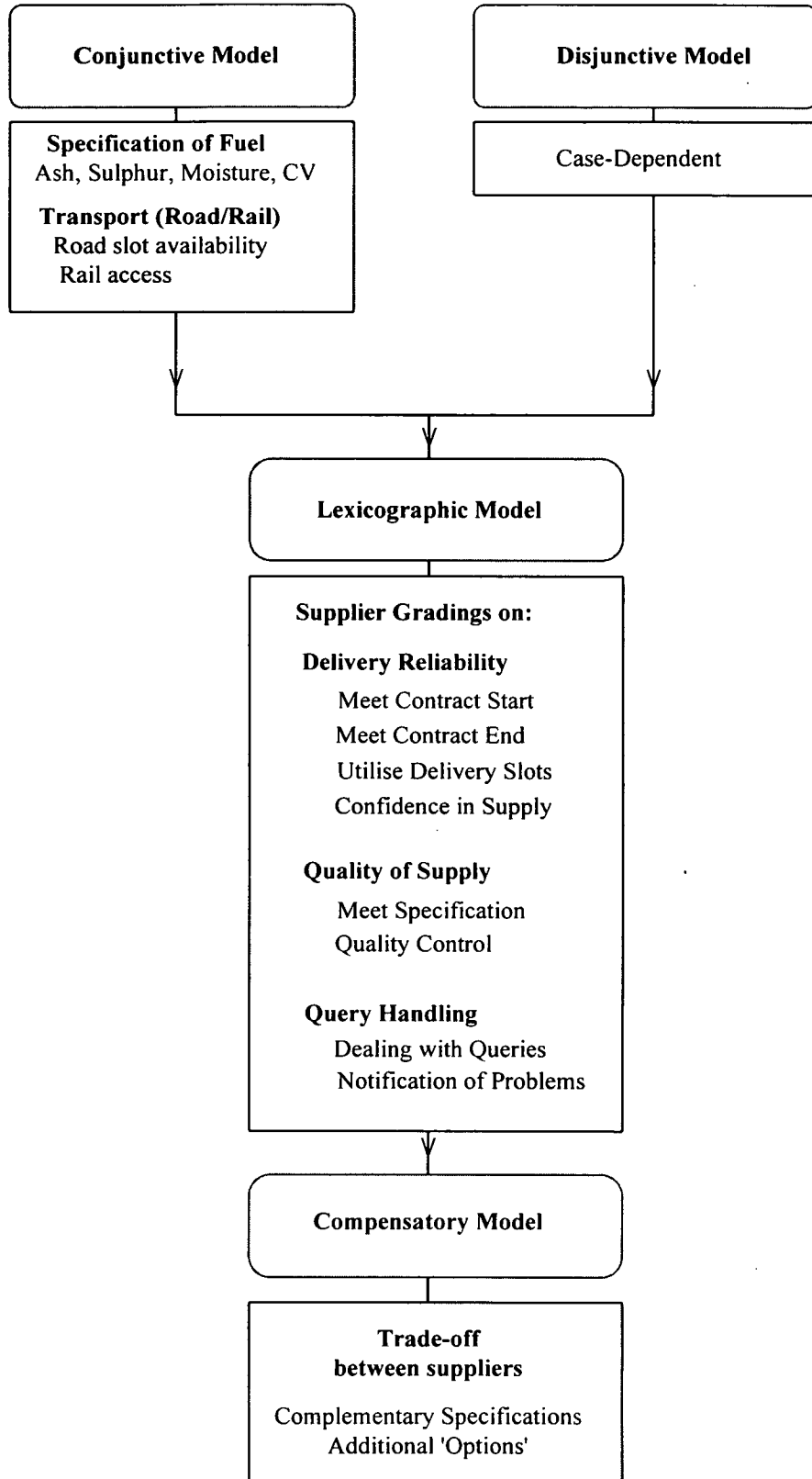


Figure 18. Application of the Decision Models to Coal Purchase

### **3.12. Chapter Summary**

There is emerging a recognisable pattern which is evident in the organisational buying process. The pattern can be followed from the initial identification of the requirement to make a purchase, through the tendering process to the final selection of suppliers. Understanding a supplier is essential to this process and to making effective organisational buying decisions.

The main criteria dominant at each stage of the decision process for coal purchase have been identified. Each criterion which is analysed by the buyer using the lexicographic decision model has been further investigated and its main attributes examined. Study of historical data of the behaviour patterns of suppliers in these fields has led to increased understanding of their performance. This increased knowledge allows the buyer to predict the future performance of a supplier and to make a purchasing decision based on the increased understanding.

Use of this grading system will benefit the purchaser by helping to ensure that the best suppliers are selected while not missing opportunities offered by new entrants into the market. It will also work in favour of all suppliers who will be given a fair chance to agree more profitable business transactions.

The Supplier Assessment Techniques developed here might be incorporated into a co-operative purchasing strategy for coal purchase. Co-operative strategy is the development of long-term, co-operative relationships with suppliers and requires a collaborative approach to supply where both supplier and purchaser work together to improve performance. Where the results of this methodology are made available to coal suppliers they will be able to take action to better meet the needs of purchasers. Improved performance will change the purchaser's perception of their ability to meet the supply criteria.

## CHAPTER 4

### DECISION SUPPORT SYSTEMS FOR COAL PURCHASE

Chapter 4 introduces the factors involved in the human decision making process. A definition of computer-based Decision Support Systems is then given, followed by a brief description of their uses in assisting in the solution of business problems. A description of the general structure of Decision Support Systems is given and the way in which this structure has been applied to the development of a Decision Support System for Coal Purchase, 'CoalMan' is demonstrated. 'CoalMan' has been developed such that its flexibility incorporates all of the complexities of coal purchase discussed in Chapters 2 and 3, including the 'Coal Supplier Grading System', developed through the application of decision models to coal purchase (See Sections 3.8.-3.11. of Chapter 3).

The chapter concludes with an explanation of Structured Query Language (SQL) and the software development package 'KnowledgePro® Windows', both of which are central to the present project.

#### 4.1. The Decision Making Process

The process of making a decision follows a series of phases. Figure 19 shows the phases of decision making as proposed by Simon [1960]<sup>103,104</sup>.

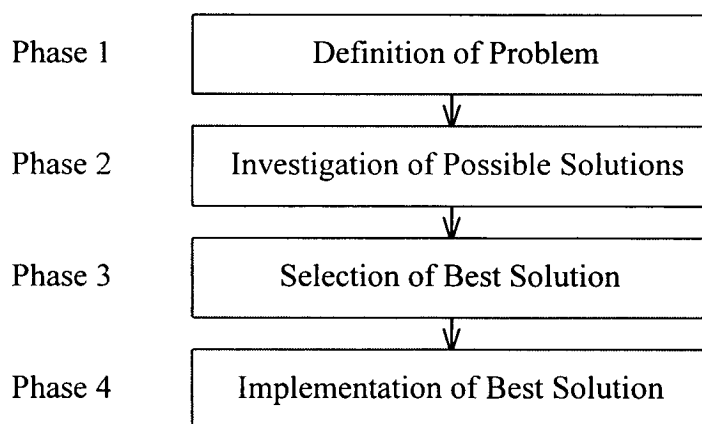


Figure 19. The Decision Process

This implies that the decision process is continuous, where the decision maker moves from defining the problem to investigation and selection of a solution and then to the implementation of the solution. However, the decision maker may, at any stage, return to a previous phase in the process<sup>105</sup>.

The goal of research and development of decision support systems has been to define and assist the decision making process.

## 4.2. Decision Support Systems

The earliest 'Decision Making Aids' were calculators and primitive computers which were employed to carry out straightforward calculations employing statistical models. However, these aids have evolved into their modern, more complex and more functional descendants; spreadsheets, financial models, CAD systems and Decision Support Systems.

In its simplest form a Decision Support System can be described as a computer-based system which assists the decision making process<sup>106</sup>. Decision support systems satisfy the requirements of either or both of Phases 2 and 3 of the decision process. They are designed to aid the handling of information in decision making<sup>107</sup> and, through improving the reliability of the calculations, promote risk reduction in the decision making process.

Turban describes the Decision Support System in his book '*Decision Support Systems and Expert Systems*' as follows<sup>108</sup>:

*"A Decision Support System is an interactive, flexible and adaptable computer based information system, specially developed for supporting the solution of a non-structured management problem for improved decision making. It utilises data, it provides easy user interface and it allows for the decision maker's own insights."*

### 4.2.1. Decision Support of Business Problems

Decision support software packages have made their impact on business in support of decisions where, while there is enough structure to the problem for a computer-based system to be of use, the judgement of the manager still has an essential role to play in the final decision-making processes<sup>109</sup>. They are used to improve business efficiency where the

process is labour intensive by providing fast, reliable solutions to the problem. Decision support systems are of particular use in repetitive problem solving.

A manager will require a Decision Support System to offer a number of functions which will depend on the field of interest in which the Decision Support System is expected to be used. Any Decision Support System designed to support business related problems should satisfy one or more of the following characteristics<sup>110</sup>:

- Aid the detection of existing or emerging problems,
- Allow managers to model a situation in order to clarify it,
- Provide functionality such that various options can readily be considered and compared.

These characteristics can be met by offering some, or all, of the following features<sup>111</sup>:

- An effective relational database structure to maintain up-to-date input data,
- User-friendly and convenient query procedures,
- Features which allow the user to carry out well-tested and model-based analyses,
- Access to other applications, such as spreadsheet data processing.

A Decision Support System uses these features to extend the decision processes of the manager to encompass the data available to solve the problem. The manager's performance is improved since the functions which appear in every instance of the problem are taken into account giving a consistent solution, within the accuracy and availability of input data. The speed at which the computer can perform these calculations allows the user to experiment with values or constraints and to compare the results.

By definition a Decision Support System will not impose a single solution but will offer the user the flexibility to define the objectives of the solution and offer a 'suggested' solution, or set of solutions. Therefore, the decision process will not be fully automated, but will allow the manager to use his own judgement in the final stage of the process.

#### **4.2.2. Characteristics of Decision Support Systems**

Decision Support Systems fall into two broad categories; data-oriented and model-oriented, although some Decision Support Systems have characteristics of both categories. Tables 15 and 16<sup>112</sup> show the characteristics of some of these Decision Support Systems.



<i>Category</i>	<i>Type of Operation</i>	<i>Task</i>	<i>Usage</i>
File drawer systems	Access data items	Operational	Simple inquiries
Data analysis systems	Analysis of files of data	Operational, analysis	Manipulation and display of data

Table 15. Data-Oriented Decision Support System

Data-oriented Decision Support Systems perform data retrieval and/or analysis. The first example in Table 15 is primarily a data retrieval method which gives the user fast access to structured databases and can be applied to regular operational tasks. The second example is a method which incorporates some basic analysis and displays the results of predefined situations in a graphical form or report<sup>113</sup>.

The data analysis system partly fits the characteristics of 'CoalMan', the decision support software written for coal purchase and coal supplier analysis. However, 'CoalMan' offers a wider functionality than is prescribed in this description.

'CoalMan' can be categorised as a model-oriented Decision Support System due to its range of functions which allows the user control over constraints and objectives of the solution. The software performs calculations on the relevant data such that the suggested decision option will meet the constraints imposed on the problem.

However, 'CoalMan' is not strictly an optimisation model since different constraints and objectives can be set such that a variety of scenarios can be tested and results given. The user must then discern the most suitable option. For this reason it is more accurate to describe 'CoalMan' as a hybrid of the optimisation and suggestion models (see Section 4.3.2.). Finlay [1989] says of this method of decision making<sup>114</sup>:

*"Most managers have realised that optimising part of a problem is not necessarily a greater help in tackling the total problem than is an answer that is sensible and understandable and not grossly wrong: resolving or being 'good enough' is the stuff of a great deal of management problem tackling."*

For this reason it is not necessarily vital to find a precise solution to the purchasing problem. The data used for some of the calculations is subject to change as demand and supply from other sources changes over time. These changes impact on the forecasts used to calculate coal requirements. Therefore, making a suggestion for a purchase which is designed for

maximum accuracy will waste resources and detract from the benefits gained from quick calculation and comparison functions.

<i>Category</i>	<i>Type of Operation</i>	<i>Task</i>	<i>Input</i>	<i>Output</i>
Representational models	Estimating consequences of particular actions	Planning, budgeting	Possible decisions	Estimated results
Optimisation models	Calculating optimal solution to combinatorial problem	Planning, resource allocation	Constraints and objectives	Solution
Suggestion models	Performing calculations that generate a suggested decision	Operational	Structured description of the decision situation	Suggested decision

Table 16. Model-Oriented Decision Support System

The models and methods employed by 'CoalMan' to reach a suggested decision are discussed briefly in Section 4.3.2. of this Chapter and in more detail in Chapter 5.

### 4.3. Structure of Decision Support Systems

A model-oriented Decision Support System has three main components which are described in the next sections<sup>115</sup>. These components form the simplified structure of a Decision Support System as shown in Figure 20.

1. Data Management System
2. Model Management System
3. Communication

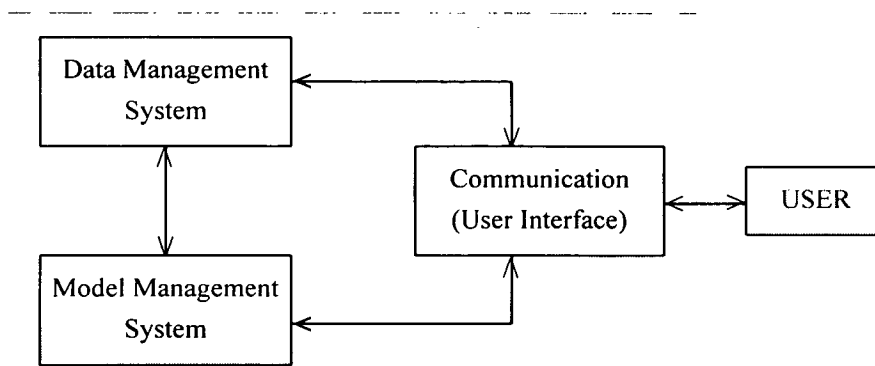


Figure 20. Decision Support System: Simplified Structure

### 4.3.1. Data Management System

The Data Management System has three elements which are inter-related to control the flow and organisation of information in the Decision Support System. These sections consist of the following<sup>116</sup>:

1. Decision Support System Database
2. Query Facility
3. Database Management System

Figure 21 shows how these components are linked to complete the data management system.

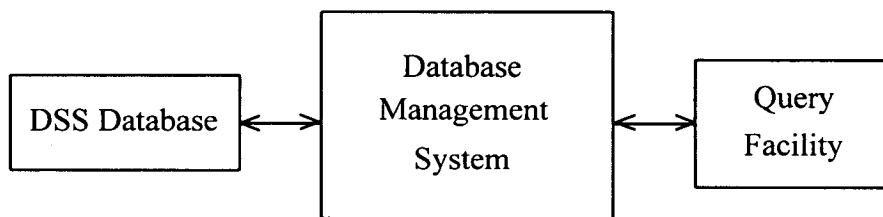


Figure 21. The Data Management System

#### 4.3.1.1. Decision Support System Database

A database is an organised collection of data which is managed in groups called 'records'. For example, all of the information about one supplier may be held in one record. Each record consists of 'fields' which hold specific details for example, company name and name of the coal mine would be separate fields within the database. Figure 22 shows a database with records and fields marked. The data held in the database is in some way related and is structured such that the needs of the organisation using it are satisfied.

Fields

	COMPANY	MINE	TRANSPORT	DELIVERY
Records	Rackwood Colliery	Hannahston	Road	Longannet
	Greystone Heating Marketing	Rigside Opencast	Rail	Roughcastle
	Scottish Coal	Blindwells	Rail	Blindwells
	Anglo	Auchentiber	Rail	Mossend
	CCCL	Blinkbonny	Road	Cockenzie

Figure 22. Database Layout

A relational database application allows the user to bring together data from separate database files and use it as if it was all stored as a single file. In database management the data is arranged in such a way as to assist with the modification and retrieval of related information, while providing an efficient means of data organisation and storage<sup>117</sup>. In general databases used by a Decision Support System will be organised so that the user's files (system databases) still exist, but are linked to the Decision Support System database to form an integrated unit. When information in the system databases is updated it will automatically be updated in the Decision Support System databases, thus keeping all data up-to-date.

A database, or selection of databases, will hold information which is both internal and external to the organisation. Table 17 lists examples of data sources and Table 18 gives examples of internal and external data sources used in coal purchase decision making.

<i>Internal Data Sources</i>	<i>External Data Sources</i>
Accounting	Industry and Market Research Data
Finance	Government Regulations
Marketing	Tax Rate Schedules
Production	Economic Data

Table 17. Data Sources

<i>Internal Data Sources</i>	<i>External Data Sources</i>
Forecasts	Coal Suppliers
Maintenance Schedules	Coal Offers
Stock Levels and Targets	Emissions Legislation and Costs
Operational Restrictions	Transport Limits

Table 18. Coal Purchase Data Sources

#### 4.3.1.2. Query Facility

The query facility uses a query language which provides the user and other Decision Support System components with access to data. The language is used to form detailed requests for data which are passed to the Database Management System (see Section 4.3.1.3) for interpretation. The query language is used to set up complex data selection and

manipulation operations<sup>118</sup>. An example of a query would be 'search for all purchases from supplier B since January 1996 and summarise by price'.

#### **4.3.1.3. Database Management System**

The Database Management System provides the interpreter between the query language and the databases. It is used for the extraction of data and to interrelate data from multiple sources. It performs the complex queries set up by the user using the query language.

#### **4.3.2. Model Management**

Models are used to represent aspects of the real world; showing the relationship between objectives and constraints, as well as between cause and effect<sup>119</sup>. Models are manipulated through the Decision Support System to give the end result expected from working through a particular set of actions.

Silver [1991] states that<sup>120</sup>:

*"...a model is an abstraction of the relevant aspects of (or some portion of) a decision problem represented in a form that decision makers can manipulate with a computer-based system. A Decision Support System model might be a statistical model, an optimisation model, a simulation model, a choice model, or some other form of computer-based model."*

Different types of models are used to represent the wide range of decision situations which arise in the real world. The three model types used by 'CoalMan' are discussed below.

##### **4.3.2.1. Mathematical Models**

Mathematical models can be applied in the analysis of a wide range of problems. Mathematical formulae are models frequently used by decision makers<sup>121</sup> and are used in decision-making situations to predict the outcomes of particular operations. For instance, linear programming is used for the analysis and calculation of optimum decisions within imposed limits or conditions.

##### **4.3.2.2. Optimisation Models**

Optimisation models are limited to use when the problem is structured enough for a model to be used as part of a more complete analysis. Alter [1980] describes them as follows:<sup>122</sup>

*"Optimisation models are used in studying situations that can be described mathematically as complicated puzzles whose goals involve combining the pieces to attain a specific objective, such as maximising profit or minimising cost."*

#### **4.3.2.3. Suggestion Models**

Suggestion models are generally applied to problems which have more structure than those where optimisation is used. They generate suggested courses of action based on applicable formulae or mathematical procedures, which may range from rules to the results of optimisation models. This type of model gives an output which is a single answer to the problem and does not allow the user to compare trade-offs or test the effects and importance of different constraints on the decision.

#### **4.3.2.4. Model Base Management System**

Software packages are available for database management as described in Section 4.3.1. of this Chapter. However, similar packages for model management are not available, so it is a function which must be designed and developed by the Decision Support System programmer.

It is the function of a model-based management system to specify the relationships between models used by the Decision Support System; specifying which model outputs are required as inputs for other models. These are handled directly within the system itself, rather than requiring special intervention by the user<sup>123</sup>.

Turban [1995] gives a list of capabilities which are thought to be important in the design of model based management systems<sup>124</sup>. This list is summarised as follows:

- *Control:* The system should support both fully automated as well as manual selection of models.
- *Feedback:* The system should provide sufficient feedback to enable the user to be aware of the state of the problem-solving process at any point in time.
- *Interface:* The user should not have the onerous task of supplying inputs when it is possible to avoid this situation.
- *Redundancy Reduction:* This can be accomplished by use of shared models and associated elimination of redundant storage that would otherwise be needed.

- *Increased Consistency:* It should be ensured that models and data used are consistent.

These functions have been incorporated, where applicable, into the model based management system developed for use in 'CoalMan'.

### 4.3.3. Communication

One of the methods of communication between a computer-based system and its user is through the graphical interface appearing on the screen. Since the user can use only the input methods which are offered by the software and cannot use a natural language (except in special circumstances) the effectiveness of the interface must be maximised to make it as 'user friendly' as possible.

The user interface provides a means by which information can be entered into the Decision Support System, and the results or solutions output can be made available to the user. Table 19 shows data input methods employed in Decision Support System construction. Information output should include the reasoning behind a suggested solution so that the user can see clearly why a particular decision has been suggested.

<i>Data Input Methods</i>	<i>Data Output Methods</i>
Data Entry	Screen Display
Menus	Print Out
Response to Questions	Data Storage in Files

Table 19. Data Input and Output Methods

Since the primary interface between the user and system is the screen display, this is the method which will be discussed in depth here. Gallitz [1985] states that a well-designed graphical user interface should satisfy four requirements<sup>125</sup>.

1. It should meet the needs of its users.
2. It must be developed within the constraints imposed by the computer system.
3. It must utilise the capabilities of the software which is available.
4. It should achieve the business objectives of the intended users.

Users of Decision Support Systems require systems that are easy to use and, at both the interface and reasoning levels, are transparent. In addition, it is believed that except in circumstances where a system is designed for specialists who work closely with system designers, over-complex systems have only a small chance of being accepted by companies<sup>126</sup>. If the user must go through difficult or tedious steps in order to get results the system will not aid decision making, it will hinder it. Decision Support System developers must therefore set out, from the beginning, to create systems that are as easy to learn and use as possible.

Information can be presented on the screen in a variety of ways, which is a facility that users find beneficial<sup>127</sup>. Computer-generated graphics are widely used to present information to decision makers. Graphs, such as line graphs, bar graphs and pie charts, are the most common graphic displays employed in presentation of data on screen. However, data should also be made available in tabular format to allow more precise representation of the solution.

#### **4.4. Specification Development with Scottish Hydro-Electric plc**

A specification for the project to develop the Decision Support Software, 'CoalMan', was designed with coal purchasers at Scottish Hydro-Electric to meet coal purchasing decision needs. This was divided into two stages and is described as follows:

*Stage 1: Appraisal of Coal Purchase practice.* It was agreed with Scottish Hydro-Electric that the appraisal should identify:

- rules and assumptions underlying decisions
- key influencing factors
- areas of risk and how risks are managed
- information used and information required
- measures of quality of decision and determining criteria

Investigation of each of these factors gave greater understanding of the coal purchase decision process. Knowledge elicitation was carried out by observing the decision making processes of purchasers in discussion sessions<sup>128</sup>. Information gained through this method was later refined by questioning the decisions at each stage to build up an adequate knowledge representation. Each purchaser has their own knowledge base within which decisions are made but if the knowledge at the time of the interview does not encompass the



problem to be addressed incorrect decisions may be made. In order to ensure completeness knowledge elicitation from a number of experts is usually required in designing a decision support system<sup>129</sup>.

Since coal purchase decision making was relatively new to the company, it was important to interview staff involved in the purchase of all fuel types so that relevant methods employed by them might be transferred to coal purchase. While these interviews were concentrated in the initial months of the development process, further elicitation was carried out throughout the course of the study.

*Stage 2:* The second stage entailed the creation of a design specification for a coal purchase Decision Support System incorporating the following features:

- where appropriate, input has to be in a form which takes account of incompleteness of information
- the ability to evaluate fuel supply tenders
- presentation of fuel offers using technical, environmental, legislative and strategic considerations
- presentation of an output in the form of purchase recommendations including justification for the decision and, where appropriate, expected values and confidence limits
- the ability to produce reports on request. These will record the decision and be of a form suitable to audit the financial justifications which must accompany HE fuel purchases
- the ability to maintain a database for use by the Decision Support System
- the software will be PC compatible

Chapter 5 describes 'CoalMan' and shows how the specifications of Stage 2 in the project have been met.

#### **4.5. KnowledgePro Windows®**

Scottish Hydro-Electric use Personal Computers (PCs) which run Microsoft Windows® Version 3.1 software. It was therefore part of their specification that anything developed for this project should be compatible with their system. In addition, the finished product had to be able to run on 'Windows 95', should Scottish Hydro-Electric upgrade their software.

In using a package to write software many of the same 'rules' regarding communication and functionality as those discussed in Section 4.3.3. can be applied. It was important that the development environment satisfied a number of requirements listed below.

- The development package needed to have an easy-to-learn, functional language and a user-friendly environment.
- Facilities to allow communication with other software packages were required.
- The software developed had to be 'stand-alone'.
- The development package had to provide the following functions:
  - i. Database Management
  - ii. Mathematical Functionality
  - iii. Structured Query Facility

The next sections show how KnowledgePro Windows (KPWin++) satisfies the requirements covered here<sup>130,131</sup>.

## **4.6. User Interface**

One of the main features of KPWin++ is its graphical user interface which makes software development straightforward from the outset. Buttons on the main development screen provide direct user access to most of the software's functions, allowing the developer to find and incorporate the functions required.

Since all of the tools are written in the KPWin++ language and the source code is included with the software, it is possible for the user to adapt the code for inclusion in his own developments. One advantage of this approach is that the user can study and understand the creation of the development tools.

The KPWin++ Designer allows the user to interactively create screens for the application. Since the designer is written in the KPWin++ language and the source code is supplied it gives examples of how some effects can be achieved by the user.

The 'Screen Designer' is the section of KPWin++ used to develop screens for use in software development. The developer builds screens by simply selecting the appropriate icons for the elements he wishes to include on the screen and placing them in the required position. The events associated with each object can then be added by the programmer.

Once this process is completed the screen designer will automatically generate the source code for use in the developing application.

The method is designed as a foundation for the further development of software. The generated code can be extended and modified using the KPWin++ language to tailor the code to produce the desired effects.

## 4.7. The KnowledgePro Language

The heart of programming with KPWin++ is the 'topic'. This is a flexible building block that the developer can configure to meet the requirements of any function required. The topic can be used to operate as:

1. a procedure
2. a function
3. a list
4. an object
5. a combination of any of the above

Examples of these are given in the next sections.

KPWin++ allows the developer to write an entire application in the high-level KnowledgePro language and then generate readable C++ code<sup>132</sup>. The result is a stand alone .exe file which can be distributed royalty free.

### 4.7.1. Procedures

Topics can be written to execute as procedures. IF-THEN statements, REPEAT UNTIL and WHILE procedures are all fully implemented with the KPWin++ language. The example given here repeats the search of a list, '?month\_list', for the variable '?start\_month' triggering another topic on each cycle, until the requisite number of months have been calculated. At this point it stops the loop and continues with the rest of the code.

*Example:*

```
repeat next_month = element ([?month_list], ?start_no)
    and do (?next_month)
    and start_no = ?start_no +1
until ?start_no = ?end_no.
```

### 4.7.2. Functions

Mathematical functions can be used from the existing libraries<sup>133</sup>. KPWin++ supports 'Math Toolkit', a dynamic link library which adds mathematical functions to the KPWin++ language. Some of the functions available with this library include trigonometric and logarithmic, exponential functions.

### 4.7.3. Lists

List handling is a powerful tool which is available in the KPWin++ language. Using the list manipulation commands it is possible to do things which would otherwise require extensive programming using procedural or backward chaining approaches.

An example of a simple list handling routine used in 'CoalMan' is given below. Here the topic is used as a routine which is called whenever a new record is read from the database file of tendered coal offers. This piece of code checks whether an offer from that company has already been accepted.

*Example:*

```
topic sort_mine.  
  if one_of (?mines_list, ?mine)  
    (* check if company offer has been accepted already before proceeding *)  
  then delivered_amount = ?delivered_amount  
    (* if used already then do not use in calcs *)  
  else (* if not used then proceed with offer in calculation *)  
    delivered_amount = ?delivered_amount + (?quantity/1000)  
    and mines_list is combine (?mines_list, ?mine).  
end. (*sort_mine*)
```

Lists are frequently used in 'CoalMan' to store groups of related items. In the example below the first topic is used to determine the user's response to a question about the maximum ash content acceptable in the purchase. The response is then read and assigned the variable name 'ash\_max', whereupon the next topic is loaded. The topic 'ash\_conditions' takes the variable 'ash\_max' say, '8%', and combines it with the relational operation 'Ash ≤ ' to give the condition 'Ash ≤ 8'.

This is then combined with the condition list, which will incorporate a series of conditions being imposed on the purchase by the user.

*Example:*

```
topic ash_content.  
    read_response ('What is the maximum Ash content you will accept?', ash_max, ).  
    do (ash_conditions).  
end. (*ash_content*)
```

```
topic ash_conditions.  
    new_condition = concat ('Ash ≤', ?ash_max)  
    and condition_list = combine (?condition_list, ?new_condition)  
    and rejection_list = combine (?rejection_list, 'costing.ASH').  
end. (*ash_conditions*)
```

#### 4.7.4. Objects

This simple example shows how inheritance can be used to create new objects. The topic 'ButtonObject' will inherit the characteristics of another topic, 'ScreenObject'.

ButtonObject is in the same class of objects as ScreenObject. This means that all of the sub-topics of ScreenObject that don't appear in ButtonObject, i.e. locate, will be copied into ButtonObject.

*Example:*

```
topic ScreenObject (c, r).  
    column is ?c.  
    row is ?r.  
    display ().
```

```
    topic display.  
    end. (*display*)
```

```
    topic locate.  
    end. (*locate*)  
end. (*ScreenObject*)
```

topic ButtonObject.

im\_a (ScreenObject, [10,3]).

topic display.

end. (\*display\*)

end. (\*ButtonObject\*)

Although object inheritance has not been used for coding calculations in 'CoalMan', it has been employed as above in the development of the user interface.

#### 4.8. Structured Query Language (SQL)

KPWin++ has a toolkit called SQLKIT, a database manipulation and query language<sup>134</sup>. This toolkit carries out the functions of the Database Management System and the Query Facility which are required in Decision Support Systems and their development (see Section 4.3.1.).

SQLKIT allows complex database manipulation. Commands can range from a simple calculation, calling an individual record from a database, to a complex algorithm on a set of records from one or more databases. Database manipulation allows the user to ask questions about the data stored in the databases through the use of *queries*. A query is designed to search for data which fit specified criteria and order the results in a manner prescribed by the user.

Queries give the flexibility of the following:

1. Select Specific Fields
2. Select Specific Records
3. Sort Records
4. Aggregate Functions
5. Making Changes to Databases
6. Logical Operators
7. Relational Operators

The following sections describe these database manipulation techniques and give examples of their use within the software 'CoalMan'.

'CoalMan' uses databases to store a range of data concerning the offers made by coal companies, the historical analysis of the coal suppliers and a range of external factors which affect the coal purchase.

#### **4.8.1. Select Specific Fields**

The most widely used command in SQL is the SELECT statement, the flexibility of which is illustrated with examples in the next two sections. The user may choose to select only a few of the fields which appear in the database e.g. company name and names of mines. The following commands may be used.

```
SELECT *  
FROM tender.dbf
```

The asterisk (\*) is the command used to select all fields, or columns, that appear in the file specified in the FROM clause. In this case the Database Management System is directed to 'tender.dbf'.

To specify particular fields to be selected from the database the following statement would be used.

```
SELECT company, mine  
FROM tender.dbf
```

This statement will select only the company name and the name of the mine from each record in the file 'tender.dbf'.

#### **4.8.2. Select Specific Records**

The user may wish to select only records which satisfy a set of criteria explicitly determined by the user.

```
SELECT company, mine, transport  
FROM tender.dbf  
WHERE transport = 'Rail'
```

This series of statements selects the company name, mine and transport entries for each record from the file only where the transport is 'Rail'. Equally, a SELECT statement can be used to set purchase criteria, for instance:

```
SELECT company, mine, transport, ash
FROM tender.dbf
WHERE ash < 8
```

This ensures that the only records analysed by the software are those that satisfy the requirements of the system to maintain the ash levels of the coals selected for purchase.

### 4.8.3. Sort Records

The records selected by the user may be sorted in an order specified by the user.

```
SELECT company, mine
FROM tender.dbf
ORDER BY company
```

This simple operation allows the user to organise the records in alphabetical order. This can be extended to order more complex requests by a succession of criteria and can include data from multiple databases, for instance:

```
SELECT tender.company, tender.mine, tender.price, supplier.delivery_grade
FROM tender.dbf, supplier.dbf
WHERE tender.company = supplier.company and tender.mine = supplier.mine
ORDER BY supplier.delivery_grade, tender.price
```

This is a complex manipulation which requires data from two databases; the tendered offers database which gives details of the company, mine and price offered and the supplier database which gives details of the results of the historical analysis of supplier behaviour. From these databases the records which match on company name and mine are retrieved. They are then ordered for display according to the grade given for delivery ability. Within each grade the offers are organised in order of price quoted for the fuel. This manipulation is shown in diagrammatic form in Figure 23. It is worth noting that any entries in the first table which do not have a corresponding entry in the second table will not appear in the solution set.





Solution - Matching Records Arranged by Delivery Grade and Price

COMPANY	MINE	PRICE	DELIVERY GRADE
Greystone Heating Marketing	Rigside Opencast	108.00	A
Scottish Coal	Blindwells	111.00	B
Rackwood Colliery	Hannahston	125.00	B
CCCL	Blinkbonny	122.00	C

Figure 23. Complex Manipulation

#### 4.8.4. Aggregate Functions

The 'Select' clause can also incorporate a series of aggregate functions. These functions return a single value from a set of records, either working on a single column name; for example SUM(quantity), or in combination with a column expression; for example SUM(quantity\*1.09). Table 20 shows the aggregate functions available with SQL and used within 'CoalMan'.

<i>Function</i>	<i>Command</i>	<i>Result</i>
SUM	SUM(quantity)	total of values in a numeric field expression
AVERAGE	AVG(sulphur)	average of values in a numeric field expression
COUNT	COUNT(company)	number of values in the field expression
MAX	MAX(ash)	highest value in a field expression
MIN	MIN(ash)	lowest value in a field expression

Table 20. Aggregate Functions used in Select clauses

### 4.8.5. Making Changes to Databases

Databases can be created, deleted and manipulated using commands available with SQL. The first two examples in the next sections allow creation and deletion of databases. The next examples describe commands which act directly on the records within the databases.

#### 4.8.5.1. Creating a Table

This command allows the programmer to create a new database file. The name given to the file may be simplified, as shown in the following example, or may be given with the full pathname e.g. D:\TEMP\tender.dbf.

*Example:*

```
CREATE TABLE tender.dbf  
(company CHAR (35), mine CHAR (25), price NUMERIC (3,2))
```

#### 4.8.5.2. Deleting a Table

Using this command the programmer may delete a table, or database, created with the 'CREATE TABLE' command. Again, the full pathname may be used if required.

*Example:*

```
DROP TABLE tender.dbf
```

#### 4.8.5.3. Inserting a Record into a Table

The INSERT function adds the flexibility of being able to add new records to an existing database. To work successfully the fields which are being inserted must match with the format of those appearing in the table. For instance, attempts to insert a character string into a numeric field in the database will be unsuccessful.

*Example:*

```
INSERT INTO tender.dbf (company, mine, price)  
VALUES ('Scottish Coal', 'Westfield', 111)
```

#### 4.8.5.4. Updating an existing Record

Occasionally existing records in databases must be updated with new data. This function allows the programmer to initiate changes to existing records. Again, formats of fields in the database table must match the data being inserted into the table.

*Example:*

```
UPDATE tender.dbf SET price = 109
WHERE company = 'Scottish Coal'
AND mine = 'Westfield'
```

#### 4.8.5.5. Deleting a Record

If the record is no longer required in the database it can be deleted.

*Example:*

```
DELETE FROM tender.dbf
WHERE company = 'Scottish Coal' and mine = 'Westfield'
```

#### 4.8.6. Logical Operators

It may be required to combine two or more conditions when selecting records from a file. These may be linked using the AND, OR and NOT operators.

*Example:*

```
SELECT company, mine, transport, ash
FROM tender.dbf
WHERE ash < 8
AND transport = 'road'
```

#### 4.8.7. Relational Operators

A range of relational operators may be used in conjunction with select statements. Table 21 gives the operators supported by SQL and their meanings. Examples are also given in some instances.

<i>Operator</i>	<i>Meaning</i>	<i>Example</i>
=	Equal	mine = 'Blinkbonny'
<>	Not Equal	
!=	Not Equal	
>	Greater Than	ash > 8
>=	Greater Than or Equal	calorific value >= 21.4
<	Less Than	moisture < 20
<=	Less Than or Equal	moisture <= 17
LIKE	Matching a pattern	
NOT LIKE	Not matching a pattern	
IS NULL	Equal to Null	quantity IS NULL
IS NOT NULL	Not Equal to Null	
BETWEEN	Range of values between lower and upper bound	quantity BETWEEN 10000 AND 20000

Table 21. Relational Operators Supported by SQL

#### 4.9. Chapter Summary

Decision making aids are widely used in the support of business problems through applications such as spreadsheets and financial models. While they can effectively manage the handling of information and make recommendations, Decision Support Systems have made most impact on problems where the judgement of a manager is still required for the final stages of the decision process.

The purchase of coal for electricity generation is one such area suitable for the application of a decision support system. The process has enough structure to warrant the use of optimisation and suggestion models, but there are aspects of coal purchase which cannot be modelled and so the final decision processes must be left to the discretion of the purchaser.

The advantages of a Decision Support System in this field is its capacity to accept variable inputs and test scenarios for comparison by the user, quickly and efficiently. This aspect of operation will be discussed in detail in Chapter 5 and results from running the software are given in Chapter 6.

The main components of a Decision Support System were given in Section 4.3; Data Management System, Model Management, Communication (User Interface). It was important that these capabilities were incorporated into the decision support software, 'CoalMan'.

Initial collaboration with Scottish Hydro-Electric plc resulted in the development of a specification for the resulting Decision Support System. These requirements, and the components necessary for the construction of the Decision Support System, had to be brought together in the search for a suitable software development package. The search resulted in the selection of 'KnowledgePro<sup>®</sup> Windows' which provided the essential functions while ensuring that the designer of the Decision Support System would have maximum flexibility to include any expansion of the research at a later date.

## CHAPTER 5

### 'CoalMan'

In Chapter 4 the philosophy behind the use of Decision Support Systems in business management was introduced and a summary of the components required for their successful application to coal purchase was given. Chapter 5 expands on this introduction and gives a detailed description of 'CoalMan', the Decision Support Software developed in the course of this project.

The chapter is organised to fulfil two purposes:

1. provide a thorough description of, and calculations used in, the Decision Support System. 'CoalMan'.
2. give detailed instructions on how to implement the software and use it.

Examples are used to illustrate screen layouts and to explain the operation of the software.

In the first section the overall structure of the software is shown in diagrammatic form, indicating the three elements of the software:

1. 'Data Input': covers the screens provided for the user to input all of the data required by the software
2. 'Processing': gives details of how this data is used in the calculations
3. 'Information Output': shows how the user can access the results of 'CoalMan'

Each component of the structure, and its associated calculations, is then considered sequentially through the chapter.

#### **5.1. Structure of 'CoalMan'**

Figure 24 shows how the elements of 'CoalMan' combine to give the overall structure. They are divided into three distinct phases; 'Data Input', 'Processing' and 'Information Output', which are evaluated in the next sections.

'CoalMan' is structured such that the majority of the data it requires comes from databases, the information in which is either directly input by the user or accessed from system databases maintained elsewhere on the system.

This data is processed using a series of rules, models and calculations, the details of which will be expanded in more detail later in this chapter.

The recommendation calculated by 'CoalMan' is displayed on the screen and the user may choose to print out the results or store them in a file. A series of summary screens is available with 'CoalMan' which give details of the purchase recommendation as a whole, rather than a list of individual coal offers. These functions are described in greater detail later in this chapter.

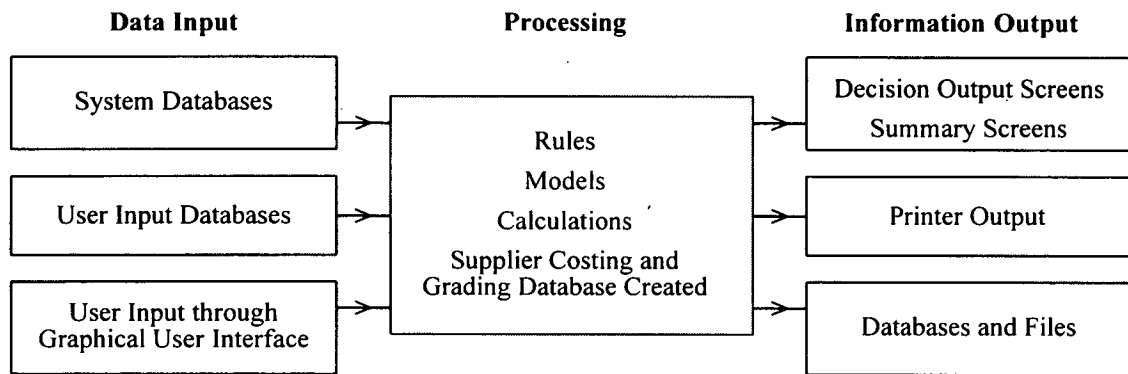


Figure 24. Structure of 'CoalMan'

It is important to note the status ascribed to the conclusions presented to the user by 'CoalMan'. The conclusions represent a possible scenario for consideration by the purchaser, but are not intended to be definitive or optimised solutions. For this reason the term 'decision suggestion' is used in this chapter.

## 5.2. Running 'CoalMan'

'CoalMan' is accessed from the operating system using the icon shown in Figure 25. This will call the software and display the opening splash screen, as shown in Figure 26.



Figure 25. 'CoalMan' Icon

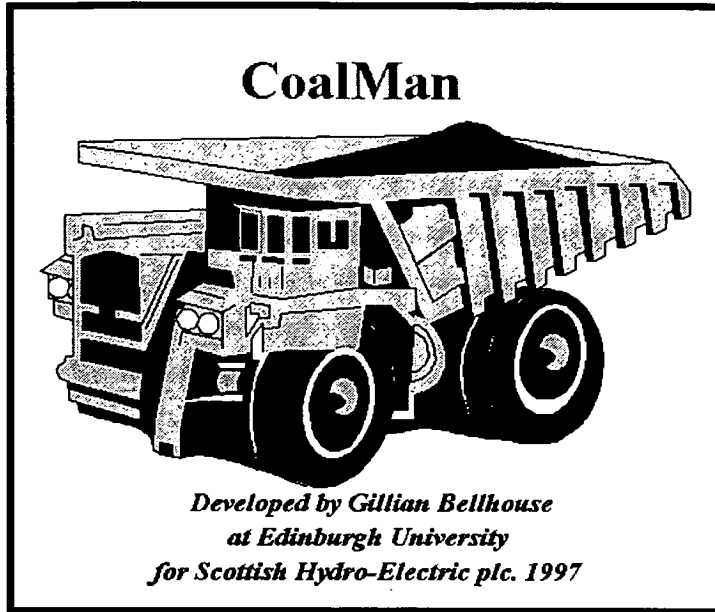


Figure 26. Opening Splash Screen for 'CoalMan'

The splash screen is displayed for a few seconds while the main screen, from which the software is controlled by the user, is created. The main screen is shown in Figure 27.

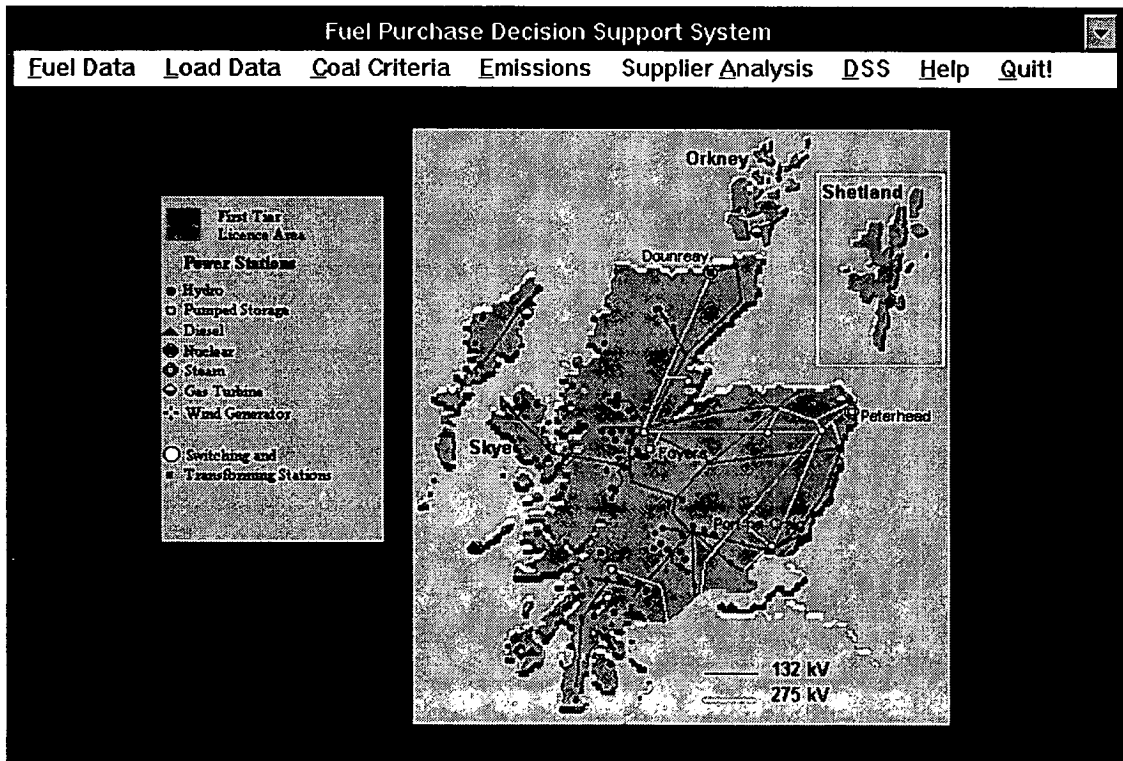


Figure 27. Main Screen for 'CoalMan'



Eight menu items are presented on the main screen. The first five items displayed from left to right access the data input screens which will be explained in detail in Section 5.3. Processing of this data is instigated by selecting the sixth option, that of 'DSS'. 'Help' calls a help screen which provides the user with an explanation of options available from this screen. Finally, 'Quit!' exits from 'CoalMan' and returns the user to the operating system.

### 5.3. Data Input

The next sections show how this information is input by the user for use in 'CoalMan'. Data input for supply and demand forecasts will not be required if the user intends to use data already stored in system databases. The data entry screens which allow the user to enter information fall into the following categories:

- Fuel Data (For Generation Sources)
- Load Data (For Electrical Demand)
- Coal Criteria
- Emissions
- Supplier Analysis

All of these will be discussed in the next sections. In 'CoalMan' all data entry screens appear in white to signal to the user that information is being requested.

#### 5.3.1. Fuel Data

This selection of screens asks for input of forecast Power Station availability from stations available to the generator. Separate screens, accessed from the menu item 'Fuel Data' on the main screen, allow for data entry for the following:

1. Coal
2. Oil
3. Gas
4. Hydro
5. Nuclear

Figure 28 shows an example of a Fuel Data entry screen. At the top of the screen two dates are shown, the first is the current date while the second shows when the data displayed was last updated. This allows the user to judge whether or not the information should be changed before the next decision calculation. As a guide, the user should expect to update

forecasts on a monthly basis to keep information up to date with other fuel buyers expectations.

The main body of the screen is a display of each of the twelve months followed by corresponding, individual edit boxes. The user is requested to enter the generation (in GWh) forecast to be supplied by the source in each month. For any fuel type which is not available the forecasts should be set to zero.

The only difference between the screen shown in Figure 28 and those that appear for other fuel sources is the inclusion of a proportional division entry point. This allows the user to enter the percentage of total coal consumption that will be assigned to each station. The stations displayed here are the coal-fired Power Stations, Longannet and Cockenzie, which correspond to those available to Scottish Hydro-Electric.

Two buttons appear at the bottom of the screen. 'Quit' closes the window without saving any changes entered by the user. 'Update Records' will change the database entry for that fuel type and will update the date given as the 'Date of Last Update' to the present date.

The screenshot displays a window titled "Coal Data Input Screen". At the top, it shows the current date as "23/12/96" and the "Date of Last Update" as "01/11/96". Below this is a section titled "Forecast Monthly Coal Output." which contains two columns of input fields. The left column lists the months from January to June, and the right column lists the months from July to December. Each month has a text box containing the number "100" followed by the unit "GWh". A vertical line separates the two columns. Below the monthly forecasts is a section titled "Proportion of Division between Stations". It contains two input fields: "Longannet" with a value of "80" and "Cockenzie" with a value of "20", both followed by a percentage sign "%". At the bottom of the screen are two buttons: "Update Records" and "Quit".

Forecast Monthly Coal Output.		
January	100	GWh
February	100	GWh
March	100	GWh
April	100	GWh
May	100	GWh
June	100	GWh
July	100	GWh
August	100	GWh
September	100	GWh
October	100	GWh
November	100	GWh
December	100	GWh

Proportion of Division between Stations	
Longannet	80 %
Cockenzie	20 %

Figure 28. Fuel Source Availability: Example Screen for Coal

### 5.3.2. Load Data

The menu item 'Load Data', accessed from the main screen, displays a list of the demand areas to which the Generator sells generated electrical energy. Selection of any item on the list opens a data entry screen for input of forecast demand. The following sales options, which were introduced in Section 2.1. of Chapter 2, are allowed for in the software:

1. 1st Tier
2. 2nd Tier
3. Interconnector

Figure 29 below shows a typical data input screen for user specification of monthly forecast demand in GWh. It can be seen that the layout of this screen is almost identical to those used for Fuel Data and that the information requested should be entered in the same way.

The screenshot shows a window titled "Load Forecast Data Input Screen". At the top, it displays "Date: 11/03/97" and "Date of Last Update: 03/08/96". Below this is a section titled "Forecast Monthly First Tier Sales" with a horizontal line underneath. The data is organized into two columns of months. Each month has a text label, a numeric input field containing the value "800", and the unit "GWh". The months listed are January through December. At the bottom of the screen, there are two buttons: "Update Records" and "Quit".

Forecast Monthly First Tier Sales		
January	800	GWh
February	800	GWh
March	800	GWh
April	800	GWh
May	800	GWh
June	800	GWh
July	800	GWh
August	800	GWh
September	800	GWh
October	800	GWh
November	800	GWh
December	800	GWh

Figure 29. Load Forecast Data Entry Screen

Again, the user is required to enter the number of GWh expected to be required in each area of demand in each of the given months. Any aspects of demand which are not applicable should be set to zero.

### 5.3.3. Coal Criteria

Since 'CoalMan' is designed to aid coal purchase decision making, additional information about the offers and the logistics of the purchase are required. These are:

1. Offers Received from Coal Suppliers
2. Road and Rail Delivery Limits for Coal
3. Rail Costs for Transportation of Coal

The entry of this data is covered in the next sections.

#### 5.3.3.1. Coal Offers

Figure 30 below shows the data entry screen for all offers received by the Generator in response to an invitation to tender for coal supply. The user enters the details of the offer directly as the screen shows. Since each coal tender may have a number of alternative offers within it, these should be entered as separate items in the database. This will allow the software to select suppliers and offers from the full range of options available to satisfy the requirements of the purchase in the most economic way.

The screenshot shows a data entry form titled "Please Complete Offer Details:". The form contains the following fields and controls:

- Company: Text box containing "Scottish Coal" with a dropdown arrow icon.
- Mine: Text box containing "Dalquhandy" with a dropdown arrow icon.
- Transport Method: Text box containing "Road" with a dropdown arrow icon.
- Delivery Point: Text box containing "Longannet" with a dropdown arrow icon.
- Price: Text box with "p/GJ" to its right.
- Total Quantity: Text box with "tonnes" to its right.
- Calorific Value: Text box with "GJ/te" to its right.
- Sulphur: Text box with "%" to its right.
- Moisture: Text box with "%" to its right.
- Ash: Text box with "%" to its right.
- 1st Delivery Week: Text box.
- Max Monthly Delivery: Text box with "tonnes" to its right.

At the bottom right of the form are two buttons: "OK" and "Cancel".

Figure 30. Coal Offer Data Entry Screen

At the top of the screen shown in Figure 30 appear two comboBoxes, so called because they combine an edit box with a list box. The arrow to the right of the edit box drops down a list box containing a number of options which may be selected by the user. In this case the top comboBox displays a list of coal companies from which the user may choose when entering the offer. This will automatically update the 'Mine' comboBox with a list of mines owned by that company. This guarantees that the names of companies and mines are entered consistently, ensuring that database records always match up. This method of data entry also makes it easy and quick for the user to enter data accurately.

Similarly, when the transport method is selected the possible destinations for the coal are automatically updated in the 'Delivery Point' comboBox. For instance, road deliveries will always show delivery direct to the station while rail deliveries will show a list of rail depots for user selection.

In each case the user may enter options which do not appear on the list, for example new suppliers, by typing directly into the edit box.

The edit boxes for 'Price', 'Total Quantity' and all aspects of the specification will correspond with details given in each supplier's tender. 'First Delivery Week', which refers to the first week in which coal can be supplied under the terms of the tender, and 'Max. Monthly Delivery', which indicates the rate of coal supply being offered, should also be entered by the user. When this window is closed by the user the software will automatically check that all fields have been entered and prompt for details where any have not been completed.

When the offer entry window is closed all of the offers which have been stored in the database are then shown on the screen. Figure 31 shows how the delivery method and destination, price and quantity for delivery are displayed. Figure 32 shows the specification details for each of the coals offered for delivery.

Display of this information in a tabular form allows the user to verify that the details entered for each offer are correct and complete. The user can also confirm that all tendered offers have been entered. This entry screen provides menu-driven access to both the offer entry screen and to an entry deletion function. The screen display can be printed out as a summary sheet if required.

Coal Offers Received					
File	Edit	Display	Quit		
COMPANY	MINE	TRANSPORT	DELIVERY	PRICE	QUANTITY
Greystone Heating Marketing	Rigside Opencast	Rail	Roughcastle	108.00	30000
Scottish Coal	Dalquhandy	Rail	Ravenstruther	107.00	100000
Scottish Coal	Blindwells	Rail	Blindwells	111.00	50000
GSGA (Coal Marketing) Ltd	Unspec	Rail	Roughcastle	105.00	10000
Andrew Maxwell	Rashiehill & Backshot	Rail	Carstairs	113.00	10000
Coal Contractors Ltd	Roughcastle North	Rail	Roughcastle	120.00	15000
I&H Brown Ltd	Cairncubie	Rail	Mossend	114.90	33000
Anglo	Auchentiber	Rail	Mossend	110.00	8000
PD Fuels	Unspecified	Rail	Ravenstruther	115.00	12000
Greystone Heating Marketing	Rigside Opencast	Road	Longannet	109.00	30000
Greystone Heating Marketing	Rigside Opencast	Rail	Mossend	101.00	30000
CCCL	Blinkbonny	Road	Cockenzie	122.00	60000
Rackwood Colliery	Hannahston	Road	Longannet	125.00	65000
Russell Coal	Easter Fortissat	Road	Longannet	119.00	20000
Anglo	Woodend	Road	Longannet	101.00	6500
Scottish Coal	Westfield	Rail	Westfield	100.00	100000

Figure 31. Coal Offers Received: Delivery Details

Coal Offers Received					
File	Edit	Display	Quit		
COMPANY	MINE	CV	SULPHUR	MOISTURE	ASH
Greystone Heating Marketing	Rigside Opencast	24.50	0.90	14.60	8.40
Scottish Coal	Dalquhandy	23.54	1.00	16.00	10.00
Scottish Coal	Blindwells	22.56	1.10	18.20	8.80
GSGA (Coal Marketing) Ltd	Unspec	25.00	1.00	15.00	13.00
Andrew Maxwell	Rashiehill & Backshot	26.90	0.90	11.00	4.00
Coal Contractors Ltd	Roughcastle North	24.00	1.00	15.00	13.00
I&H Brown Ltd	Cairncubie	24.50	0.50	15.00	8.00
Anglo	Auchentiber	24.04	0.80	13.80	13.90
PD Fuels	Unspecified	23.54	1.00	16.00	10.00
Greystone Heating Marketing	Rigside Opencast	24.50	0.90	14.60	8.40
Greystone Heating Marketing	Rigside Opencast	24.50	0.90	14.60	8.40
CCCL	Blinkbonny	22.60	1.00	13.00	11.00
Rackwood Colliery	Hannahston	24.50	0.95	12.00	12.00
Russell Coal	Easter Fortissat	24.00	0.73	8.00	15.00
Anglo	Woodend	22.26	0.62	15.00	14.20
Scottish Coal	Westfield	21.28	1.80	20.20	10.30

Figure 32. Coal Offers Received: Specification Details

### 5.3.3.2. Road and Rail Delivery Limits for Coal

As explained in Chapter 2 there are limits placed on road and rail deliveries into Longannet and Cockerzie Power Stations. These limits must be monitored throughout the decision process to ensure that the total delivery capability will not be exceeded by the additional coal purchase. The software will not make any suggestion which exceeds the delivery limits fixed on the purchase.

The limits can be varied by the user using the screen shown in Figure 33 so that any system changes can be taken into account.

	Road		Rail	
Longannet	40	kte	50	kte
Cockerzie	0	kte	10	kte

Save Changes      Quit

Figure 33. Delivery Limits Data Entry Screen

### 5.3.3.3. Rail Costs for Transportation of Coal

It is possible to have coal delivered to a rail depot and loaded on to a train ready for delivery. The cost of this will be quoted in the tender as the 'Free on Rail' cost of the coal. It is normally the responsibility of the Generator to pay for transportation to the Power Station, although suppliers are free to offer coal on a rail delivered basis.

At the time of writing rail charges vary depending on the depot from which the coal is being transported and the Power Station for which it is destined. With rail privatisation, however, this system may change and alternative pricing schemes may be introduced. For this reason it is important that the user can input delivery charges and alter them. Figure 34 below shows the data entry screen for this information.

Rail Costs Input Screen			
Rail Details		Quit	
Please Update the Costs of Rail Transport Below:			
Rail Depot	Destination		
	Longannet	Cockenzie	
Millerhill	2.75	1.45	£/tonne
Thornton	2.10	3.80	£/tonne
Mossend	3.50	3.70	£/tonne
Ravenstruther	3.18	3.70	£/tonne
Blindwells	2.95	1.18	£/tonne
Inverkeithing	1.70	1.70	£/tonne
Carstairs	3.60	4.60	£/tonne
Roughcastle	2.40	3.00	£/tonne
Westfield	2.15	3.15	£/tonne

Figure 34. Rail Costs Data Entry Screen

### 5.3.4. Emissions

Coal purchasing decisions will normally be constrained by Power Station emissions limits. The information required falls into two categories; the taxes levied on emissions emitted and the formulae used to calculate those emissions. The next sections show how 'CoalMan' handles data entry requirements for this information.

#### 5.3.4.1. Emissions Taxes

In Chapter 2 the types of emissions legislation imposed on the ESI were discussed. At present the only proposed tax on emissions is the landfill, or ash, tax which is set by the Government. This is still subject to discussion, but the proposed tax for disposal of Power Station ash is £2/tonne ash produced<sup>135</sup>.



Taxation of carbon dioxide (CO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>) and oxides of nitrogen (NO<sub>x</sub>) has not been implemented but in the future legislation for this may be introduced. For this reason they have been included in the software. Until legislation is introduced the user may employ these options to place a notional value on the emissions associated with generation. This will be of particular importance when the Generator is coming close to its annual emissions limits, in which case the user might wish to apply an economic incentive to reduce emissions in the purchasing decision, for instance, by penalising poor quality coals. Figure 35 shows the screen designed for user input of emissions taxation or notional cost data. In the USA Generators are penalised \$2000 for every tonne of SO<sub>2</sub> they produce over the limit of their permit<sup>136,137</sup> (see Section 2.10.2. of Chapter 2).

The screenshot shows a window titled "Environmental Tax Input Screen". Inside the window, the text "Environmental Taxes or Costs." is underlined. Below this, there are four rows of input fields:

Category	Value	Unit
Landfill/Ash Tax	2	£/te produced
SO2 Charge	0	£/te emitted
NOx Charge	0	£/te emitted
CO2 Charge	0	£/te emitted

At the bottom right of the input area, there is a button labeled "Quit".

Figure 35. Emissions Taxation Levels Input Screen

### 5.3.4.2. Emissions Formulae

The formulae used for calculating the emissions of SO<sub>2</sub> and NO<sub>x</sub> are given in this screen. The SO<sub>2</sub> formula shown is the agreed basis for compliance with emissions reductions under the UK National Plan to conform to the Large Combustion Plant Directive (see Section 2.9. of Chapter 2). It can be varied by the user, for example, following investments which permanently reduce emissions.

As shown in Figure 36 the NO<sub>x</sub> calculations are different for Longannet and Cockenzie Power Stations. This is due to the installation of low NO<sub>x</sub> burners at Longannet which has a lower emission rate, as explained in Chapter 2.

At present there is no formula given for the calculation of emissions of CO<sub>2</sub> and no legislation applies for abatement from Power Stations.

The screenshot shows a window titled "Emission Formula Input Screen". Inside, there is a section titled "Emissions Formulae". Under "SULPHUR", it shows "1 te Sulphur in Coal" followed by an arrow pointing to a text box containing "1.9", and then "te SO2 out". Under "NITROGEN", there are two entries: "Longannet" with "1 te Coal input" followed by an arrow to a text box containing "7", and "kg NOx out"; and "Cockenzie" with "1 te Coal input" followed by an arrow to a text box containing "9", and "kg NOx out". At the bottom of the window are two buttons: "Save Changes" and "Quit".

Figure 36. Emissions Calculations Input Screen

If there are any technological changes to either of these stations which affect these formulae, these parameters may be changed accordingly. In this way it will be possible to update the software.

### 5.3.5. Supplier Analysis

Supplier Analysis is a Supplier Assessment method where the user attributes a grade to each supplier in each of the categories discussed in Chapter 3. 'Lotus Approach - Release 3 for Windows' is used to run this section. Figure 37 shows the screen used for data entry, as it appears in the 'Lotus Approach' window.

The screen is divided into 4 sections:

- Company Details
- Delivery Gradings
- Quality Gradings
- Query Handling

The first section allows the user to enter details of each supplier, such as company name, name of mine and details of contacts within the company. As with the screen designed for entry of coal tenders, the company name and name of the mine are entered using comboBoxes which speed up data entry while ensuring accuracy and consistency.

The next three sections represent the three categories introduced as the Coal Purchasing Criteria in Chapter 3. The user must grade the supplier based on past experience. Guidance for the allocation of grades is given on a separate screen which is shown in Figure 38.

Figure 37. Supplier Assessment: User Grade Selection Screen

Grades A - D are allocated by clicking on the appropriate radio button with the left mouse button. Grades A - C should be set to match the user's perception of how the supplier will perform based on experience or on knowledge about present circumstances which may affect the supplier's performance. Grade D can be used where there has been no previous experience of the company, and in this case the supplier will be treated as a Grade B supplier, but this situation will be indicated in the purchase decision suggestion given by the software by denoting the supplier grade 'B\*'.

<b>Gradings Explanation</b>		
<b>Delivery Gradings</b>	<b>Meet Contract Start</b> A. Consistently meet start of contract. B. Miss contract start occasionally C. Consistently miss contract start.	<b>Meet Contract Deadline</b> A. Consistently meet delivery deadlines. B. Occasional contract overrun. C. Consistently fail to supply.
	<b>Utilise Delivery Slots</b> A. Above expectations of utilising delivery slots. B. Consistently meet expectations of utilisation. C. Disappointed at past utilisation.	<b>Confidence in Supply</b> A. Supplier has large portfolio of sites. B. No reason to doubt ability to supply. C. Supplier has history of problems or proposes supply from untested site.
<b>Quality Gradings</b>	<b>Meet Specification</b> A. Never disappointed. B. Generally meet specification. C. Coal bad in past and requires action!!	<b>Quality Control</b> A. Demonstrated excellence. B. Some deviation in quality measurements. C. No satisfactory quality control methods.
	<b>Dealing with Queries</b> A. Supplier works to help purchaser. B. Variable in discussion and action. C. Discuss problems but don't act on them.	<b>Notification if Problems</b> A. Immediate notification of any problem. B. Variable in notification of problems. C. Purchaser must identify and raise problems.
<b>Note:</b> All 'Grades D' are used for suppliers who are 'unknown'. This grade will automatically class the supplier as a 'Grade B*' wherever used.		

Figure 38. Supplier Assessment: Gradings Explanation

#### 5.4. Processing: The Decision Support System

Once all of the information required by 'CoalMan' has been entered by the user, or is accessible in system databases, the next step is to process this information using the Decision Support System section of the software. Figure 39 shows the processes involved in the Decision Support System in the form of a simplified flowchart which is divided into six stages. Stages 1-5 are expanded in more detail in the following sections. Stage 6 is described in Section 5.5. of this chapter.

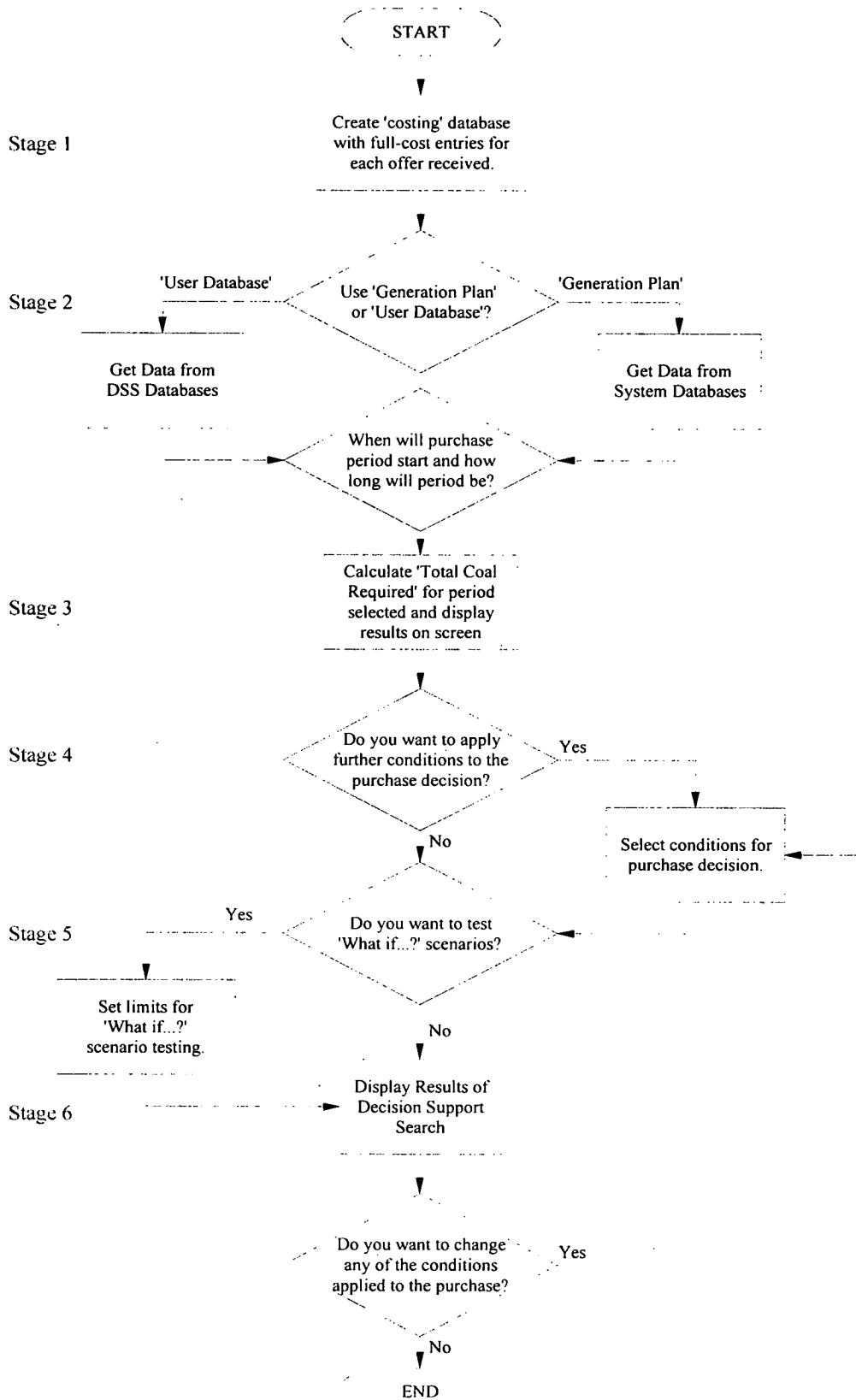


Figure 39. Excerpt from Flowchart of Software Process

### 5.4.1. Stage 1: Creation of 'Costing' Database

When the Decision Support System is started, the first stage in the calculations is the creation of the 'Costing' database; the definitive database for all of the offers received in response to the invitation to tender taking into account rail costs and emissions costs and outputs. Information required here comes from 4 sources:

- Coal Offers Received
- Transport Costs
- Emissions Formulae
- Emissions Taxes/Costs

#### 5.4.1.1. Transport

For each offer tendered by a coal company the first aspect checked is the method by which the coal will be transported from the mine to the station. This is because, where the purchaser is responsible for transport, rail deliveries incur a separate transportation cost which must be included with the price tendered in the offer. All prices for quoted road deliveries are given as the delivered tender price.

The software allocates each rail delivery offered in the tender to the Power Station to which it will be most economical for the coal to be delivered. The closer a mine is to a particular Power Station the lower the total rail charges will be. The lower cost option will be selected by the software as the better option.

Since all prices for coal are tendered in terms of pence per Gigajoule (p/GJ) the next step in calculating the value, or price, of an offer is to convert rail cost from £/tonne to p/GJ using Equation 8 below.

$$\text{Total Rail Cost (p / GJ)} = \frac{\text{Rail Charge from Depot to Station (£ / tonne)}}{\text{Calorific Value of Coal (GJ / tonne)}} * 100 \quad (8)$$

The total rail cost in p/GJ is then added to the tendered cost of the offer to give the full cost of the offer. This places all offers on a comparable basis.

### 5.4.1.2. Emissions

The next step in the creation of the 'costing' database is the calculation of the total emissions costs associated with each offer. The first emission calculation is that for ash, taking into account the tax levels input by the user using the screen shown in Section 5.3.4.1. The formula used is given by Equation 9 below.

$$\text{Ash Cost (£)} = \frac{\text{Ash Content (\%)} * \text{Coal Quantity (tonne)}}{100} * \text{Ash Tax (£ / tonne)} \quad (9)$$

The next emission cost which must be calculated is that for SO<sub>2</sub>. Equation 10 below shows the calculation.

$$\text{SO}_2 \text{ Cost (£)} = \frac{\text{Sulphur Content (\%)} * \text{Coal Quantity (tonne)} * 1.9}{100} * \text{SO}_2 \text{ Cost (£ / tonne)} \quad (10)$$

Where:

1.9 = Conversion Factor for Sulphur Content to SO<sub>2</sub> Emissions (See Section 5.3.4.1.)

As discussed in Section 2.1.2.2. of Chapter 2, Longannet and Cockenzie Power Stations have different formulae for the calculation of NO<sub>x</sub> emissions following the installation of low-NO<sub>x</sub> burners at Longannet Power Station. Equation 11 shows the calculation.

$$\text{NO}_x \text{ Cost (£)} = \frac{\text{Coal Quantity (tonne)} * \text{Output Factor (kg)}}{1000} * \text{NO}_x \text{ charge (£ / tonne)} \quad (11)$$

Output Factor = 7 kg for Longannet

Output Factor = 9 kg for Cockenzie

The figures calculated with the above formulae and the full details of each offer are then entered into the 'costing' database for use in the next part of the Decision Support System of 'Coal Man'.

### 5.4.2. Stage 2: Data Collection from Forecasts

Forecast data concerning availability of Generation from other sources and electrical demand has two possible sources. The first source is directly from user input through the screens supplied with 'CoalMan' and discussed in Section 5.3. The second source is a set of databases held by Scottish Hydro-Electric, or the user of the system.

Stage 2 of the 'CoalMan' Decision Support System requires the user to select from which source data to be used in the purchase analysis will be drawn. Figure 40 below shows this question as it is displayed on the screen. Three options are offered to the user; 'User Input - Coal Forecast', 'User Input - All Sources' and 'Generation Plan'. Each of these will be discussed in detail in Section 5.5.3.2.

On this screen some of the menu options are disabled (shown in grey). These will be enabled later in the decision process once the user has answered the questions as required by the software and the preliminary calculations of Stage 3 have been carried out.

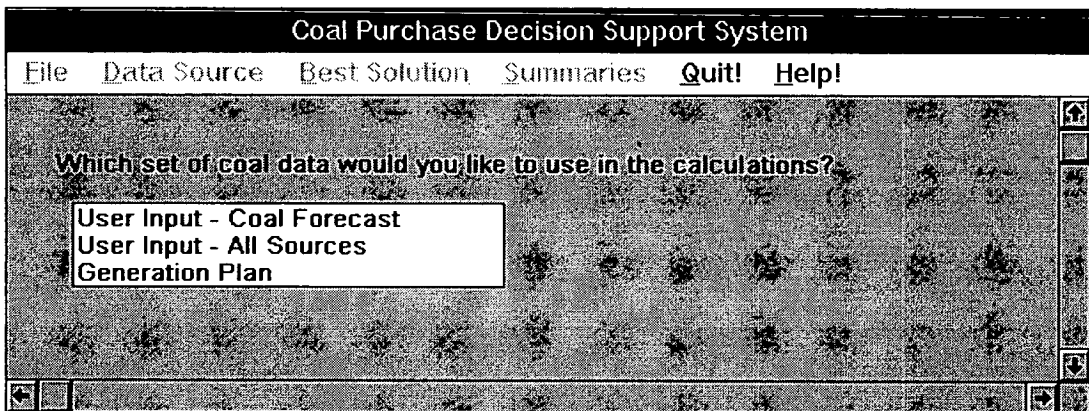


Figure 40. Data Source Selection Question

### 5.4.3. Stage 3: Calculation of Coal Required to Meet Demand

#### 5.4.3.1. Setting The Duration of the Purchase

The Decision Support System in 'CoalMan' requires a period for the purchase to be set before a decision solution can be suggested. This is defined by answering two questions displayed on the screen as shown in Figures 41 and 42 below. The first question asks the user to specify the first month to be considered, this is displayed on the screen and a second



question is presented. The user is now requested to enter the number of months over which the study is to be carried out. The default value for this is set at 3 months, but can be up to 12 months.

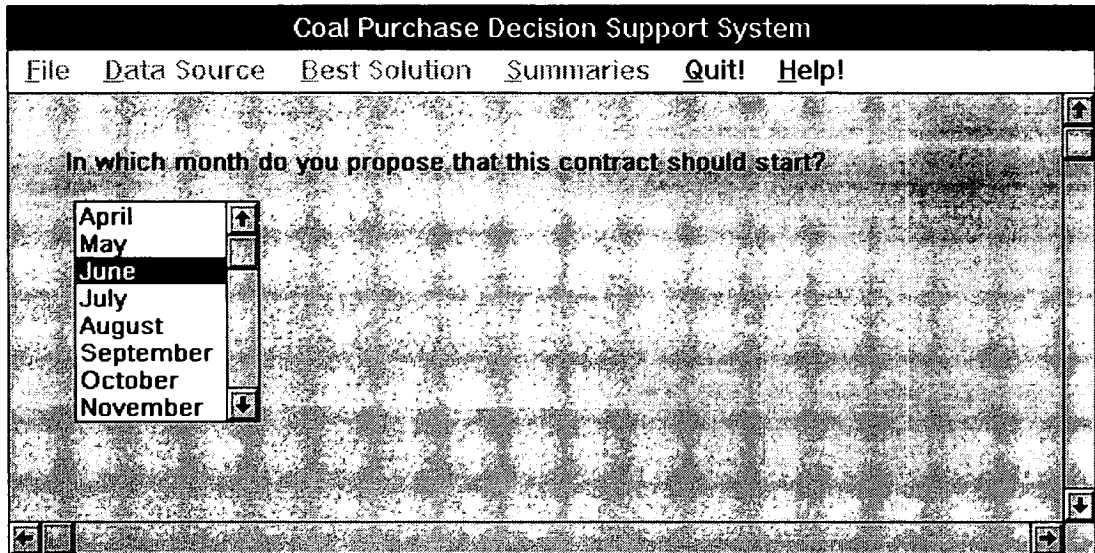


Figure 41. 'Contract Start' question displayed on screen

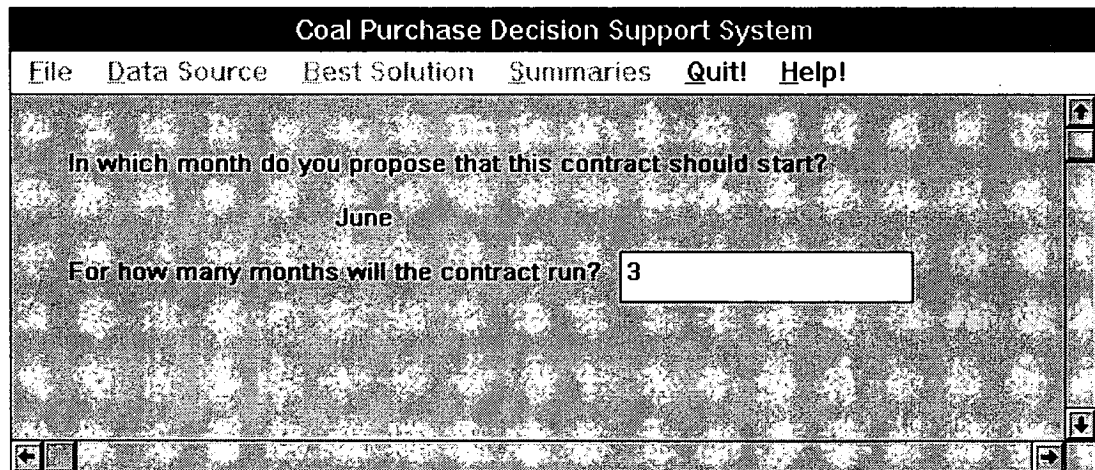


Figure 42. 'Duration of Purchase' question displayed on screen

#### 5.4.3.2. Calculation of 'Total Coal Required'

Once the user has answered the software's questions about the data source to be used and starting month and duration of the purchase the total coal required is calculated. As can be seen from the previous section containing the user selection screens, there are three options

available to the user when choosing the source of the forecasts used in the Decision Support System.

The information given by the user concerning the source of the data used in the calculations and the duration of the contract is used in the calculation of the total coal required in the coal purchase. In the next sections the calculations used for each source are given. In each case, generation or demand given in Gigawatt hours (GWh) is converted to kilotonnes (kte) of coal by dividing by 2 since this equates approximately with the following formula:

$$\text{Coal Burned (kte)} = \frac{3.6 * \text{Energy Produced (GWh)}}{\text{Efficiency of Power Station}(\eta) * \text{Calorific Value (GJ / te)}} \quad (12)$$

#### 5.4.3.2.1. User Input - Coal Forecast

When this option is selected, the data used in the calculation of the total coal requirement is taken directly from the information entered by the user through the 'Coal Data Input Screen'. In this case the formula for the calculation is given in Equation 13.

$$\text{Total Coal Required (kte)} = \sum_{\text{Duration}} \frac{\text{Monthly Coal Forecast (GWh)}}{2} \quad (13)$$

This is the sum of the forecast coal burn over each month of the duration of the contract and is found by dividing the expected electrical output from coal-fired Power Stations by 2, as given in Section 5.4.3.2. This is the most simple of the options available to the user.

#### 5.4.3.2.2. User Input - All Sources

This option calculates the total coal required from the difference between the total energy demand forecast and the total supply availability forecast. If the resulting figure is positive then a coal purchase will be recommended, however, a negative result will cause the software not to make a recommendation to purchase coal. If a purchase recommendation is required, however, the user may proceed with the rest of the software. Equation 14 gives the calculation used in 'User Input - All Sources'.

$$\text{Total Coal Required (kte)} = \frac{\text{Total Electrical Demand (GWh)} - \text{Total Supply (GWh)}}{2} \quad (14)$$

Where:

$$\text{Total Electrical Demand} = \sum_{\text{Duration}} (\text{1st Tier} + \text{2nd Tier} + \text{Interconnector Demand})$$

$$\text{Total Supply} = \sum_{\text{Duration}} (\text{Nuclear Forecast} + \text{Gas Forecast} + \text{Hydro Forecast} + \text{Oil Forecast})$$

### 5.4.3.2.3. Generation Plan

Figure 43 below shows an excerpt of a database developed for use by Scottish Hydro-Electric. The database is updated from files maintained on Scottish Hydro-Electric's computer network so that the data is always kept up to date.

		APR	MAY	JUN
GWh	Longannet @ 80% of Total GWh	140	138	126
	Cockenzie @ 20% of Total GWh	66	34	32
	Total	206	172	158
	Capacity	299	380	417
CONSUMPTION	Longannet (kte)	64	62	57
	Cockenzie (kte)	32	17	15
	Total	96	79	72
	Total	2124	1763	1617
CAL. VAL.	Stock Weighted Average (nett)	22	22	22
LONGANNET PURCHASES	Committed	65	86	96
	Uncommitted	0	0	0
COCKENZIE PURCHASES	Committed	11	20	26
	Uncommitted	0	0	0
SULPHUR	Stock Weighted Average (nett)	0	0	0
STOCK (kte)	LONGANNET	37	38	61
	COCKENZIE	37	17	20
	TOTAL	74	54	81
	TOTAL	1641	1215	1804

Figure 43. Excerpt from Computer Network Database for Scottish Hydro-Electric

Using the data given in the database shown in Figure 43, Equation 15 determines the total coal requirement over the period selected by the user.

$$\text{Total Coal Required (kte)} = \text{Longannet Forecast (kte)} + \text{Cockenzie Forecast (kte)} \quad (15)$$

Where:

$$\text{Longannet Forecast (kte)} = \sum_{\text{Duration}} (\text{Longannet Consumption} - \text{Longannet Committed Purchases})$$

$$\text{Cockenzie Forecast (kte)} = \sum_{\text{Duration}} (\text{Cockenzie Consumption} - \text{Cockenzie Committed Purchases})$$

### 5.4.3.3. Results of Stage 3

The results of the calculations up to the end of Stage 3 are then displayed on the screen. An example is given in Figure 44.

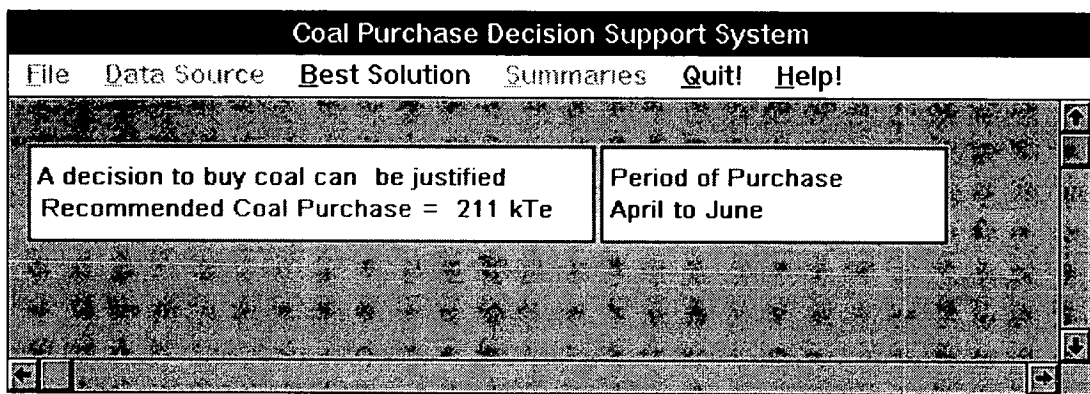


Figure 44. Results at End of Stage 3

### 5.4.4. Stage 4: Imposing Conditions on the Purchase

The initial option available to the user when displaying a solution to the coal purchase decision is to organise the solution with respect to one of the following:

1. Tender Price
2. Full Economic Calculation
3. Supplier Grade
4. User Defined Criteria

A decision made under these conditions is one which takes into account only the offers themselves. That is, there is no limit placed on the quality of the coal to ensure that it meets the specification limits of the stations. These methods are designed to give the user fast and simple access to an indicative decision support solution. They are also valuable methods of testing the feasibility of the purchases and whether there are, indeed, enough offers available

to satisfy the quantity requirements of the purchase, without any other restrictions being placed on the purchase. These options may be used as a reference against which to measure the effects of applying constraints to the purchase. The following sections show how each of these options may be used.

#### **5.4.4.1. Tender Price**

The principal means of tender selection is based on the delivered price of the coal. If the suppliers are ranked in order of cost, with lowest cost the most preferred, then the most competitive package of purchases can be recommended.

While this method allows a direct comparison of the tendered offers it is limited in its scope of selection criteria. For example, the 'cost' of the coal is limited to fuel cost and transport cost and does not take into account the economic penalty of emissions. For example, no account is made for the trade-off between coal price and ash content. Where economic penalties are significant, these should be taken into account in the recommendations.

#### **5.4.4.2. Full Economic Calculation**

Competition in the market place makes it imperative that purchases are made economically. However, the price of the fuel offered is not the only cost associated with the fuel purchase. The costs of emissions must also be considered when making a purchasing decision since electricity companies have a duty to their customers and shareholders to purchase economically.

Selection of this option makes the coal purchase recommendation based on a 'full-cost' calculation, shown by Equation 16 below.

$$\text{Full Cost} = \text{Tender Price} + \text{Transport Cost} + \text{Emissions Cost} \quad (16)$$

Since the specification of the coal will affect emissions and, therefore, the costs incurred through these emissions, it is important that the user is allowed the option to take these charges into consideration when calculating the 'value' of the coal source. An offer may appear economic on first inspection of price, but also has the potential to have, say, a high ash content. The emissions charges which this will incur will outweigh the benefits of its lower price.

It is important to compare purchases with and without environmental constraints being applied to allow the buyer to assess the effects of legislative constraints on the purchase recommendation. These include differences in cost and the exclusion of suppliers which would otherwise have been successful in the tender (see Section 5.4.4.4.). Such comparison is crucial in the justification of 'non-economic' considerations.

#### **5.4.4.3. Supplier Grade**

In Chapter 3 a novel method of coal supplier assessment was discussed. This showed how each supplier can be graded on three characteristics; 'Delivery Reliability', 'Quality of Coal Supplied' and 'Handling of Queries'. The supplier can then be given a total grade as a function of all three individual grades. The overall grade assigned to each supplier using the supplier assessment method is used here as to rank the coal purchase recommendation.

On the screen, accepted offers are ranked in order of the total grade assessed for each supplier. This means that the recommended suppliers will be those which have performed best over all contracts organised with them. Within each grade the offers are ranked according to tendered price. Suppliers who were given a 'Grade D', because the purchaser had no previous experience of their performance, are shown with a 'B\*' rating which denotes that they are unknown.

#### **5.4.4.4. User Defined Criteria**

The above methods are limited in their scope for making a purchase decision and, while they can be good indicators for the user, they do not take into account the many options and constraints which may be required in the purchase. For this reason the user can fix limits on the purchase within a set of criteria identified as those of importance in coal purchase. The following section shows how this is organised within the decision support software.

##### **5.4.4.4.1. New Conditions**

The criteria which are used to impose conditions on the purchase are divided into two groups; 'Criteria for Selection' and 'Criteria for Decision'. 'Criteria for Selection' are the specification limits for the coal while 'Criteria for Decision' are those based on the grades allocated by the user for Delivery, Quality and Query Handling. Figure 45 shows the selection screen where the user can choose the criteria whose limits are to be set.

Under 'Criteria for Selection' the user can fix the limits to reflect the circumstances under which the purchase is being made. The user may define the specification criteria which are of greatest importance in this situation. These include:

1. Calorific Value
2. Ash Content
3. Sulphur Content
4. Moisture Content

'Criteria for Decision', the second set of selection criteria, come from the historical analysis of delivery, quality and query grades. These may be selected by the user as required, for example, to allow only suppliers which perform with a Grade A or B in Delivery (see Chapter 3). The purchase recommendation may, therefore, be delimited depending on the importance of:

1. Ability to deliver within timescale
2. Quality of coal supplied
3. Query Handling

The user may select any number of the criteria displayed on the screen to impose limits on the purchase.

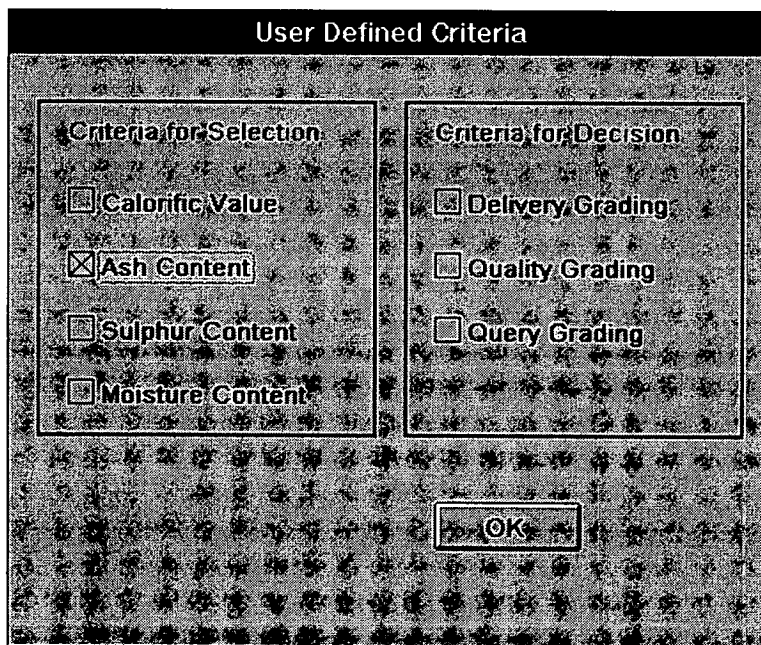


Figure 45. Selection Screen for Setting Limits on Purchase

Next, a screen to allow the user to input the limits on the purchase is presented. An example is given in Figure 46.

The user of the system can choose from these criteria in such a way that the selection and order of suppliers can be tailored to suit particular purchase requirements. For example; the user may be restricted in the choice of supplier by the lack of road delivery slots available. Thus, any supplier who cannot deliver by rail will automatically be rejected by the software. Equally, the user may require immediate delivery of resources, so this would also reduce the number of acceptable suppliers in the database.

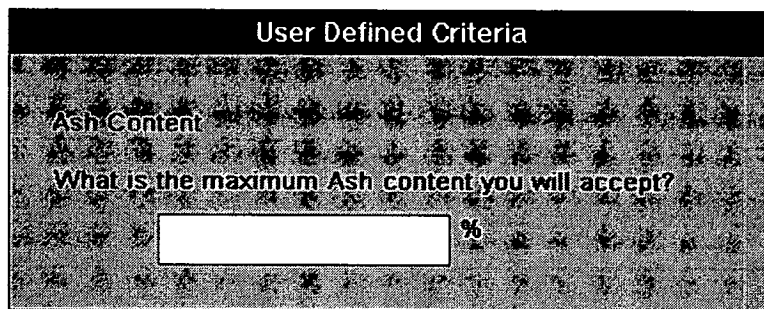


Figure 46. Limits Entry Screen for User Defined Criteria

The user can run 'CoalMan' with and without these restrictions in order to assess the cost of limiting the decision space. It is then possible to judge whether or not the additional cost of imposing the limits can be justified.

#### 5.4.4.4.2. Existing Conditions

The 'Existing Conditions' option allows the buyer to use the most recent set of conditions, imposed on the purchase under 'New Conditions', in more than one set of calculations, without them having to be re-entered.

#### 5.4.5. Stage 5: 'What If...?' Scenarios

As discussed in Chapter 2 a proportion of the coal used for electricity generation makes up the difference between other sources of electrical energy and total demand. Variance in demand and production from other sources of generation mean that the quantity of coal to be purchased is uncertain. By testing 'What If...?' scenarios the user can examine how the coal purchase recommendation will change if there is variation in any aspect of generation



or demand. The user is not restricted to testing variation in individual sources or demand areas, but can test the cumulative effects of variation in any combination, or even all of the options offered here. By testing and comparing different scenarios the user can establish which set of circumstances will have greatest impact on the coal purchase and assess whether action should be taken to minimise its effects.

Figure 47 shows the initial screen used to select aspects of generation and demand to vary in the scenario. The user marks the criteria for selection by clicking the left mouse button over the associated check box. In this example, 'Hydro Generation' is shown as a checked option, although as many options as required may be checked. The next screen, shown in Figure 48, requires the user to predict whether a source of generation or demand will increase over, or decrease below, the expected forecast and, finally, the screen shown in Figure 49 allows the user to estimate this increase/decrease as a percentage of the total forecast for the selected source of generation or demand.

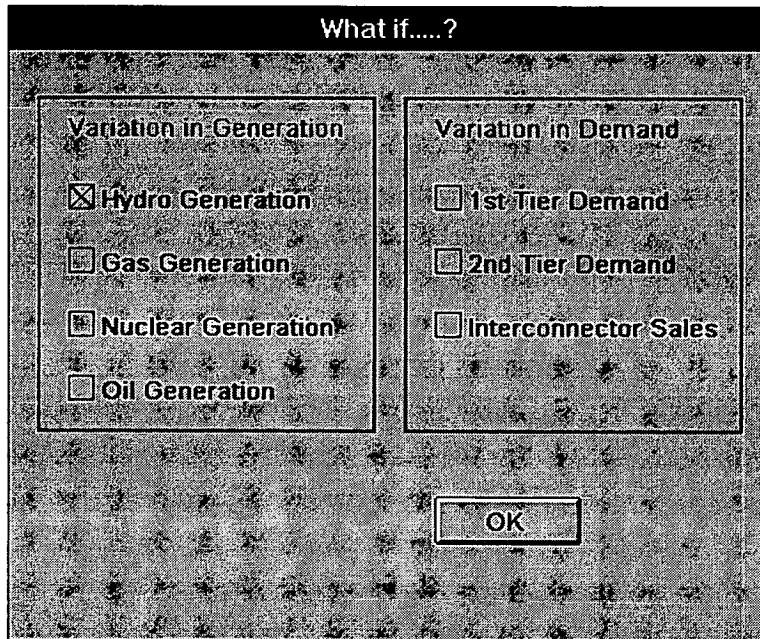


Figure 47. Criteria Selection Screen for Testing 'What if...?' Scenarios

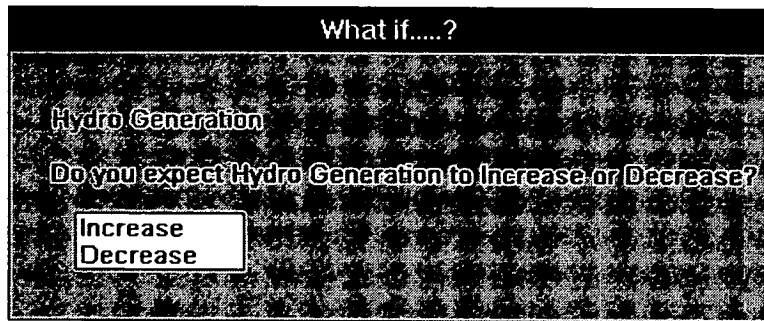


Figure 48. Input Screen for Variation in Supply or Demand

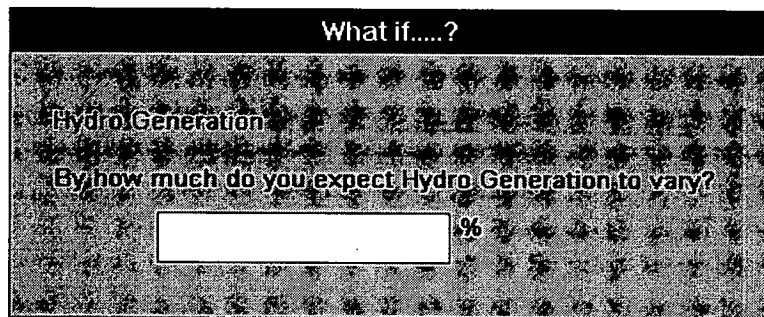


Figure 49. Input Screen for Magnitude of Variation in Supply or Demand

The percentage variation entered for each source selected by the user is translated into the quantity of coal required to meet the corresponding increase in coal-fired generation. This quantity is then added to the original figure for coal required and the purchase analysis is carried out using the new figure.

The decision recommendation which will be displayed on the screen immediately following the scenario will be ranked in terms of tender price alone. As discussed in Section 5.4.4.1. of this chapter, this method of differentiating between offers is of limited value and so it is recommended that further conditions are set, following the testing of a 'What If...?' scenario, using the 'New Conditions' or 'Existing Conditions' options.

#### 5.4.5.1. Reset Values

This option allows the user to reset the total quantity of coal recommended for purchase to the values determined using the original calculations (from user input) before any 'What If...?' scenarios were tested. The results displayed on screen are ranked by tender price.

## **5.5. Stage 6: Displaying Results of Decision Support Search**

Three techniques are employed in the display of the decision solution. These give the user a full analysis of each offer accepted by the Decision Support System of 'CoalMan'. The processes used are:

1. Main Solution Screen
2. Summary Screens
3. Graphs

Each of these screens are discussed in detail in the following sections.

### **5.5.1. Main Solution Screen**

The main solution screen displays the recommended decision proposed by the Decision Support System of 'CoalMan' from the offers received in response to the 'Invitation to Tender'. The solution is based on the conditions imposed on the purchase by the user in response to system limits. A typical recommendation is shown in Figure 50 below.

The screen is divided into 4 sections, inside which are displayed:

1. Recommended Coal Purchase
2. Period of Purchase
3. Conditions for Purchase
4. The Decision Solution

Each of these areas contains a hypertext region which means that pointing and clicking on the coloured words will automatically open the 'help' window and display an explanation about that region.

Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kTe		Period of Purchase April to June		Conditions for Purchase Full Economic Calculation			
LONGANNET				TENDER	FULL COST		
COMPANY	MINE	DELIVERY ROUTE	QUANTITY	(p/GJ)	(p/GJ)	GRADE	
Greystones Heating Marketing	Rigside Opencast	Road Longannet	30	109.0	109.7	B	
Scottish Coal	Westfield	Rail Westfield	90	110.0	111.0	A	
GSGA (Coal Marketing) Ltd	Unspec	Rail Roughcastle	4.5	115.0	116.0	B	
Russell Coal	Easter Fortissat	Road Longannet	18	119.0	120.3	B*	
Scottish Coal	Dalquhundy	Rail Ravenstruther	90	121.0	121.8	B	
Software Selection Above Line All Entries Below also meet Selection Criteria							
Rackwood Colliery	Hannabston	Road Longannet	65	125.0	126.0	B*	
Anglo	Aucheniber	Rail Meessend	8	125.0	126.2	B	
Andrew Maxwell	Rashiehill & Backahut	Rail Carstairs	10	126.0	126.3	B*	
I&H Brown Ltd	Cairncubie	Rail Meessend	33	128.9	129.6	A	
PD Fuels	Unspecified	Rail Ravenstruther	12	129.0	129.8	B*	
Coal Contractors Ltd	Roughcastle North	Rail Roughcastle	15	130.0	131.1	B*	
Software Selection Above Line All Entries Below also meet Selection Criteria							
COCKENZIE							
Scottish Coal	Blindwells	Rail Blindwells	24.9	116.0	116.8	B	
Software Selection Above Line All Entries Below also meet Selection Criteria							
CCCL	Blinkbonny	Road Cockenzie	60	122.0	123.0	C	

Figure 50. Main Solution Screen

### 5.5.1.1. Recommended Coal Purchase

This figure is the total amount of coal recommended for purchase during the period under investigation. The data source used in the calculation of this figure is selected by the user in the series of questions asked when the Decision Support System is initially run.

Also given in this box is a description of whether or not a coal purchase can be justified by the software. For instance, if the user selects 'User Input - All Sources' when asked to choose a data source, and the calculations reveal that demand over the duration of the contract will be less than the total supply from other sources, then additional coal will not be required at the coal station(s). However, flexibility in 'CoalMan' allows the user to view the purchase merit order as if a purchase was justified.

### **5.5.1.2. Period of Purchase**

This is the period of time selected by the user for investigation, from the beginning of the first month to the end of the second month shown. The selection of these months dictates the data used for the calculations and, once set, is fixed for that particular decision solution.

### **5.5.1.3. Conditions for Purchase**

The conditions displayed here are those dictated by the user with the menu item 'Best Solution'. A purchase solution calculated using the three simplified options; 'Tender Price', 'Full Economic Calculation' and 'Supplier Grade' will be displayed with the corresponding phrase appearing in the box. The constrained decision made using the 'User Defined Criteria' of 'New Conditions' or 'Existing Conditions' will show a detailed list of the limits imposed by the user. Displaying these limits allows the user to review the purchase solution in printed form and compare different solutions and scenarios with all of the purchase conditions available.

### **5.5.1.4. The Decision Solution**

The decision solution is displayed as a 'purchase merit order' in the form of two tables; one corresponding to each of Longannet and Cockenzie power stations. Every line in each table corresponds to an offer which has been accepted by the software to meet the conditions of the purchase. All of the offers that fit the criteria are displayed in descending order in the tables. If there are not enough offers to supply either of the stations then a warning message will appear on the screen before the decision screen is displayed.

Once the coal purchase requirement for each station has been filled, a line will appear with the words 'Software Selection Above Line. All Entries Below also meet Selection Criteria'. This signifies that all of the offers appearing above the line are recommended for purchase and will meet the total coal requirements calculated. All of the offers which appear below the line will also meet the criteria for the purchase, allowing the user to decide to take additional coal if required.

The table is composed of eight columns. The first two columns contain the recommended supplier and mine from which the coal will be purchased. The next two columns are the delivery route for the coal, including the transport method and, if being transported by rail,

the rail depot through which it will come. For road deliveries this column will display the destination of the coal. Columns 5-7 show details of the quantity of coal expected for delivery over the period (kte), the price of the coal as delivered to the station (p/GJ) and the cost of the fuel when emission costs are included (p/GJ). Column 8 displays the full supplier grade assigned to the supplier, as described in Section 5.4.4.3.

### 5.5.2. Summaries

Two summary screens are included with this software. The first is a full summary of the offers which have been recommended for purchase, 'Purchase Analysis', and the second shows a summary of the offers which have been rejected, 'Rejected Offers'. These screens summarise the purchase suggested such that the user can evaluate it as a whole

#### 5.5.2.1. Purchase Analysis

It is important for the user to be able to judge the effects that a package of purchases will have, rather than looking at each individually. This screen shows a full summary of the offers which have been accepted for purchase. Figure 51 below shows an example of a summary screen.

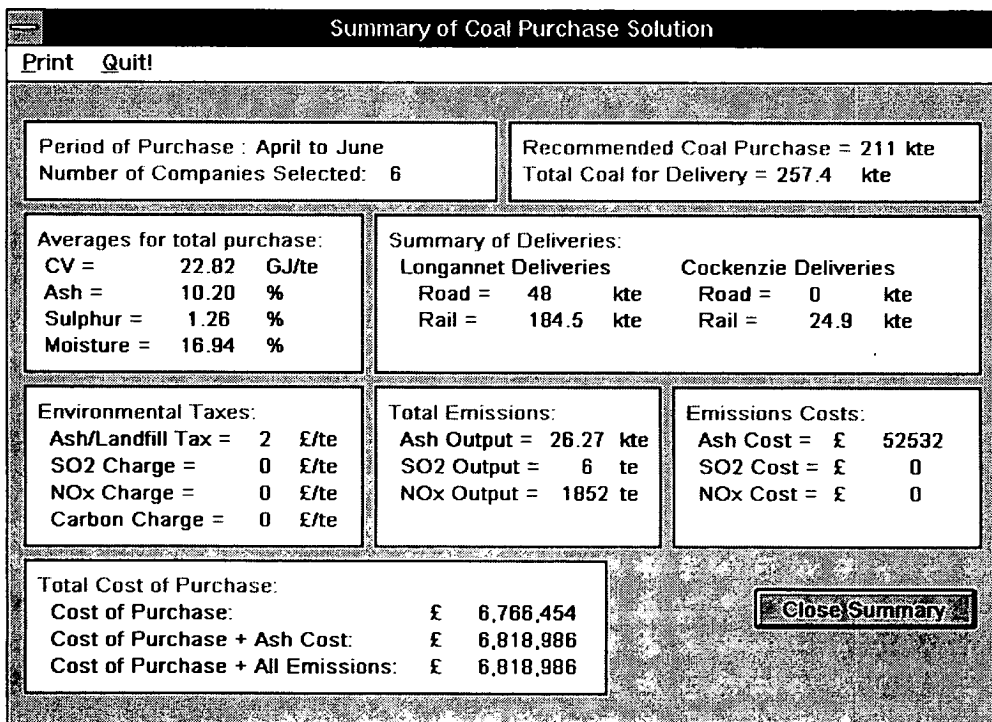


Figure 51. Summary of Coal Purchase Solution

At the top of the summary screen is displayed the Period of Purchase and the Recommended Coal Purchase, along with the Total Coal Delivery required to ensure that requirements will be covered. Also displayed is the number of contracts which are to be accepted if the recommended coal purchase is to be met.

Below this the averages of sulphur, moisture, nitrogen, ash and calorific value are given for the cumulative purchase. This allows the user to ensure that the total purchases will not exceed the limits set at the stations.

Next, a breakdown of the deliveries in terms of transportation to each station is shown. For both stations the total quantity of coal which will be delivered by road and rail as a result of the purchase is displayed.

A cumulative summary of all of the emissions is displayed. The first box has the taxes levied on the emissions, while the second box has the total emissions which combustion of the coal will yield. The costs of those emissions at the given tax rates are then shown.

In the bottom section the full cost of the purchase is displayed in three ways:

1. Offer Price (including transportation)
2. Offer Price + Cost of Ash Disposal
3. Offer Price + Cost of All Emissions

This summary allows the buyer to see how the cost of the purchase is affected when different constraints are placed on the purchase. It also shows the sector in which the cost is altered; from basic cost of the purchase, ash disposal or full emissions calculation.

#### **5.5.2.2. Rejected Offers**

This screen displays all offers which have been rejected and the conditions which were placed on the purchase which rejected them to allow the purchaser to analyse why different offers were rejected by the software and justify them with a fully auditable system. The screen is designed to look similar to the final decision screen to make the software consistent. Figure 52 shows a typical 'Rejected Offers' screen for the criteria shown in the 'Conditions for Purchase' box.

Retention of purchasing decisions and the information upon which these decisions were based assist in the development of a credible audit trail. That is, a clear reason for rejecting any offer. The user must be able to justify this at every stage of the process.

The screenshot shows a window titled "Rejected Offers" with a "Quit!" button in the top left. A message box in the center reads "Reasons for Rejection of Supplier Offers costing.ASH >= 12". Below this is a table with three columns: COMPANY, MINE, and DELIVERY ROUTE. The table contains the following data:

COMPANY	MINE	DELIVERY ROUTE
GSGA (Coal Marketing) Ltd	Unspec.	Rail
Russell Coal	Easter Fortiesal	Road
Anglo	Auchentiber	Rail
Rackwood Colliery	Hannahston	Road
Coal Contractors Ltd	Roughcastle North	Rail

Figure 52. Rejected Offers Screen

### 5.5.2.3. Graph Results

Selection of this option, which is accessed through the 'Summaries' menu option, displays a bar graph of the coal requirements calculated for each month in the period selected for investigation. A typical example is given in Figure 53. These coal requirements will be met through stock levels maintained at the station and deliveries made during the period of purchase. The user can use this graph to ensure that stock levels and proposed deliveries will be sufficient to meet the requirements for each month. If they do not the user can elect to take additional coal supply from one or more suppliers where available.



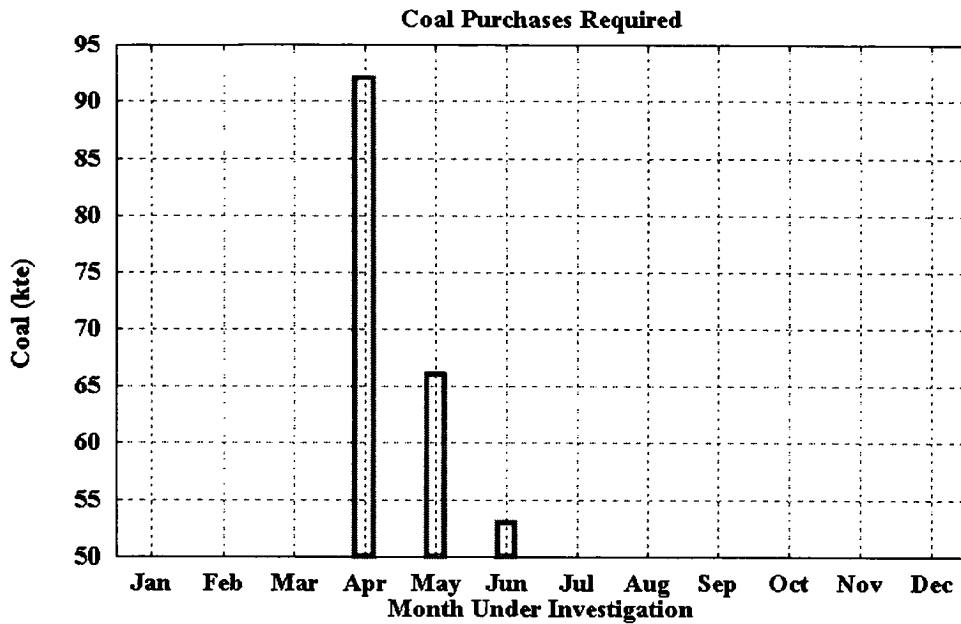


Figure 53. Graph of Coal Requirements Over Duration of Contract

## 5.6. Chapter Summary

In this chapter the Decision Support Software developed for coal purchase has been described. The 3-tier structure of 'CoalMan'; Data Input, Processing and Information Output has been given and then each section described in detail. Instructions about how 'CoalMan' is accessed and what the user should expect to see on the screen have been presented.

The first stage of the software is Data Input in which the user is required to input data concerning:

- Fuel Data (For Generation Sources),
- Load Data (For Electrical Demand),
- Coal Criteria,
- Emissions,
- Supplier Analysis

The second stage of 'CoalMan' is decision making which was described in a simplified form using a flowchart divided into stages. Those stages were then expanded on individually and a full description of the calculations used in 'CoalMan' were given to maintain transparency of the system at every stage. Finally, the methods employed by 'CoalMan' for information output were given, completing a full run of the software.

'CoalMan' is a highly flexible tool designed to aid the coal purchase decision process. Chapter 4 gave the standards which define a Decision Support System, all of which are satisfied by 'CoalMan'. Also given in Chapter 4 were the requirements of Scottish Hydro-Electric plc which were formulated through extensive discussion with members of the fuel purchasing team. The requirements of both the Decision Support System and Scottish Hydro-Electric have been successfully drawn together in the development of 'CoalMan'.

In comparison with using the traditional 'pen and paper' approach, 'CoalMan' significantly decreases the time spent analysing coal offers. It presents a fast, consistent analysis package which encompasses the broad range of influences on coal purchase. 'CoalMan' offers the user a number of scenario options which can be combined to apply complex constraints to the purchasing decision. This approach to solving the complex problems associated with medium-term coal purchase gives the user flexibility to explore combinations of purchases which would previously have been too time consuming to investigate.

'CoalMan' has been developed with 'ease of use' at its core. It is a user friendly package, designed to be learned quickly and effectively. It includes help screens at every stage, giving access to information about the scenarios and functions available within 'CoalMan'.

'CoalMan' ranks offers such that the requirements of the purchase are met while taking into account the quantity, quality and delivery criteria selected by the user. It also ensures that external influences, such as emissions limits and transport constraints, are included in the analysis of each offer. Results are displayed in a clear format, with a full analysis of the package of offers recommended. This allows the user to quickly determine the acceptability of the solution suggestion and to easily compare the results of testing different scenarios.

In Chapter 6 a selection of scenarios are presented to represent some of the options available to the user in the development of a coal purchase solution suggestion.

## CHAPTER 6

### EVALUATION AND EXAMPLE RESULTS

The Decision Support System developed for this project, 'CoalMan', was introduced in Chapter 5. In this chapter example results from running the software are presented and the differences between the outcomes of the various scenarios tested are described. The implications of each 'purchase merit order', recommended for each scenario, are described in detail.

For each of the five examples the screens showing the 'purchase merit order' results and the full purchase summary are given and the outcome analysed for compliance with the initial specification.

#### 6.1. Purchase Criteria

In Chapter 5 the options available to the user for setting the purchasing criteria were given. Here five examples are used to illustrate some of the options which may be chosen, but they are not exhaustive. The five examples presented are:

1. Full Economic Calculation
2. Supplier Grade
3. Constrained on Sulphur Content
4. Complex Constraints
5. Increasing SO<sub>2</sub> Emissions Charges

The coal offers which make up the database used in these scenarios are given in Figures 31 and 32 in Chapter 5. Chapter 2 introduced specification limits which each purchase must adhere to if the coal is to be accepted at the Power Station. These limits are given in Table 22 and will be referred to later in this chapter when results are presented for analysis.

To allow comparison the same purchasing problem is solved, but in each case the criteria applied to the purchase are changed. The data input presented here is for a 3 month period (April - June) from Scottish Hydro-Electric's 'Generation Plan'. The purchase recommendation is for 211 kte of coal to be delivered over the period of the purchase.

	Accepted at Station (per delivery)	Limits on Average of Deliveries
Calorific Value	21.4 GJ/Te min	21.4 GJ/Te min
Sulphur Content	2% max	<1.1%
Moisture Content	20% max	<17%
Inerts (Moisture + Ash)	28% max	28% max

Table 22. Specification Requirements at Longannet and Cockenzie

## 6.2. Full Economic Calculation

Supplier selection in terms of 'Full Economic Calculation' was first addressed in Section 5.4.4.2. of Chapter 5. This calculation includes the cost of the fuel, its transport to the power station and the cost of the emissions produced in the combustion process.

Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kte		Period of Purchase April to June		Conditions for Purchase Full Economic Calculation			
LONGANNET				TENDER	FULL COST		
COMPANY	MINE	DELIVERY ROUTE		QUANTITY	(p/GJ)	(p/GJ)	GRADE
Greystone Heating Marketing	Rigside Opencast	Road	Longannet	30	109.00	109.70	B
Scottish Coal	Westfield	Rail	Westfield	90	110.00	111.00	A
GSCA (Coal Marketing) Ltd	Unspec	Rail	Roughcastle	4.5	115.00	116.00	B
Russell Coal	Easter Fortissat	Road	Longannet	18	119.00	120.30	B*
Scottish Coal	Dalquhandy	Rail	Ravenstruther	90	121.00	121.80	B
Software Selection Above Line: All Entries Below also meet Selection Criteria							
Rackwood Colliery	Hannahston	Road	Longannet	65	125.0	126.0	B*
Anglo	Auchentiber	Rail	Mossend	8	125.0	126.2	B
Andrew Maxwell	Rachihill & Backehol	Rail	Carstairs	10	126.0	126.3	B*
I&H Brown Ltd	Cairncubie	Rail	Mossend	33	128.9	129.6	A
PD Fuels	Unspecified	Rail	Ravenstruther	12	129.0	129.8	B*
Coal Contractors Ltd	Roughcastle North	Rail	Roughcastle	15	130.0	131.1	B*
COCKENZIE							
Scottish Coal	Blindwells	Rail	Blindwells	24.9	116.00	116.80	B
Software Selection Above Line: All Entries Below also meet Selection Criteria							
CCCL	Blinkbonny	Road	Cockenzie	60	122.0	123.0	C

Figure 54. Full Economic Calculation: Results

It can be seen from Figure 54 that a total of thirteen offers meet the purchase selection criteria, but only the six offers above the line are recommended to meet the total purchase requirements. It should be noted that the total quantity recommended for purchase is greater than the requirement. This is because the software continues to include offers in the table until the requirements of the purchase are met, even if this means that the recommendation is exceeded by a great deal. In this case the user may choose not to include some of the offers recommended if a subset of the recommendation will meet the requirement.

One of the highest graded suppliers, I & H Brown, has been placed below the cut-off line because of its high price. The high quality and service, and the accompanying benefits associated with purchasing from a reliable supplier, are not reflected in this purchase suggestion.

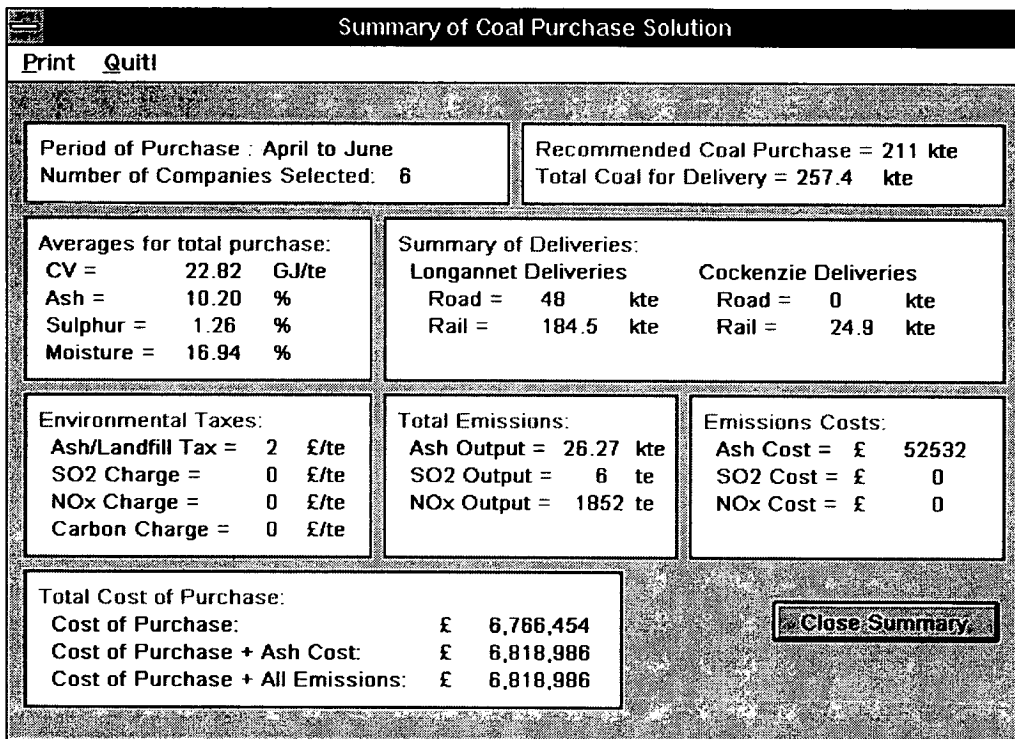


Figure 55. Full Economic Calculation: Summary

The summary screen for this solution is shown in Figure 55. It can be seen from this that the calorific value is higher than the minimum energy content required and the moisture level is within the 17% maximum. However, the sulphur content exceeds the 1.1% tolerance for stock held at the station which takes the total purchase outwith the

specification limits. This is because of the high sulphur content of Scottish Coal's 'Westfield' offer, of which 90kte is included in the recommended package.

The cost of this purchase, including ash cost, is calculated as £6,818,986 which is equivalent to approximately £26,491 per kilotonne. This figure will be used as a reference in the following sections of this chapter.

### 6.3. Supplier Grade

As discussed in Section 3.7. of Chapter 3 'Supplier Grade' refers to the method of supplier assessment developed in the course of this project. The supplier is graded on three characteristics; 'Delivery Reliability', 'Quality of Coal Supplied' and 'Handling of Queries'. The total grade is given as a function of the three individual grades.

Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kte		Period of Purchase April to June		Conditions for Purchase Supplier Grading Only			
LONGANNET COMPANY	MINE	DELIVERY ROUTE		QUANTITY	TENDER (p/GJ)	FULL COST (p/GJ)	GRADE
Scottish Coal	Westfield	Rail	Westfield	90	110.00	111.00	A
I&H Brown Ltd	Cairncubie	Rail	Mossend	33	128.90	129.60	A
Scottish Coal	Dalquhundy	Rail	Ravenstruther	90	121.00	121.80	B
Software Selection Above Line All Entries Below also meet Selection Criteria							
GSGA (Coal Marketing) Ltd	Unspec	Rail	Roughcastle	10	115.0	116.0	B
Greystones Heating/Marketing	Rigside Opencast	Road	Longannet	30	109.0	109.7	B
Anglo	Auchentiber	Rail	Mossend	8	125.0	126.2	B
Russell Coal	Easter Fortissat	Road	Longannet	20	119.0	120.3	B*
Rackwood Colliery	Hannahaton	Road	Longannet	65	125.0	126.0	B*
Andrew Maxwell	Rashiehill & Backshot	Rail	Carstairs	10	126.0	126.3	B*
RD Fuels	Unspecified	Rail	Ravenstruther	12	129.0	129.8	B*
Coal Contractors Ltd	Roughcastle North	Rail	Roughcastle	15	130.0	131.1	B*
Software Selection Above Line All Entries Below also meet Selection Criteria							
COCKENZIE Scottish Coal	Blindwells	Rail	Blindwells	24.9	115.00	116.80	B
Software Selection Above Line All Entries Below also meet Selection Criteria							
CCCL	Blinkbonny	Road	Cockenzie	60	122.0	123.0	C

Figure 56. Supplier Grading: Results

Here the software employs the Supplier Grade to rank the coal offers so that the suppliers which are recommended are those which have the best performance record in previous

purchases. Using this method to sort the offers gives the results shown in Figure 56. In this scenario four offers are recommended for purchase to meet demand, giving a total purchase of 237.9 kte.

Of the three offers appearing at the top of the 'Longannet' table two are offers which were selected in the previous scenario; Scottish Coal's Westfield and Dalquhandy offers. The third, which lies second in the purchase merit order, is from I & H Brown's Cairncubie mine and has a Supplier Grade 'A'. Since its high cost is not taken into account in this scenario it has moved up the table from 9th place to 2nd.

The offer which has the lowest price has dropped below the 'purchase recommendation' line in the solution to 5th place. Even amongst the other Grade 'B' suppliers it is a low scoring 3rd place and so, under these selection criteria, is not deemed to be a good purchase. However, as all offers which fit the purchase criteria appear on the screen the user may elect to make a purchase from that supplier if a need for additional coal is recognised and the 'cut-off' point moves in the table.

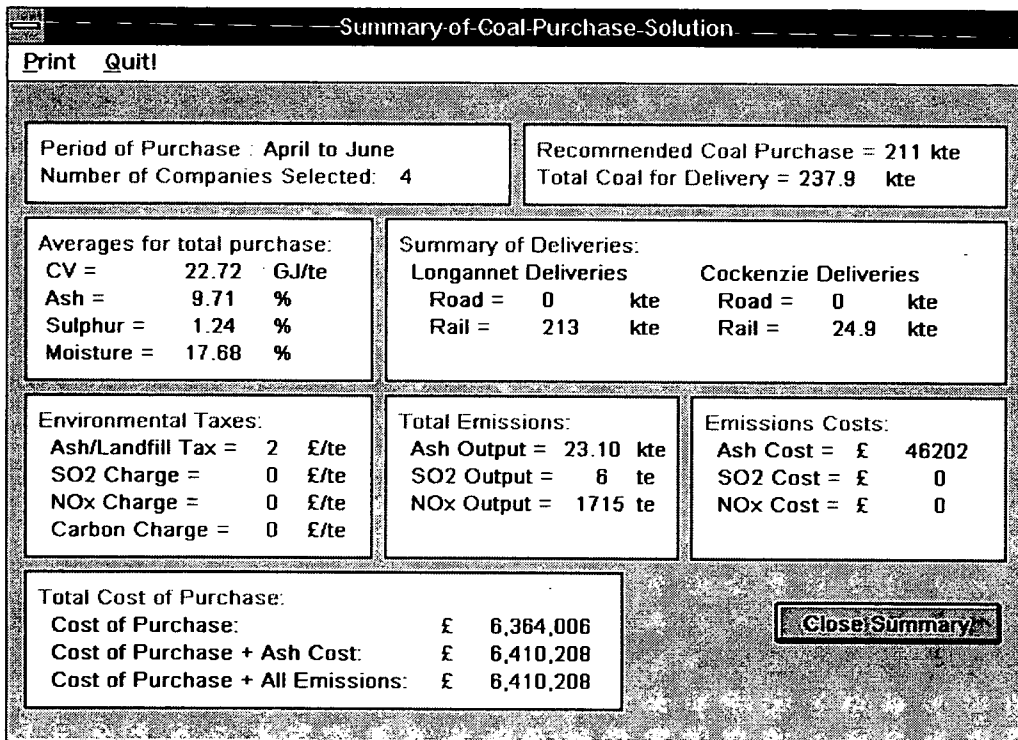


Figure 57. Supplier Grading: Summary

The summary screen for ranking offers by 'Supplier Grade' is given in Figure 57. Again the total purchase selection exceeds the limits for sulphur content and moisture content is now too high. This purchase would not be acceptable. Therefore, it is necessary to impose further criteria to limit the sulphur content of the package.

The cost of the purchase package is £6,410,208, approximately equivalent to £26,945 per kilotonne. This represents a rise of £450 per kilotonne which means that a package of suppliers who are perceived to be 'best' is less competitively priced than one based on price alone.

This indicates that it is worth an extra £450 per kilotonne to avoid suppliers who have a history of poor performance. Consider that in Section 3.8.3. of Chapter 3 the additional cost of transferring missed road deliveries onto rail was calculated to be £5,040 per day for 2100 kilotonnes, equivalent to approximately £2,400 per kilotonne, and it is clear that this purchase recommendation offers reduced perceived risk associated with low graded suppliers at a cost of £450/kilotonne.

#### **6.4. Constrained on Sulphur Content**

In both of the previous scenarios the results of the purchase suggestion have not been acceptable because they did not satisfy the limits for sulphur content. In this example the results of imposing restrictions on the sulphur content are studied.

From Table 22 it can be seen that each individual offer may have a sulphur content of up to 2%. To meet the upper limit of 1.1% for the overall purchase the maximum for the sulphur criterion is set to 1.5%. This allows the software to find a purchase package whose average sulphur content is less than 1.1% while allowing individual purchases to have a sulphur content which falls outwith this limit.

Fixing the sulphur content of the purchases to a maximum of 1.5% reduces the number of acceptable offers from thirteen to twelve. The offer which exceeds the limit and, therefore, does not appear on the screen is the one from Scottish Coal's Westfield Mine which has a sulphur content of 1.8% (see Chapter 5, Figure 32). Nine companies now fall above the 'purchase recommendation' line. This is because the offer from Westfield was for a large quantity (90 kte) which is being replaced by a number of offers for smaller amounts of coal.



The offers that meet the sulphur criteria are ranked in order of price, which means that the offer from Greystone Heating Marketing is at the top of the table. Again, this means that 'Supplier Grade' has no input into the decision suggestion.

Three of the offers have a 'B\*' grading, which means that the companies have no purchase history upon which a grade can be based. This means that if the buyer cannot get sufficient information about the company and its operations a purchase from that source will carry substantial perceived business risk (see Chapter 3). Untested suppliers about whose operation the buyer has some knowledge will therefore be more likely to be accepted since the buyer has information upon which to judge the future performance of the supplier.

Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kte		Period of Purchase April to June		Conditions for Purchase Sulphur <= 1.5			
LONGANNET COMPANY	MINE	DELIVERY ROUTE		QUANTITY	(p/GJ)	FULL COST (p/GJ)	GRADE
Greystone Heating Marketing	Ragside Opencast	Road	Longannet	30	109.00	109.70	B
GSSA (Coal Marketing) Ltd	Unspec	Rail	Roughcastle	4.5	115.00	116.00	B
Russell Coal	Easter Fortissat	Road	Longannet	18	119.00	120.30	B*
Scottish Coal	Dalquharry	Rail	Ravenstruther	90	121.00	121.80	B
Anglo	Aucheniber	Rail	Mesaend	7.56	125.00	126.20	B
Rackwood Colliery	Hannahston	Road	Longannet	30	125.00	126.00	B*
Andrew Maxwell	Rashiehill & Backshot	Rail	Carstairs	9.6	126.00	126.30	B*
I&H Brown Ltd	Cairncubie	Rail	Mesaend	33	128.90	129.60	A
Software Selection Above Line All Entries Below also meet Selection Criteria							
PD Fuel	Unspecified	Rail	Ravenstruther	12	129.0	129.8	B*
Coal Contractors Ltd	Roughcastle North	Rail	Roughcastle	15	130.0	131.1	B*
COCKENZIE							
Scottish Coal	Blindwells	Rail	Blindwells	24.9	116.00	116.80	B
Software Selection Above Line All Entries Below also meet Selection Criteria							
CCCL	Blinkbonny	Road	Cockenzie	60	122.0	123.0	C

Figure 58. Sulphur Constrained: Results

The summary screen for this purchase suggestion is given in Figure 59. It shows that for the full purchase the sulphur content is now 0.9%, a figure which is well below the 1.1% maximum limit for cumulative purchases. Moisture and calorific value are also within the limits of the purchase recommendation and so the total purchase would be acceptable on specification.

The cost of ash disposal is £49,342 which represents a saving of £3190 when compared with the purchase recommendation given in the first example where only price was taken into account.

The cost per kilotonne when compared with the 'Full Economic Calculation' has increased by £2,600. One of the lowest cost offers, which came from Scottish Coal's 'Westfield' site, has been rejected because of its high sulphur content, but the price of its removal amounts to an increase of £234,000 for the total cost of the purchase.

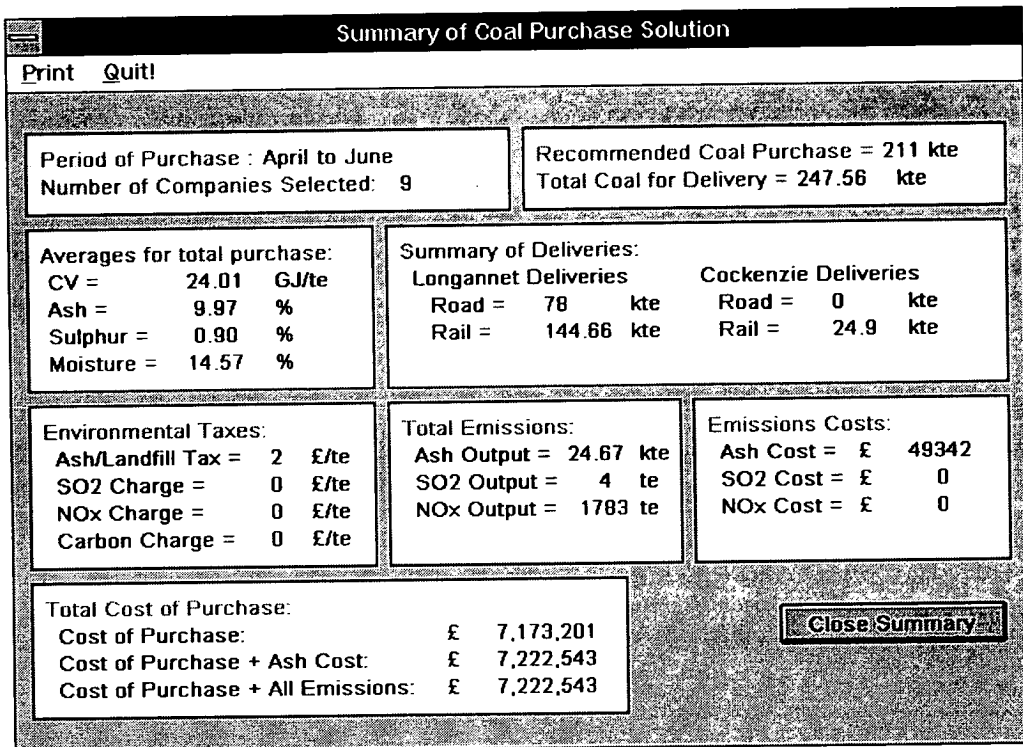


Figure 59. Sulphur Constrained: Summary

## 6.5. Complex Constraints

This example shows that the user can combine, not only two technical specifications, but may also combine a technical specification with the company's experience with a supplier. Here the constraints are used to reject offers with a sulphur content of more than 1.5%, as well as removing all suppliers who have been untried. The limits mean that there are not enough offers in the database to satisfy the requirements of the purchase and a window is displayed on the screen warning the user. The window is shown in Figure 60.

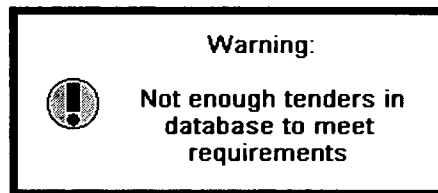


Figure 60. Warning Window

Although there are not enough offers which fulfil the purchase criteria available in the database the software displays those that do meet the requirements. The results are shown in Figure 61. Since there will not be enough coal purchased through this selection to meet demand the buyer will need to find alternative sources of the fuel. Here, three options are available to the user:

1. Relax criteria to include untried suppliers.
2. Approach selected suppliers for additional coal supply.
3. Approach known suppliers who have not responded to the 'Invitation to Tender' for additional coal supplies.

The best solution for the Utility will depend on the circumstances under which the purchase is being made and will be at the discretion of the user.

The summary screen for this process is shown in Figure 62. From it the total specification of the purchase merit order can be seen to fall within the quality limits of the stations and is therefore acceptable. Any additional purchases which the user makes to meet demand must therefore not take the total purchase over the acceptable boundaries.

Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kte			Period of Purchase April to June		Conditions for Purchase Sulphur <= 1.5 , Delivery Grade A - C		
LONGANNET				TENDER		FULL COST	
COMPANY	MINE	DELIVERY ROUTE		QUANTITY	(p/GJ)	(p/GJ)	GRADE
Grayston Heating Marketing	Rigside Opencast	Road	Longannet	30	109.00	109.70	B
GSGA (Coal Marketing) Ltd	Unspec	Rail	Roughcastle	4.5	115.00	116.00	B
Scottish Coal	Dalquhandy	Rail	Ravenstruther	90	121.00	121.80	B
Anglo	Auchentiber	Rail	Mossend	7.56	125.00	126.20	B
I&H Brown Ltd	Cairncubie	Rail	Mossend	33	128.90	128.60	A
Software Selection Above Line All Entries Below also meet Selection Criteria							
COCKENZIE							
Scottish Coal	Blindwalls	Rail	Blindwalls	24.9	116.00	116.80	B
Software Selection Above Line All Entries Below also meet Selection Criteria							
CCCL							
	Blinkbonny	Road	Cockenzie	60	122.0	123.0	C

Figure 61. Complex Constraints: Results

Summary of Coal Purchase Solution		
Print Quit!		
Period of Purchase : April to June Number of Companies Selected: 6		Recommended Coal Purchase = 211 kte Total Coal for Delivery = 189.96 kte
<b>Averages for total purchase:</b> CV = 23.78 GJ/te Ash = 9.47 % Sulphur = 0.90 % Moisture = 15.78 %		<b>Summary of Deliveries:</b> Longannet Deliveries Road = 30 kte Rail = 135.06 kte Cockenzie Deliveries Road = 0 kte Rail = 24.9 kte
<b>Environmental Taxes:</b> Ash/Landfill Tax = 2 £/te SO2 Charge = 0 £/te NOx Charge = 0 £/te Carbon Charge = 0 £/te	<b>Total Emissions:</b> Ash Output = 17.99 kte SO2 Output = 3 te NOx Output = 1380 te	<b>Emissions Costs:</b> Ash Cost = £ 35974 SO2 Cost = £ 0 NOx Cost = £ 0
<b>Total Cost of Purchase:</b> Cost of Purchase: £ 5,414,989 Cost of Purchase + Ash Cost: £ 5,450,963 Cost of Purchase + All Emissions: £ 5,450,963		<input type="button" value="Close Summary"/>

Figure 62. Complex Constraints: Summary

## 6.6. Increasing SO<sub>2</sub> Emissions Charges

Three examples are given in this section of the effects of increasing SO<sub>2</sub> emissions charges on the coal purchase suggested solution. The charges applied here are given in UK Pounds per metric tonne of SO<sub>2</sub> emitted (£/te) and are as follows:

1. £150/te SO<sub>2</sub> emitted.
2. £300/te SO<sub>2</sub> emitted.
3. £1000/te SO<sub>2</sub> emitted.

### 6.6.1. Charge of £150/te SO<sub>2</sub> emitted.

In this example the charge levied on emissions of SO<sub>2</sub> is £150/te emitted. Figure 63 shows the purchase suggestion displayed when this charge is included in the calculations, and the offers are ranked in order of 'full economic cost'.

Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kte		Period of Purchase April to June		Conditions for Purchase Full Economic Calculation			
LONGANNET				TENDER	FULL COST		
COMPANY	MINE	DELIVERY ROUTE		QUANTITY	(p/GJ)	(p/GJ)	GRADE
Graystone Heating Marketing	Rigside Opencast	Road	Longannet	30	109.00	120.20	B
GSGA (Coal Marketing) Ltd	Unspec	Rail	Roughcastle	4.5	115.00	127.40	B
Reesell Coal	Easter Fortissat	Road	Longannet	18	119.00	129.00	B*
Scottish Coal	Dalquhandy	Rail	Ravenstruther	90	121.00	133.90	B
Scottish Coal	Westfield	Rail	Westfield	90	110.00	135.10	A
Software Selection Above Line All Entries Below also meet Selection Criteria							
I&H Brown Ltd	Cairncubie	Rail	Moessend	33	128.9	135.4	A
Aegio	Auchentiber	Rail	Moessend	8	125.0	135.7	B
Andrew Maxwell	Rashishill & Backshot	Rail	Carstairs	10	126.0	135.8	B*
Rackwood Colliery	Hannahaton	Road	Longannet	65	125.0	137.1	B*
PD Fuels	Unspecified	Rail	Ravenstruther	12	129.0	141.9	B*
Coal Contractors Ltd	Roughcastle North	Rail	Roughcastle	15	130.0	143.0	B*
Software Selection Above Line All Entries Below also meet Selection Criteria							
COCKENZIE							
Scottish Coal	Blindwells	Rail	Blindwells	24.9	116.00	130.70	B
Software Selection Above Line All Entries Below also meet Selection Criteria							
CCCL	Blinkbonny	Road	Cockenzie	60	122.0	135.6	C

Figure 63. Charge of £150/te SO<sub>2</sub> Emitted: Results

When compared with the order of suppliers in Section 6.2., where no charge was levied on SO<sub>2</sub>, it is demonstrated that the top five purchases recommended for delivery to Longannet

Power Station have stayed the same, however, the ranked order has changed. Scottish Coal's 'Westfield' offer, which came second place in the reference solution, is now placed fifth in the rank, while Greystone Heating Marketing has maintained its position at the top of the table. Only one of the suppliers is untried (B\* Graded) and contributes 7% of the total purchase.

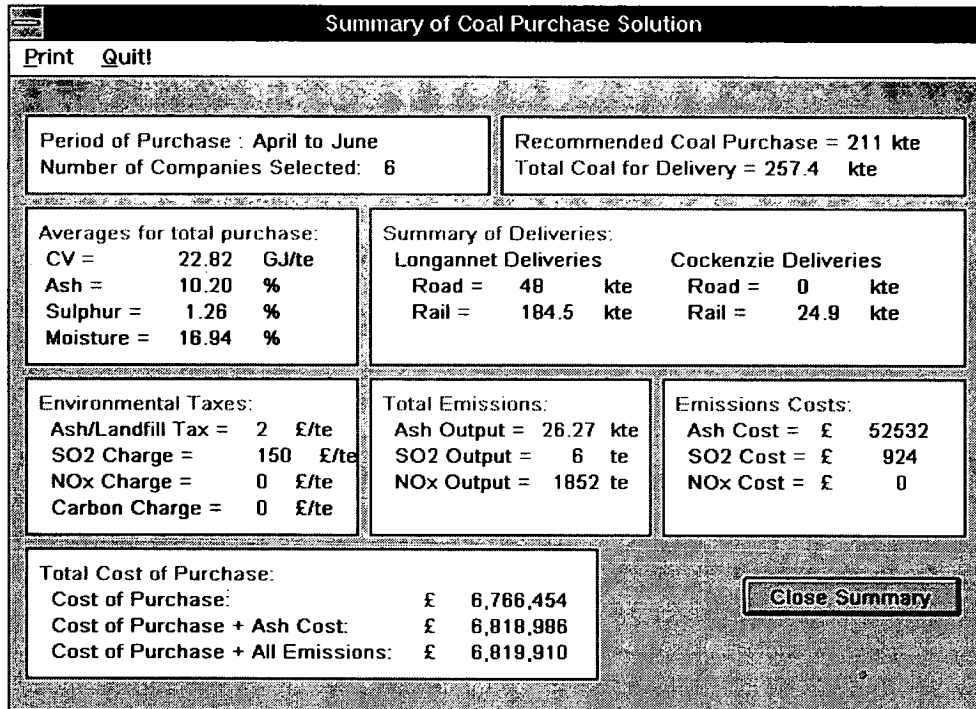


Figure 64. Charge of £150/te SO<sub>2</sub> Emitted: Summary

Figure 64 shows the summary of the purchase recommendation. Here, the cost per kilotonne is £26,495, an increase of approximately £100/kte on the original 'full economic calculation' presented in Section 6.2. However, the average sulphur content falls outwith the limit, so this purchase would not be accepted at the Power Station.

### 6.6.2. Charge of £300/te SO<sub>2</sub> emitted.

In this example the charge levied is set at £300/te SO<sub>2</sub> emitted, approximately equivalent to the cost of a tradeable emissions permit in the USA. Figure 65 shows the purchase suggestion screen, with all offers ranked in order of 'full cost', which includes the SO<sub>2</sub> levy.

Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kte		Period of Purchase April to June		Conditions for Purchase Full Economic Calculation			
LONGANNET	COMPANY	MINE	DELIVERY ROUTE	QUANTITY	TENDER (p/GJ)	FULL COST (p/GJ)	GRADE
	Greystone Heating Marketing	Rigside Opencast	Road Longannet	30	109.00	130.60	B
	Russell Coal	Easter Fortiesat	Road Longannet	18	119.00	137.60	B*
	GSGA (Coal Marketing) Ltd	Unspec	Rail Roughcastle	4.5	115.00	138.80	B
	I&H Brown Ltd	Cairncubie	Rail Mossend	33	128.90	141.20	A
	Anglo	Auchentiber	Rail Mossend	7.56	125.00	145.20	B
	Andrew Maxwell	Rashiehill & Backshot	Rail Carstairs	9.6	126.00	145.40	B*
	Scottish Coal	Dalquharry	Rail Ravenstruther	90	121.00	146.00	B
	Rackwood Colliery	Hannahston	Road Longannet	30	125.00	148.10	B*
Software Selection Above Line. All Entries Below also meet Selection Criteria							
	PD Fuels	Unspecified	Rail Ravenstruther	12	129.0	154.0	B*
	Coal Contractors Ltd	Roughcastle North	Rail Roughcastle	15	130.0	154.9	B*
	Scottish Coal	Westfield	Rail Westfield	100	110.0	159.2	A
COCKENZIE							
	Scottish Coal	Blindwells	Rail Blindwells	24.9	116.00	144.60	B
Software Selection Above Line. All Entries Below also meet Selection Criteria							
	CCCL	Binkbonny	Road Cockenzie	60	122.0	148.2	C

Figure 65. Charge of £300/te SO<sub>2</sub> Emitted: Results

Scottish Coal's 'Westfield' offer has dropped to the bottom of the table, where it was in second place without the levy, and this shift has meant that four suppliers who were not originally accepted have moved above the line, taking the number of purchases recommended for Longannet Power Station up to 8.

Greystone Heating Marketing are still at the top of the purchase suggestion, however, I&H Brown have moved from their original 9th place position to 4th place in the ranked order, suggesting that the low sulphur content of the coal on offer works to the company's advantage. The purchase now includes three untried suppliers (B\* Graded) which account for 23% of the total coal purchase.

Figure 66 shows the summary of the purchase recommendation. The average sulphur content has dropped below the 1.1% limit which makes this an acceptable solution since all of the quality parameter limits are met. The average calorific value has also increased from 22.82 GJ/te to 24.01 GJ/te.

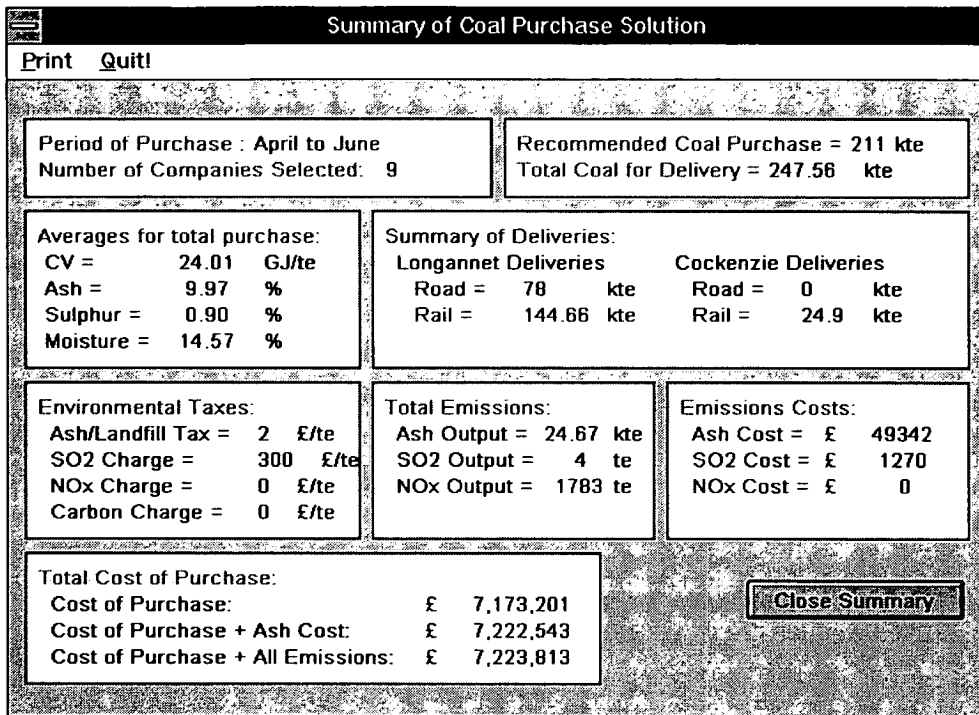


Figure 66. Charge of £300/te SO<sub>2</sub> Emitted: Summary

The cost per kilotonne of the coal has risen by £2,689 to £29,180 due to the increase in cost of the SO<sub>2</sub> emissions. The more expensive coal offers have become the more economical option for the buyer.

### 6.6.3. Charge of £1000/te SO<sub>2</sub> emitted.

In this final example the levy applied to emissions of SO<sub>2</sub> is set at £1000/te. This charge is representative of the fine levied in the USA for any emissions over the limit of the Generator's permits (See Section 5.3.4.1 of Chapter 5).

Figure 67 shows the ranked order of the offers. The eight suppliers who appeared at the top of the rank for Longannet Power Station in the last example are still at the top, however, in this case I&H Brown are now at the top and Greystone Heating Marketing have dropped to third position.

The suppliers which are selected for supply to Cockenzie Power Station have, however, changed order and the offer from the 'Grade C' supplier, CCCL, is now selected for purchase.



Coal Purchase Decision Support System							
File Data Source Best Solution Summaries Quit! Help!							
A decision to buy coal can be justified Recommended Coal Purchase = 211 kte			Period of Purchase April to June		Conditions for Purchase Full Economic Calculation		
LONGANNET COMPANY	MINE	DELIVERY ROUTE	TENDER	QUANTITY	(p/GJ)	FULL COST (p/GJ)	GRADE
I&H Brown Ltd	Cairncubie	Rail Mossend		33	128.90	168.40	A
Russell Coal	Eastar Fortiesat	Road Longannet		18	119.00	178.10	B*
Graystone Heating Marketing	Rigside Opencast	Road Longannet		30	109.00	179.50	B
Anglo	Auchaniber	Rail Mossend		7.56	125.00	189.40	B*
Andrew Maxwell	Rashiehill & Beckahol	Rail Carstairs		9.6	126.00	199.90	B*
GSSA (Coal Marketing) Ltd	Unspec	Rail Roughcastle		4.5	115.00	192.00	B*
Rackwood Colliery	Hannahaton	Road Longannet		30	126.00	199.70	B*
Scottish Coal	Dalquhandy	Rail Ravenstruther		90	121.00	202.50	B
Software Selection Above Line All Entries Below also meet Selection Criteria							
Coal Contractors Ltd	Roughcastle North	Rail Roughcastle		15	130.0	210.3	B*
FD Fuels	Unspecified	Rail Ravenstruther		12	129.0	210.5	B*
Scottish Coal	Westfield	Rail Westfield		100	110.0	271.7	A
COCKENZIE							
CCCL	Blinkbonny	Road Cockenzie		24	122.00	207.10	C
Software Selection Above Line All Entries Below also meet Selection Criteria							
Scottish Coal	Blindwells	Rail Blindwells		60	116.0	209.4	B

Figure 67. Charge of £1000/te SO<sub>2</sub> Emitted: Results

The summary of the solution recommendation is shown in Figure 68. Again, the sulphur content of the purchase has dropped further to 0.89% and all of the other quality parameters are still within the limits given in Table 22, making the purchase acceptable at the Power Station.

The cost per kilotonne has increased to £29,342, a step of £162 between this and the example given for an SO<sub>2</sub> emissions levy of £300/te. Price increases are therefore not proportional to the sum levied on the emissions. However, the price of each fuel (in p/GJ) is greatly affected. The sulphur content dictates the supplier's position in the table, and the prospects for selection. It has been demonstrated that companies which appear to be the lowest cost option when compared on offer price can become high cost when the sulphur content of the coal is taxed.

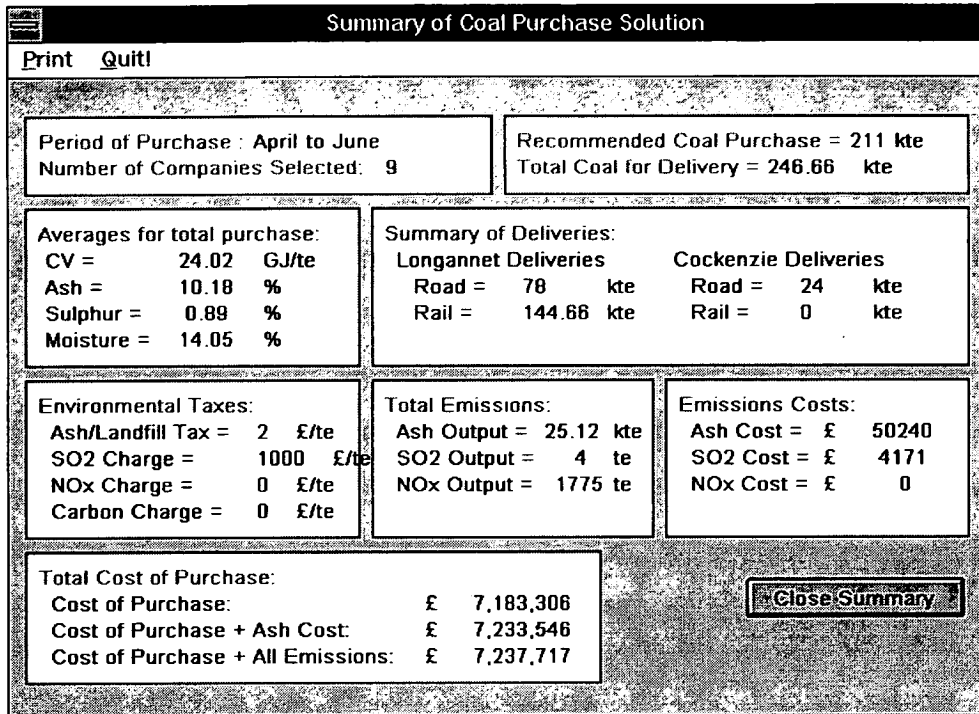


Figure 68. Charge of £1000/te SO<sub>2</sub> Emitted: Summary

## 6.7. Chapter Summary

Of the many variations on the constraints which the user can apply to the purchase using the available options a representative sample of five have been presented. They show the evolution of a purchase decision as the user must modify the criteria to ensure that the selected offers meet the specification limits of the purchase.

The examples have shown that there are occasions when the criteria applied to the purchase are strict enough that there is not an adequate number of offers available in the database to meet the quantity required to satisfy coal demand. In this case the user may be forced either to relax the criteria in some way, or to seek other sources of coal, while still endeavouring to meet the purchase specification criteria. As stated in Chapter 4, 'CoalMan' is not designed to give a final, absolute solution to the problem of coal purchase. Instead the user must expect a structured solution suggestion which can be used to develop the final coal purchase decision.

The advantages of 'CoalMan' include the speed at which the criteria may be tested and compared, reducing the time which the coal buyer must spend on the task of supplier selection and allocation.

'CoalMan' offers the user seven constraints from which to construct the limits placed on the purchase. The example in Section 6.5. uses only two criteria, although all of the seven available criteria may be used simultaneously to apply complex constraints to the purchase. 'CoalMan' demonstrates that it is possible to combine technical specifications with the Generator's experience of a supplier.

'CoalMan' allows the user to test the validity of the coal offers received in response to the invitation to tender for coal supply and, for a given purchasing problem, can be used to confirm, or otherwise, decisions reached on the basis of traditional 'engineering judgement'. A recommendation close to that which has been identified will give the purchaser confidence in his own judgement, while a different result will add depth to the range of solutions which can be compared before making a purchase.

## CHAPTER 7

### DISCUSSION AND CONCLUSIONS

Coal purchase is worth millions of pounds annually to Generators who rely on it for generation of electrical energy. In the financial year 1994/95, 15% of the electricity traded by Scottish Hydro-Electric came from coal-fired generation. The fuel purchased to meet this requirement cost in excess of £35 million and, given that Scottish Hydro-Electric supply electricity to only 3% of the population of the UK, this indicates the scale of coal-purchase for the larger companies in the country.

#### 7.1. Fuel Purchase

The three major influences on coal purchase have been the privatisation of the Electricity Supply Industry in 1990, the ensuing 'dash-for-gas' and privatisation of the National Coal Board in 1994. These have affected the position of coal-fired generation in the merit-order, making it increasingly mid-merit as gas-fired stations take the base-load position. The effects of these changes on coal contract arrangements are covered in the next sections.

##### 7.1.1. Privatisation

Before privatisation of the Electricity Supply Industry and the National Coal Board, successive Governments ensured a market for the coal produced by the National Coal Board by prohibiting the Electricity Supply Industry from purchasing foreign coal. For decades the Electricity Supply Industry was hostage to the fortunes of the coal industry. In the 1960s the CEGB burned around 65 million tonnes of coal every year, fuel for approximately 84% of its generating capacity which accounted for more than one third of the coal industry's total output<sup>138</sup>.

When the Electricity Supply Industry was privatised, the Government stated that the new, privately owned electricity companies should not be tied to the British coal industry because competition in the electricity market would only be effective when complemented with competition in the fuel market.

By allowing the newly privatised companies to purchase coal competitively on the World Market, the Government effectively broke the stronghold that the coal industry had on the

most fundamental source of domestic and commercial energy in the UK. It was, essentially, the first step in the process that resulted in the eventual privatisation of the National Coal Board.

Under the 1980 Coal Industry Act the National Coal Board had been required to lower operating costs and reduce stocks in order to break even, without Government subsidy, by 1985. The unrest within the industry as closures were announced led to strike action which lasted for over a year and signalled the end of national ownership. Ten years later the National Coal Board was sold into private ownership.

The privately owned coal companies must now compete with one another for contracts with Generators who have coal-fired plant. The Government subsidies and regulation which kept the mines afloat and guaranteed sales for so many years have given way to private enterprise.

For companies in the ESI, competition for markets and high quality fuel supply are still comparatively new. The franchise break in 1998 will open the competitive electricity market to include all consumers, a move which will ensure that cost-effectiveness, where shareholders now expect dividends in recognition of their investments, has even greater bearing on the industry than in the past.

Not only has Scottish Hydro-Electric had to come to terms with the competitive electricity market, they now have to purchase all of the coal they require, a role originally carried out by ScottishPower on their behalf. Prior to April 1995, Scottish Hydro-Electric had no previous experience of going out to tender for coal offers and, therefore, had no structured means of differentiating between the offers received.

### **7.1.2. 'Dash-for-Gas'**

The Electricity Regulator's endorsement of the industry's 'dash-for-gas' in 1993 has meant that generation from gas-fired power stations has increased by some 700%<sup>139</sup> since 1992/93. Gas-fired stations take approximately 2 years to build, in comparison with a construction period of 6-10 years for coal-fired stations<sup>140</sup>. Their capital costs equate to £750/kW, significantly less than for coal-fired plant, for which capital costs amount to £900/kW<sup>141</sup>. This corresponds to a capital saving of £150 million for a 1000MW station.

Gas is a cleaner, more efficient fuel, having a higher calorific value with no ash and negligible sulphur emissions associated with its combustion, when compared with coal. In the competitive market it is economically viable to generate more from stations which have lower capital costs, shorter construction times and higher thermal efficiency; in short, they are most cost-effective when run continuously.

Despite the advantages of gas, it would not be feasible for any Generator to replace all of its plant with gas-fired plant. One reason for this is that this approach would effectively return the UK to a situation similar to that of the 1960s, when around 82% of generation was dependent on a single fuel; coal. For political reasons this would not be advantageous for the country. Secondly, it would not make economic sense to mothball all of the coal-fired capacity ahead of time.

The advantages of using gas have meant that gas-fired generation has moved from its original position in the peaking region of the merit-order, to base-load generation, a position traditionally taken by coal-fired plant. This shift has meant that coal-fired stations take an increasingly mid-merit position which has had a profound effect on all aspects of generation from the fuel. These effects are summarised in the next sections.

### **7.1.3. Changes in Generation from Coal-Fired Plant**

The move of coal-fired generation from base-load to increasingly mid-merit has meant that it must now respond to variation in base-load supply. These variations mean that the quantity of coal required to meet electricity supply changes with time. The quantities of coal purchased are no longer large and predictable, requiring long-term contracts, but have been reduced to quantities more effectively purchased on the medium-term market.

### **7.1.4. Contractual Agreements for Coal Purchase**

It was stated in Section 2.2. of Chapter 2 that the types of contract used for the purchase of a particular fuel are dictated by the position of the generating source in the merit-order. Fuel purchased for base-load generation, such as gas, nuclear and coal, are purchased on long-term contracts while fuel sources used for mid-merit demand, including coal, are purchased on medium-term contracts. Therefore, as coal-fired generation takes a more mid-merit position the timescales on which coal is purchased have been directly affected. Increasingly, long-term coal contracts are being replaced with medium-term contracts which

must be arranged such that they can absorb the variation in other sources and demand which have so much effect on coal-fired generation.

Since coal purchase under medium-term contracts is comparatively new for electricity Generators they have little previous experience upon which to base their definition of a 'good purchase'. They do not have any methods of differentiating between coal suppliers and their offers, or of analysing the strategic merit of any particular mix of offers.

### **7.1.5. Emissions and Coal Purchase**

Concern over potential environmental changes caused by enhanced global warming and acid deposition has focused on their cause. One of the main contributors to the emission of the gases thought to be responsible for these effects is the Electricity Supply Industry (ESI), through the use of fossil-fired power stations. Calls for limits on present levels have led to emissions legislation in, for example, the UK and in the wider European Union.

Limits on SO<sub>2</sub> and NO<sub>x</sub> emissions, the proposed tax or tradeable permit scheme for SO<sub>2</sub> and CO<sub>2</sub> emissions and the tax levied on ash disposal mean that the full cost of generating from coal-fired plant must include the cost of disposing of the products of generation.

Government funded research into clean coal technologies indicates that the future of coal-fired generation is optimistic, but that the emissions associated with the combustion of coal must be controlled if that future is to be assured. Generators which own coal-fired plant must now ensure that their emissions do not exceed limits imposed by legislation so if generation from coal is to be made cleaner then new technologies must be made available at competitive prices.

## **7.2. Supplier Assessment Techniques**

Chapter 3 introduced strategic purchasing and the implications of the strengths and weaknesses of the market on organisational buying behaviour. Coal purchase is commercially critical in a climate where there is a strong purchasing element and the supply market is weak, such as in Scotland, and also in environments where there are large influential fuel suppliers, such as England and Wales. It is becoming increasingly important for Utilities to recognise the strategic issues encompassed in medium-term coal purchase

and to respond accordingly. The integration of strategic purchasing policies into coal purchase for electricity generation is proposed.

The coal purchase decision process can be followed from the initial identification of the requirement to make a purchase, through the tendering process to the final selection of suppliers. Understanding a supplier is essential to this process and to making effective organisational buying decisions.

The main criteria dominant at each stage of the decision process for coal purchase have been isolated and their main attributes identified. The three categories used in Coal Supplier Assessment are:

1. Delivery Performance
2. Quality Performance
3. Query Handling

The analysis of historical performance has been developed into a grading system for suppliers which the user may use to predict the future performance of suppliers based on past experience. The three categories for Coal Supplier Assessment are subdivided as follows for allocation of grades for the 'Coal Supplier Grading System':

### **7.2.1. Delivery Performance**

If coal is not delivered to a given station when it is required, electricity production could be jeopardised. In such circumstances the unplanned shortfall of coal supplies will have to be made up from other coal suppliers or other fuel sources. A coal supplier's ability to deliver can be broken down into four categories for analysis:

1. *Ability to start supplies when agreed:* The circumstances of the purchase dictate that the contract starts on time, or close to time, so it is in the interests of the purchaser to avoid selecting suppliers who have a history of delayed first deliveries.
2. *Ability to complete contract within deadline:* The purchaser should avoid selecting suppliers who have a history of not completing contracts within the deadline because otherwise the late deliveries must be rescheduled which will affect deliveries from other coal suppliers.



3. *Ability to optimise use of power station access limitations:* The lowest cost way to deliver coal to power station is by road since it must be handled fewer times after it leaves the mine. However, due to the environmental impact of coal trucks travelling in the local area, road access to power stations is restricted. These limits and the additional cost of delivering coal by rail mean that each road delivery slot has a financial value associated with it.
4. *Confidence of purchaser in coal company's ability to supply:* The purchaser may have particular reasons for having high or low confidence in the supplier being able to meet the delivery constraints. Reasons for low confidence would be the opening of a new mine for supply, or a history of problems at the pit or elsewhere in the supply chain.

### **7.2.2. Quality Performance**

There are two defining factors in how a supplier is graded for the quality of his coal. The first is based on past performance and the analysis of the coal he is offering to the purchaser. The second is a measure of how he manages the quality of his coal on site.

1. *Meet specification:* The owners of a coal-fired power station fix a range of acceptable values for all the constituents of the coal delivered. At the station the specification of the coal stock is analysed and the new delivery will only be accepted if it will not take the average of any constituent of the stock outwith the acceptable limits.
2. *Quality Control:* Each mine should have its own test facilities for checking the coal before it is despatched to the power station. If the coal arriving at the station yields test parameters which consistently prove to be different from those which the supplier measured there may be problems supplier testing facilities. Problems with testing facilities at the station will be revealed by discrepancies for all deliveries from all suppliers.

### **7.2.3. Query Handling**

The query handling grade is determined by two aspects of supplier behaviour. The first is based on how the coal supplier responds to queries from the purchaser. The second is ascertained by how he has performed in the past when problems have arisen.

1. *Dealing with Queries:* How a supplier handles queries about the progress of a contract, or problems which are affecting it, will determine how he is graded in this section. He will be judged on how he behaves when he has to be contacted about problems with his supply and, thereafter, how he acts to remedy the issue.
2. *Notification of Problems:* At times when the purchaser is in a position of strength, for instance when there are many suppliers and few purchasers, it is in the best interests of the supplier to inform the purchaser of any problems which may affect his ability to meet the requirements of the purchase. If he thinks he won't be able to utilise his delivery slots then it may be possible for the purchaser to schedule another company to deliver coal at that time and reduce loss.

#### **7.2.4. Benefits of Using the 'Coal Supplier Grading System'**

By using the 'Coal Supplier Grading System' and knowledge about each supplier's particular circumstances, the buyer can make a purchasing decision based on prediction of supplier performance. Use of this grading system also benefits the Generator by assisting the buyer to ensure that the best suppliers are selected while not missing opportunities offered by new entrants into the market. It also works in favour of all suppliers who are given a fair chance of making a sale.

The Supplier Assessment Techniques developed here would be suitable for incorporation into a co-operative purchasing strategy for coal purchase where the results of the methodology would be made available to coal suppliers. Under these circumstances suppliers will be able to improve their performance to meet the needs of the Utilities and hence change the purchaser's perception of their ability to meet the supply criteria. This will mean that they will move further up in the 'purchase merit order' when compared on the strength of Supplier Grade.

### **7.3. Decision Support of Coal Purchase**

Decision making aids are widely used in the support of business problems through applications such as spreadsheets and financial models. While they effectively manage the handling of information and make recommendations, Decision Support Systems have made greatest impact where the judgement of a manager is still required for the final stages of the decision process.

The purchase of coal for electricity generation has enough structure to warrant the use of a Decision Support System, but there are aspects of coal purchase which cannot be modelled and so the final decision processes must be left to the discretion of the purchaser.

All of the factors given here, which directly affect coal purchase, have been incorporated into a decision support system called 'CoalMan'.

- Supplier Assessment Techniques in the form of the 'Coal Supplier Grading System'
- Emissions Legislation and Limits
- Logistics of Coal Purchase, including delivery and quality limits.
- Variation in Generation from Other Sources

'CoalMan' is a highly flexible tool which allows the user to test multiple scenarios in a fast and straightforward way. By giving detailed results and analysis of the purchase solution suggestion 'CoalMan' offers the user the opportunity to compare the outcomes of the different scenarios tested.

#### 7.4. Benefits of Analysing Medium-Term Coal Purchase

Mousley (1997), the Director General of 'The Confederation of United Kingdom Coal Producers' advocates that, in the light of a move in gas prices from 10p/therm in January 1996 to 23p/therm in January 1997<sup>142</sup>, the Government should take action to ensure that the fuel mix of the United Kingdom be fixed as shown in Table 23<sup>143</sup>.

<i>Source</i>	<i>Proportion</i>
Coal	30%
Gas	30%
Nuclear	30%
Renewable	10%

Table 23. Proposed Fuel Mix

However, this approach only partly addresses the problem of how coal is best employed to meet its share of the UK's electricity requirement. For coal producers long-term contracts provide the stability required to allow them to invest in further development, thereby guaranteeing future indigenous coal supply for Generators. However, as coal-fired generation becomes increasingly mid-merit state these contracts are replaced with medium-

term contracts, removing the stability which is vital to the industry. The author concludes that, while Mousley's recommendations go some way to meeting the requirements of the coal industry, the only way to ensure long-term stability and growth in both industries is to ensure that coal-fired generation is guaranteed a base-load position in the merit-order.

The author concludes that the experiment of purchasing coal exclusively on the medium-term market is one which neither the coal industry, the electricity supply industry, nor the country as a whole can afford to await the outcome.

However, if the Government does not respond to the request of the coal industry and those who foresee instability in burning gas, a premium fuel, in power stations, the present policies of electricity supply companies will be allowed to continue unchecked and coal-fired generation will become firmly mid-merit. Even more so than at present, methods of analysing coal purchases on the medium-term market will be vital to successful purchase of coal. Software such as 'CoalMan' will become an invaluable tool in planning purchases of coal on the medium-term market.

The energy market is exceptionally volatile. Even the gas market, which was thought to be stable, has shown in the last year that it does not have the steady price it was thought to have. One way to counteract some of the volatility in gas prices would be to arrange hedging such that, at times of peak demand for gas, the supply could be interrupted. However, this carries the risk of having gas supply suspended at short notice, and so alternative fuel sources must be maintained as back-up supply. One risk is replaced with another.

As has been discussed above, generation from coal is now taking an increasingly mid-merit position in the merit-order and as such it has had to absorb the planning variance associated with other sources. Scottish Hydro-Electric has a unique generation mix, having a large proportion of hydro capacity, base-load generation in the form of nuclear and gas and extensive coal-fired generation in mid-merit. Demand also falls into three categories; 1st Tier, 2nd Tier and through the Interconnector to the England and Wales Pool. Each of these fuel sources and demand categories has associated planning variance, as discussed in Chapter 1, Section 1.6.

For Scottish Hydro-Electric the greatest risks directly associated with coal purchase on the medium-term market may be summarised as:

1. *Delivery and Quantity:* In order to generate electricity, stocks of coal are required at the station. If deliveries are delayed significantly or delivery slots are not fully utilised, and these problems correspond with increased demand for coal-fired generation over the forecast, there is an increased risk of having insufficient stock to meet requirements.
2. *Quality:* The quality of fuel arriving at the station must be within limits set by the owners of the station and as close as realistically possible to the specification quoted in the offer. If it does not meet these parameters then the risk of the fuel being rejected at the station rises. If sulphur content is higher than expected then the risk of exceeding the annual limits for SO<sub>2</sub> and incurring a financial penalty increases. If calorific value is low then more coal must be used and output of nitrogen compounds will increase, with the same consequences.
3. *Price:* As with all fuels there is certain risk associated with price. The volatility of price in the short-term gas market is mirrored by some volatility in the medium-term coal market which also has to be addressed. However, long-term contracts with coal-suppliers alleviate this risk without having to accept reduced service, such as with long-term, interruptible gas supplies.

It is important to note that, while cheap coal might be available on the market, if the coal is not of high enough quality, or does not arrive at the station on time, then the benefits of low price are immediately lost. Therefore, it is important that a trade-off is found where the benefits of knowing a supplier's past history can be employed.

Advantages of a decision support system in coal purchase are that the user can employ it to test the validity of the coal offers received in response to the invitation to tender for coal supply. Another advantage is that knowledge is not lost if the Scottish Hydro-Electric Engineer responsible for coal purchase is replaced.

'CoalMan' can be used by the purchaser to confirm, or otherwise, decisions he has reached on the basis of traditional 'engineering judgement' for a given purchasing problem. A result which is close to that which has been identified will give confidence in the purchaser's own judgement, while a different result will add depth to the range of solutions which the buyer can compare before making a purchase. Further depth is introduced by allowing the purchaser to test 'What If...?' scenarios and explore options which may not have been apparent in the first analysis.

## **7.5. Conclusions**

Recent years have seen a significant increase in generation from gas-fired stations which has led to a reduction in coal-fired generation. However, in the United Kingdom 45% of all electricity is produced from coal. Given the reserves of coal in this country, and elsewhere in the world, coal-fired generation will always be a key factor in meeting energy requirements.

Medium-term coal purchasing has become a more efficient means of procurement since the 'dash-for-gas' has made coal generation an increasingly mid-merit electricity source. Therefore, it is of great importance to generators to be able to analyse the benefits and effects of each individual offer and rank them relative to one another.

It has been proven that Supplier Assessment techniques can be successfully applied to coal suppliers. It has been established that the three criteria best suited to grading supplier performance are delivery, quality and query handling. Within each of these criteria it has been demonstrated that eight factors are used to determine the overall grade of the supplier. Supplier Assessment and grading adds a previously unqualified dimension to the decision process since it quantifies the buyer's experience of each supplier and uses this knowledge to predict the future performance of the supplier.

In recent years more stringent legislative measures for controlling emissions, such as landfill tax and sulphur limits, have had an impact on generation from fossil fuels. When planning to buy coal the buyer must now incorporate these legislative measures and the corresponding financial value of the emissions into the overall cost of the purchase.

The advantages of applying Decision Support Systems to coal purchase have been demonstrated with the development of 'CoalMan' which has been designed to aid the fuel buyer's decision making process. It incorporates all of the major influences on the coal purchase decision process. 'CoalMan' stores all of the data required regarding transport limits, emissions costs and formulae, forecast generation from other sources and electricity demand in a series of databases which are readily accessible by the user.

Supplier Assessment takes the form of direct assessment by the user based on experience of previous supplier performance in past purchases. Using this innovative methodology past experience is used to predict future performance of suppliers.

'CoalMan' significantly decreases the time spent analysing coal offers using the traditional 'pen and paper' approach. By encompassing the broad range of influences on coal purchase 'CoalMan' presents a fast, consistent analysis package. It offers the user a number of scenario options which can be combined to apply complex constraints to the purchasing decision. The software approach to solving the complex problems associated with medium-term coal purchase gives the user flexibility to explore combinations of purchases which would previously have been too time consuming to investigate.

While it is designed to aid a complex decision process, 'CoalMan' has been developed with 'ease of use' at its core. It is a user friendly package, designed to be learned quickly and effectively. It offers user help screens at every stage such that the user always has access to information about the scenarios and functions offered by 'CoalMan'. However, it still depends on the user's knowledge and understanding of coal purchase to make the final decision to purchase.

'CoalMan' ranks offers such that the requirements of the purchase are met while taking into account the quantity, quality and delivery criteria selected by the user. It also ensures that external influences, such as emissions limits and transport constraints, are included in the analysis of each offer. Results are displayed in a clear format, with a full analysis of the package of offers recommended. This allows the user to quickly determine the acceptability of the solution suggestion and to easily compare the results of testing different scenarios.

## **7.6. Recommendations for Future Work**

While the definition of the 'Coal Supplier Grading System' and its application through the decision support system, 'CoalMan', is an innovative development in the field of coal purchase, the lack of available data has meant that in some respects it still could be expanded. As a complement to the research and findings presented here the author considers that the following research and modifications to 'CoalMan' are necessary to enable the development of a more thorough software package.

1. Variation of Other Generation Sources and Demand
2. Statistical Analysis of Variation
3. Demand Forecasting
4. Post-Purchase Supplier Analysis

Although the list is not definitive it includes major issues which, it is considered, will benefit the coal purchase decision making process.

### **7.6.1. Variance of Other Generation Sources and Demand**

With further data analysis of the effects of changes in supply from other sources, or variation in demand, on generation from individual coal-fired stations could be carried out. Examples of events which cause variance in generation from other sources and, hence, coal-fired plant, include:

- Unplanned maintenance or outage at any station
- Unexpected variation in rainfall (in the case of Hydro)
- Nuclear refuelling schedules
- Weather patterns which affect demand
- Pool price

Since coal-fired stations are used to meet different parts of mid-merit generation the effects of these events on generation at a particular station could be analysed so that it would be possible to predict the station at which demand for coal would vary.

By incorporating the results of this research into 'CoalMan' the coal buyer could be given the opportunity to select various events from a list and test their effects, both individually and cumulatively, on the requirements for coal at each station and, therefore, on the coal purchase solution suggestion. This would mean that the full supplier assessment and supplier ranking process would be designed to ensure that the fuel was always delivered to the station which would be affected by the event.

### **7.6.2. Statistical Analysis of Variation**

For each of the events that would be included in the software as detailed above it would be informative to calculate the statistical 'chance' of the events happening. Not only could this be calculated for the events happening at any time, but their chance of happening in the particular month(s) of the period of study could be calculated.

The advantage of incorporating this sort of analysis into 'CoalMan' would be that the user would be warned that particular events had a high 'chance' of occurring and the user could choose to test the particular scenario.



### **7.6.3. Demand Forecasting**

Forecasting demand accurately would have a profound effect on prediction of coal use and would complement the research advocated in the two previous sections. The findings of the results of current research in this field could be used in analysis of the effects of these predictions on coal purchase, that is, better forecasting of demand means less impact from variation between forecast and actual demand.

The incorporation of these results into 'CoalMan' would aid the coal requirement prediction process.

### **7.6.4. Post-Purchase Supplier Analysis**

An additional method of supplier analysis should be developed, based on storing details of past purchases for analysis. The information given by the user 'post-purchase' should be used to calculate the 'Supplier Grade' for each supplier, for each contract. These records could be analysed historically such that an overall grade would be calculated for each supplier. However, it should be possible for the user to over-rule these grades if, for any reason, it is believed that the supplier will behave in a different way from that predicted by the software.

The software should have the capacity to reject records as they become out dated. This would mean that for each supplier only their performance over a fixed number of contracts would be taken into account, or that only contracts which fall within a certain time period would be used. Again, these limits should be determined by the user in line with the purchase requirements.

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## APPENDIX A.1

### SYSTEM REQUIREMENTS FOR 'CoalMan'

#### Hardware Requirements

To run 'CoalMan' the following minimum hardware requirements must be met:

- 486-based, IBM compatible PC
- Colour Monitor (17" preferred)
- 8 Mb RAM (minimum)
- Hard Disk with minimum 12 Mb of available storage space

#### Software Requirements

In order to run 'CoalMan' the following software must be installed:

- Microsoft Windows Version 3.1. or higher
- Lotus Approach - Release 3 for Windows
- GnuPlot for Windows (Freeware, supplied with 'CoalMan')

## APPENDIX A.2

### PUBLISHED PAPERS

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# MODELLING EMISSIONS FROM FOSSIL-FUELLED POWER STATIONS FOR THE PURPOSES OF DISPATCH

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## ABSTRACT

One of the main contributors to the emission of the gases thought to be responsible for enhanced global warming and acid deposition is the Electricity Supply Industry (ESI), through the use of fossil-fuelled power stations. Calls for limits on present levels have led to EU and UK emissions legislation.

Traditional dispatch algorithms consider mainly economic factors and annual emissions restrictions, but legislation involving Carbon Taxation or Tradeable Emissions Permits would require algorithms which consider the environmental cost. The software discussed here implements one such algorithm for modelling the emissions from Coal-, Oil- and Gas-fired Power Stations.

## 1. INTRODUCTION - POWER STATIONS AND ELECTRICITY GENERATION.

As global industrial development increases it is matched by an increase in energy demand. Within this energy growth the demand for electricity has increased at a rate higher than average, increasing its share of total world-wide energy use.

Around 46% of the world's total electricity generation is from fossil fuels. Of this fraction, solid fuels are responsible for 58% while natural gas and fuel oils account for 23% and 19% respectively<sup>[1]</sup>. The technology for exploitation of fossil fuels is well developed and available in virtually every country of the world, either as reciprocating engines or as some form of turbine. However, the widespread adoption of this reliable and affordable source of primary energy has brought with it the potential problem of the emission of gaseous and particulate contaminants as the products of combustion. When the concentration of emissions reaches a significantly high value, the phenomenon is termed "pollution".

Fossil-fuelled Power Stations are one of the largest contributors to gaseous emissions. In the past the main concern was the effect of these on human health, but, more recently attention has focused on the contribution of carbon dioxide (CO<sub>2</sub>) to enhanced global warming and the role of sulphur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) in acid deposition<sup>[2]</sup>.

It can be seen from Figure 1 that around 39% of all carbon dioxide emissions in the United Kingdom come from the ESI. This is attributed to the use of fossil-fuelled power stations.

The issues are international. At the Earth Summit in June 1992 the United Kingdom signed the United Nations Convention on Climate Change, the first step in international efforts to address the threat of

global warming. This has committed all developed countries to maintaining their CO<sub>2</sub> and other greenhouse gas emissions levels at 1990 levels by the year 2000. While this legislation will, initially, affect countries with high emissions levels and high dependence on fossil fuels it will also affect those countries with excessive investment in nuclear and hydroelectric power, such as France and Sweden.

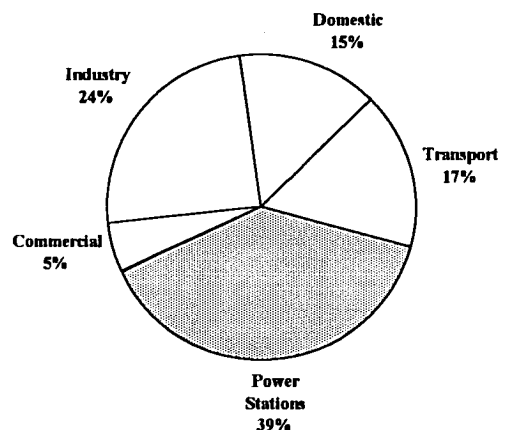


Figure 1: UK Carbon Dioxide Emissions by Sector

The question of the form legislation should take remains a difficult one. Should countries be forced to reduce their overall emissions, regardless of the type of industry they support and their present emissions levels, or should any restrictions be introduced with the national economies of the countries involved and their position in supplying World markets in mind? Legislators, policy makers and engineers must now rationalise the rising demand for electricity with the desire to be more energy efficient and to protect the environment.

While emission restrictions, such as the annual limits now enforced in the UK<sup>[3]</sup>, go some way to meeting these reductions, it is thought that eventually more appropriate methods must be adopted to ensure the desired reductions. Two such suggestions are carbon taxation and tradeable emissions permits<sup>[4]</sup>. Any legislation would effectively add an environmental cost to the generation of electricity and would require the utility operators to alter the dispatch algorithms used in determining the generating mix.

As can be seen from Figures 2 and 3 the ESI is responsible for about 70% of the total emissions of sulphur dioxide and 42% of the emissions of nitrogen oxides in the United Kingdom, data which reflect the important role the ESI may play in the reduction of harmful emissions.

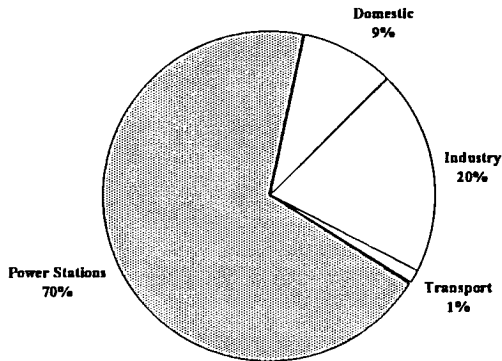


Figure 2: UK Sulphur Dioxide Emissions by Sector.

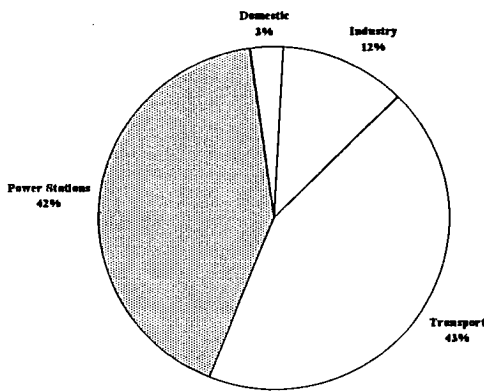


Figure 3: UK Nitrogen Oxides Emissions by Sector.

## 2. PRESENT DISPATCH ALGORITHMS

The generating mix used to meet the customer load is determined by several criteria and this order of generating plant usage is known as *dispatching*. Generators in the UK currently use economic dispatching principles to make optimum use of existing generating capacity or purchased power resources to meet customer demand. The goal is purely financial, with resources utilised according to their incremental operating costs; the only restraint being annual emissions limits. At present, the environmental burden of energy production is determined by short time scale generating strategies and spot market responses. Future legislation will most likely lead to EU generating companies amending the criteria used to determine the decisions involved in these factors, introducing a need for longer term planning by the utilities.

## 3. MODELLING EMISSIONS

A first generation, P.C. based, emissions simulator has been written to quantify the level of emissions released into the atmosphere through the generation of electricity. Despite assumptions made in the development of the simulator, the volumes of emissions are considered accurate enough to be used for taxation calculation purposes. The model is designed to calculate the levels of  $\text{CO}_2$ ,  $\text{SO}_x$

and  $\text{NO}_x$  and the particulate emissions of ash from coal-, oil- and gas-fired power stations. The magnitude of emissions is determined on the basis of generated output, at a specific level, for an hour.

The model makes it possible to calculate the emissions for different power stations operating at varying outputs up to full generating capacity and allows the constituents of the fuel to be adjusted for different types of coal, oil and gas. The simulator yields an indication of emission levels from a wide range of fossil fuelled power stations.

## 4. ASSUMPTIONS MADE IN THE DEVELOPMENT OF THE MODEL.

The combustion of fuels for the production of electricity is highly complex so, for reasons of simplicity, several assumptions have been made to allow the development of a preliminary model.

### 4.1. Combustion Processes.

The assumptions made in the development of the algorithm used in the emissions simulator are that:-

1. *The combustion is complete and that the fossil fuels release the full amount of energy per kg as indicated by the calorific value. This is felt to be a valid assumption since plant is designed for maximum energy levels.*
2. *The fuel being burned may be completely defined on an elemental basis.*
3. *The constituents of the fuel will react according to this elemental definition. In the case of the emissions occurring in relatively large quantities, such as  $\text{CO}_2$  and  $\text{SO}_2$ , it may be interpreted as reasonably valid.*
4. *All elements of the fuel will be completely oxidised, where applicable, to form gaseous emissions. This is a valid assumption since the combustion of fossil fuels occurs in excess air, giving negligible concentrations of unburnt constituents in the exhaust gas. [5, 6, 7]*
5. *Moisture will be emitted as a vapour.*
6. *The ash component of coal and oil will be completely emitted as a particulate pollutant. In the case of coal this assumption is valid for horizontally and tangentially fired pulverised systems, where 60-90% of the total ash is taken off by the flue gas.*
7. *No pollution abatement apparatus is in use.*

On the whole, the seven assumptions are reasonably valid and simplify the model substantially, but accuracy is sacrificed. [Determining the effect of these assumptions on accuracy requires further work, but a preliminary estimate suggests that the model will be between  $\pm 15\%$  and  $\pm 25\%$  accurate.]

### 4.2. Combustion Chemistry.

This section describes the chemical reactions associated with the constituents of fossil fuels and the emissions that their combustion yields.

#### 4.2.1. Coal and Oil Reactions.

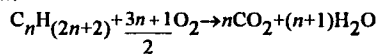
In the combustion of coal and oil some assumptions are made. These are that:

1. *The constituents of coal are Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur and Ash.* These substances constitute more than 90% of the coal used in Power Stations.
2. *The constituents of oil are carbon, sulphur, hydrogen and ash.* These substances constitute more than 99% of the oil used in Power Stations. [6, 10]
3. *All Carbon in the fuel is completely oxidised to give CO<sub>2</sub>.* In the presence of excess air negligible levels of Carbon Monoxide (CO) are emitted [6].
4. *All Sulphur in the fuel is completely oxidised to give SO<sub>2</sub>.* With Sulphur Trioxide (SO<sub>3</sub>) only forming approximately 10% of SO<sub>x</sub> emissions [6,8], this assumption is reasonably valid.
5. *Fuel Nitrogen is completely oxidised to nitric oxide and that this is the only source of NO<sub>x</sub> emissions.* This assumption disregards any contribution to NO<sub>x</sub> emissions by the thermal mechanism, which is very temperature dependent [6]. However, with no flame temperature being specified it may be taken that, for a typical pulverised coal-fired system, approximately 80% of nitric oxide (NO) emissions are due to fuel bound nitrogen [7]. Despite its short lifetime, nitric oxide forms 90-95% of NO<sub>x</sub> emissions [9].
6. *Any hydrogen present within the coal or oil reacts to form water, adding to the moisture already present in the fuel.*

#### 4.2.2. Gas Reactions.

In the combustion of gas it is assumed that:

1. *The constituents of gas are Methane, Ethane, Propane, Butane, Pentane and Hexane.* This is valid since these account for over 98% of the total, with all other components present in percentages of less than 0.001.
2. *The alkanes which make up the gas will all be completely oxidised to give carbon dioxide and water vapour.* In the presence of excess air, negligible levels of carbon monoxide (CO) are formed. Corresponding to the general reaction formula below:



3. *There is no formation of NO<sub>x</sub> emissions from the oxidation of nitrogen in the atmosphere.* That is, the effects of increasing the temperature of combustion are not taken into account [5].

The assumptions made in this model are, for the most part, reasonably valid and allow emissions levels to be calculated directly for varying electrical outputs. This model would not be accurate enough for the analytical examination of emissions for dispatch, but it does provide an indication of the magnitude of emissions and their dependence on fuel type and station output.

## 5. THE ALGORITHM

The algorithm required to calculate the emissions can be followed through a number of steps:-

1. The first stage is to calculate the mass of fuel which will be burned to meet the demand for electricity, taking into account the efficiency of the plant.
2. The second stage is to divide all masses of constituents by their corresponding molecular weights. This is necessary because the reaction equations use molar quantities.
3. The third stage is to calculate the number of moles of gaseous pollutants emitted per kg of fuel. These values are multiplied by the molar quantities for each product and the total mass of fuel burned per hour to give hourly emissions levels.
4. The final stage is the calculation of the oxygen required to oxidise one kg of fuel, and hence, the mass per hour required at the selected operating factor.

## 6. EMISSIONS DURATION CURVES

Electricity demand is traditionally represented by a 'load duration curve' such as shown in Figure 4. A week is considered and the numbers of the hours within the week for which each demand level was exceeded is shown.

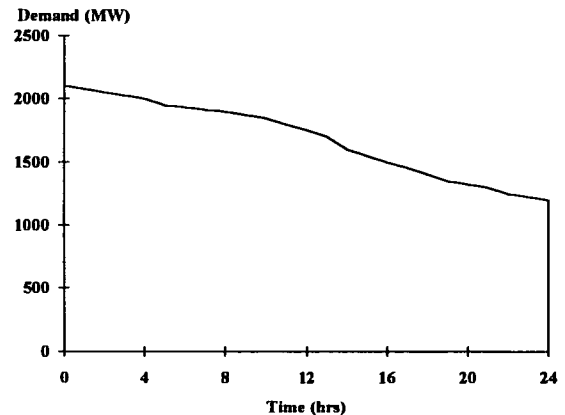


Figure 4: Typical Load Duration Curve

If a power system consisting stations described in Table 1 is available to meet this demand, the plant usage would be as shown in Figure 5.

Station Code	Capacity (MW)	Average Load Factor	Merit Order Position
Nuclear 1	600	1.00	1
Thermal 1	600	1.00	2
Thermal 2	400	1.00	3
Hydro Gp 1	200	0.80	4
Hydro Gp 2	200	0.65	5
Hydro Gp 3	200	0.55	6
Hydro Gp 4	200	0.50	7

Table 1: Stations in Power System

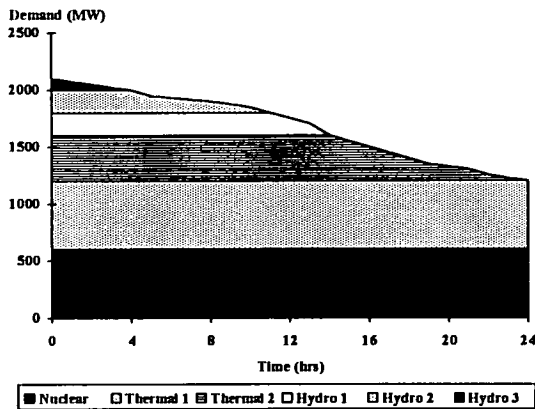


Figure 5: Load Duration Curve Showing Plant Usage

Using the emissions software developed, the equivalent gaseous output may be determined. This can also be plotted as a duration curve such as the one shown for CO<sub>2</sub> in Figure 6.

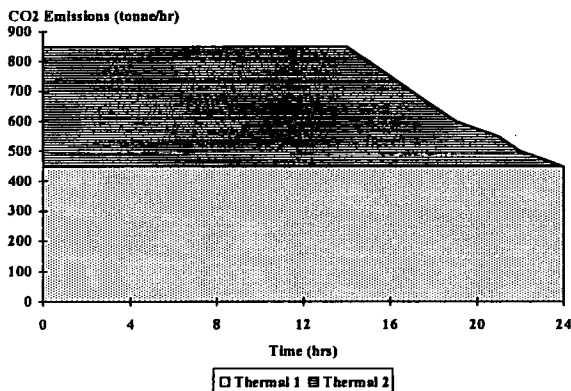


Figure 6: Emissions Duration Curve

The area under the curve quantifies the overall emissions from the electricity generating plant and it is this area that, under new EU legislation, electricity planners must endeavour to reduce.

## 7. CONCLUSIONS

The Windows environment, in which the emissions simulator runs, is becoming almost standard for programmers today and the C language, in which the software is written, is widely used throughout industry. The database introduces flexibility for the user by allowing data to be entered, saved and edited as required. Thus, the software can be tailored to suit the individual user. Once the fuel composition and station efficiency information is entered no further knowledge of the combustion processes is necessary.

The emissions software has been successfully written and tested. The fuel data used for the preliminary calculations was supplied by the relevant fuel companies, while station efficiency levels were generalised for the purposes of testing. The completed software package calculates the hourly emissions levels for a selected fuel and power station, at a specific operating factor.

The 1990's has brought with it the prospect of a society caught between a rising demand for electricity, and a desire to save energy and protect the environment. The effects of the introduction of further emissions legislation in the EU would be the inclusion of an environmental value in the costs of electricity generation. This would require the utility operators to alter the dispatch algorithms used in determining the generating mix, involving the use of models such as this one to simulate plant emissions.

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# FUEL PURCHASE FOR MIXED FUEL GENERATORS

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## ABSTRACT

*In the increasingly competitive UK electricity generation market, cost-effective fuel procurement will prove to be a critical factor in business success for UK power Generators.*

*This project aims to formalise the fuel purchasing decision process and develop decision reduction techniques. These will be incorporated into interactive decision support software specifically designed to maximise the effectiveness of fuel purchasing.*

## 1. INTRODUCTION

Fuel procurement is the largest single item in the operating expenditure of any electricity Generator, and as such, is crucial to competition within the industry. In 1994 the UK electricity generating industry purchased 35.9 million tonnes oil equivalent of coal and 3.58 million tonnes of oil for the production of electricity [1].

Within most electricity generating utilities there is a constant need to have a balanced portfolio of fuel purchase contracts. Even within the purchase of any one particular fuel, several contract types are often maintained to ensure maximum flexibility of supply. The procurement of black fuels (coal and oil) is one such area and is exposed to a number of influences not experienced by other fuels. Commercial aims of fuel purchase include minimising system operating costs with regard to security, whilst respecting operational and legislative constraints.

## 2. BACKGROUND

Although it is fairly straight forward to purchase black fuels, the complexity and range of influencing factors make the effectiveness (or "goodness") of the decision itself much harder to assess. For the present study, initial work has concentrated on analysis of past data from one Generator, looking at any major variances from expectations and examining the influence of variation in other factors.

## 3. MERIT ORDER

In an increasingly competitive electricity market the struggle to become a base-load generator is set to become more intense. Being a base-load generator offers financial security in terms of guaranteed generation and therefore shorter pay-back periods for capital investment of generation projects. Technical reasons for being base-load Generators include not having repeatedly to reduce output from stations, especially important for nuclear generation due to the risk of fuel poisoning.

With the projected increase in generation from gas, use of coal seems likely to decrease, moving from base-load generation to marginal generation. The consequences of this will be increasing significance of the magnitude of variation in coal use relative to its total use. As a result, planning of coal consumption and purchase will become increasingly critical to utilities, especially those who traditionally had a large dependency on coal. Figure 1 shows how the breakdown of electricity generation has changed in recent years.

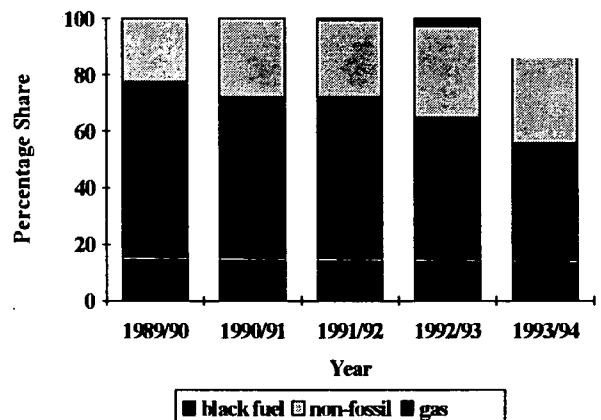


Figure 1: Breakdown of Electricity Generation, 1989-94 [2]

Figure 2 shows a typical load duration curve for an electricity network supplied by a variety of fuel sources. Generators are positioned on the merit order according to their variable costs, flexibility and contractual obligations. Some types of generation occupy the lower 'base-load' element of the merit order.

Nuclear and gas are used as base load on the basis of both cost and contractual obligations.

Hydro, where available to the utility, is used to supplement the base load. Generation from hydro plant is small in the UK context, although much more significant in Scotland. Hydro production has flexible and inflexible components which are a function of recent weather patterns. This determines its position in the merit order.

The difference, if any, between demand and generation is met by the combustion of black fuels. Coal is becoming increasingly mid-merit in the UK following the expansion of less flexible gas generation.



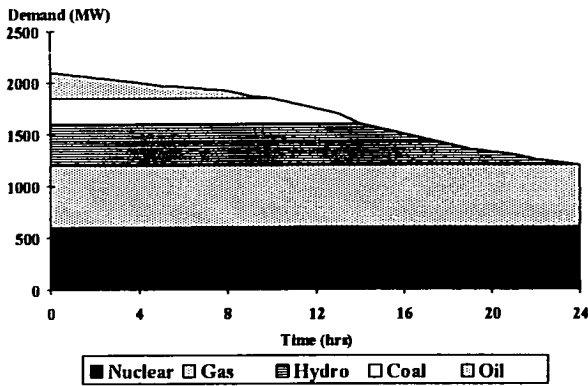


Figure 2: Typical Load Duration Curve

Competition in UK electricity generation has concentrated in the base load component of the generating market since deregulation in 1990. This is largely due to new entrants building modern high efficiency gas fired power stations. The survival of these new entrants will be critically dependent on achieving the lowest cost base.

#### 4. CONTRACTS

Each fuel type used for electricity generation is purchased in a different way, allowing maximum flexibility with regard to security of fuel supply. Power station fuel can be purchased in a number of ways:

- i. 'Take-or-Pay' Contracts: An Electricity Utility can agree with any supplier to take a minimum amount of fuel at an agreed rate over a particular period. They must 'take-or-pay' for this energy in accordance with the contract.<sup>[3]</sup> These contracts are generally related to energy which is not stored. e.g. gas.
- ii. Standard Contracts: Here a supplier tenders for a contract to supply a specified amount of fuel within a period, from a few months up to several years. Such contracts usually apply to fuels which will be stored. e.g. coal and oil.
- iii. Spot Market: These are short term purchase agreements where energy is supplied quickly and at a price close to marginal cost.

Figure 3 shows how, for a typical multi-fuel generator, the contracts would fit together to ensure flexibility in fuel supply.

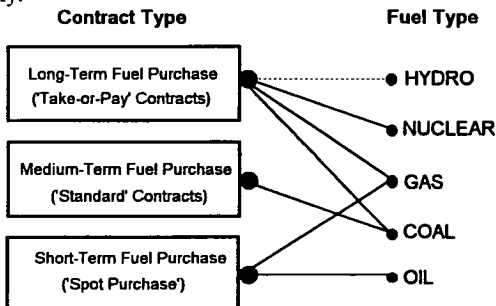


Figure 3: Fuel purchase contract types according to fuel.

## 5. PORTFOLIO MANAGEMENT

In managing fuel purchase, decisions must be taken on types, timescales for purchase and quantities in which to buy. Operating a portfolio of fuel types and suppliers offers the Generator a means to achieve more flexibility and, hence, lower cost solutions. This section considers different fuels from the point of view of associated contract types and flexibility in use.

### 5.1. Nuclear

Although, for technical reasons nuclear generation may lack the ability to respond rapid to changes in system demand, it can respond to market conditions given time. At the time of writing nuclear Generators have priority over other forms of generation when selling electricity into the UK Electricity Market. They have 'take-or-pay' contracts which allows them guaranteed sales of all the electricity they produce.

### 5.2. Gas

In the UK between financial years 1992/93 and 1993/94 electricity generation from gas increased by more than 700%<sup>[4]</sup>. At present 13% of the UK's total electricity generation comes from gas<sup>[5]</sup>.

Electricity generation from gas tends to be inflexible due to contractual obligations to their fuel suppliers. Nevertheless, the commercial decision to 'turn-down' gas and pay a penalty to the supplier may be taken, despite the economic penalties which this attracts. Utilities can also increase their options through operating several gas fired power stations and by having direct involvement in the gas market.

### 5.3. Hydroelectricity

Historical data on run-off within catchment areas is used to forecast generation of electricity from hydroelectric plants. Since rainfall is not controllable, water appears at first sight to be inflexible. Pondage normally allows some degree of flexibility although this can be lost if reservoirs are filled by a spell of heavy rainfall, or reservoirs are emptied through drought.

### 5.4. Oil

In terms of fuel purchase, oil is generally bought as required on the spot market. Since privatisation electricity generation from oil has fallen by a quarter and by 1993 represented only 8% of fuel used for generation in the UK<sup>[6]</sup>. Oil is now largely a stand-by source of generation.

### 5.5 Coal

As previously mentioned, coal is increasingly taking a mid-merit role in the UK electricity generating industry. It now

tends to occupy the position between less flexible generation and demand.

Because of its mid-merit position, black fuel purchase inherits the planning variance from other sources of generation and demand for electricity.

Experience gained from dealing with the practicalities of coal purchasing, for example transport and processing, suggest a lead time of approximately three months from initially identifying a need to purchase coal to first deliveries. Generators must therefore ensure sufficient coal is stocked to cover uncertainty in consumption over this lead time.

Generators operate a portfolio of coal supply contracts over a range of time periods, from a matter of months to a number of years. Usually only a proportion is committed to longer-term arrangements, the rest is left to shorter-term (less than one year) purchases.

Reasons for purchasing coal under longer-term contracts:

- i. It creates supply by giving coal producers the stability and confidence to invest in new mines.
- ii. Mines usually have some capacity to increase production over the base-supply contracts. Generators can therefore purchase additional tonnages at close to the marginal cost of producing the coal. This lowers the average price.
- iii. Risk management technique of 'locking-in' some prices for a period ahead.

Apart from the price benefit, some of the coal demand is left to short-term purchases because of uncertainty in coal requirements in the developing market.

The balance between the volume of coal committed to long-term contracts and short-term 'spot' purchases is set by the degree of certainty in planning and the economic incentive of potential marginal cost supplies. Utilities must therefore rationalise the benefits of security of fuel supply with the uncertainty associated with the changing industry.

## 6. RESULTS

While it is possible for utilities to ignore the uncertainties associated with fuel purchase, simply because the losses are not apparent, this does not take advantage of positive opportunities which may otherwise be missed. [7]

In the previous discussion of portfolio management, it was stated that uncertainty is an important influence in the organisation of contracts. The formalisation of the fuel purchasing decision process and its related uncertainties is

therefore central. This study will aid the development of decision reduction techniques which will be incorporated into interactive decision support software.

All forms of generation have related production difficulties and unplanned outages, even base load. For each individual fuel type used by the Generator in this study the difference between its planned use and its eventual use over the same period have been calculated. It is this set of differences and their causes that this work aims to analyse and so develop techniques for optimum fuel purchasing.

By comparing the actual generation from each source with the planned usage at the start of the selected period the major influences on coal use can be found. Further analysis of the figures gives an indication of what the differences between planned and actual generation mean in terms of black fuel stock required to meet a shortfall from another source, or extra reserves left due to an unexpected increase in output from elsewhere.

If gas and nuclear energy are assumed to be base-load then the difference between planned and actual generation can be analysed; thus the causes and effects of these differences can be examined.

A graph of the differences between actual output and planned output by fuel source is given in Figure 4. It can be seen from this that whenever the actual output from gas or nuclear is less than the planned schedule (a negative figure on the graph) the deficit in generating availability is made up by extra generation from black fuel. It can also be seen that whenever demand is higher than expected there is increased black fuel burn. Since black fuel burning makes up the difference between the 'Take-or-Pay' electricity supply (from gas and nuclear) and the demand it can be expected to reflect any variances between plan and actual use.

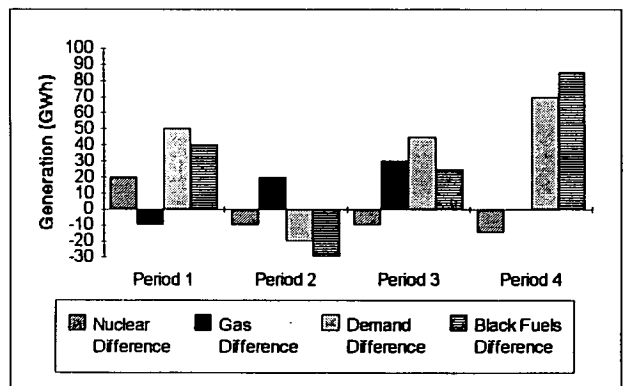


Figure 4: Graph of Differences Between Actual and Planned Generation and Demand.

For the example utility described in Figure 4 above it can be seen that given the two 'take-or-pay' contracts and the relative reliability of those sources, black-fuel generation

mainly reflects variance in the demand. The following 'first-stage' analysis might be made:

**Period 1.**

- **Nuclear** - In this period there has been an unplanned increase in generation from nuclear fuel.
- **Gas** - Generation from gas is lower in this period than had been planned.
- **Demand** - Demand is greater than had been expected in this period, this may be due to cooler weather than was forecast.
- **Coal** - Coal generation has had to be increased in this period to counter the effects of variance in output from other fuels and demand.

**Period 2.**

- **Nuclear** - Nuclear generation has been less than planned in this period.
- **Gas** - Gas has shown an increase in output in this period.
- **Demand** - Reduced demand could be attributed to comparatively warm weather, reducing requirements for heating.
- **Coal** - The reduction in demand and the increase in gas generation has only been partly offset by the reduction in nuclear generation, hence coal has not significantly changed.

**Period 3.**

- **Nuclear** - Nuclear generation has been less than was planned for this period.
- **Gas** - Gas has shown a greater increase in output in this period than the last one.
- **Demand** - For this period demand has been higher than expected.
- **Coal** - The combination of differences in supply and demand has meant that more coal has been used than was expected.

**Period 4.**

- **Nuclear** - Nuclear generation has again been below expected levels.
- **Gas** - Gas output has been exactly as expected.
- **Demand** - Large increase in demand possibly due to low temperatures and increased requirements for heating.
- **Coal** - Reduced nuclear output and high demand have combined to increase coal generation.

The consequences of large variations in output from other sources, and the fluctuations which can occur in demand, can result in substantial variation in coal use.

## 7. CONCLUSIONS

Initial work in this field made it apparent that many of the factors influencing fuel purchase were little studied or understood, and that their interaction was not documented. Commercial imperatives in the privatised Electricity Supply Industry may now bring added weight to maximising fuel purchase effectiveness.

In the future, as the merit order for generation changes and black fuel use becomes more marginal new measures will be required to cope with the uncertainties created by the variance of coal generation. As coal generation becomes more marginal variance will become more significant relative to overall generation and coal demand will begin to appear more volatile.

Each Generator must take advantage of every opportunity available to improve its competitiveness. If the efficiency of fuel procurement is to be maximised in the long-term the factors which cause most variation in its use will have to be taken into account. The work being undertaken here will culminate in the formalisation of the fuel purchasing decision process and its related uncertainties. The project objective is to provide a valuable DSS tool for Generators in the ESI.

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# Simulation of gaseous emissions from electricity generating plant

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*In electricity supply networks, traditional dispatch algorithms are based on features such as economics and plant availability. Annual limits on emissions from fossil-fuelled stations are regarded as a restriction and set a ceiling on generation from particular stations. With the impending introduction of financial penalties on emissions, for example carbon taxation, algorithms will have to be developed which allow the dispatch engineer to assess the cost in real-time of different generation options involving fossil-fuelled plants. Such an algorithm is described in this paper. Copyright © 1996 Elsevier Science Ltd*

*Keywords: gaseous emissions, emissions simulation, power generation*

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## I. Background

Concern over potential environmental changes caused by enhanced global warming and acid deposition has focused on their cause. One of the main contributors to the emission of the gases thought to be responsible for these effects is the Electricity Supply Industry (ESI), through the use of fossil-fired power stations. Calls for limits on present levels have led to emissions legislation in, for example, the UK and in the wider European Union.

This paper describes a software suite, written to allow the simulation of different types of fossil-fuelled stations in terms of the associated gaseous emissions from electricity generation. This could provide a basis for assessment of both the financial and other costs of burning fossil fuels.

## II. Emissions and their effects

As global industrial development increases, it is matched by an increase in energy demand. Within this energy growth, the demand for electricity has increased at a rate higher than average, increasing its share of total worldwide energy use. Indications are that the demand for electricity will continue to grow disproportionately in the future.

Around 46% of the world's total electricity generation is from fossil fuels. Of this fraction, solid fuels are responsible for 58% while natural gas and fuel oils account for 23% and 19% respectively<sup>1</sup>. Fossil fuels have provided a reliable and affordable source of primary energy for many years. The technology for exploitation of fossil fuels is well developed and available in virtually every country of the world, either as reciprocating engines or as some form of turbine. However, the widespread adoption of energy economies based on fossil fuels has brought with it the potential problem of the emission of gaseous and particulate products of combustion. When the concentration of emissions reaches a significantly high value, the phenomenon is termed 'pollution'. Fossil-fuelled power stations are among the largest contributors to gaseous emissions (see Figure 1). In the past the main concern was the effect of these on human health but more recently attention has focused on the contribution of carbon dioxide (CO<sub>2</sub>) to enhanced global warming and the role of sulphur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) in acid deposition<sup>2</sup>.

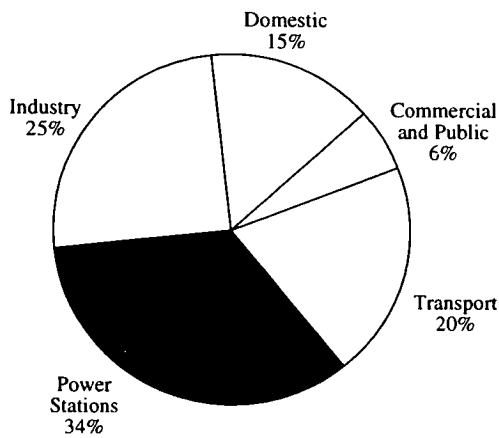
The problem of excessive emissions is international. Table 1<sup>3</sup> shows the ranking of the top thirty countries in terms of emissions of the gases responsible for enhanced global warming per head of population. The countries of the Gulf are prominent in both lists, probably due to their activities in winning hydrocarbon fuels and partly through their widespread use of such fuels.

The thirty countries with the highest annual emissions of CO<sub>2</sub> are shown in Table 2. As might be expected, this indicates that overall the major contributors to emissions levels are the largest of the industrialized countries: the United States, Russia, China and Japan.

At the Earth Summit in Rio de Janeiro in June 1992, the United Kingdom signed the United Nations Convention on Climate Change, the first step in the international efforts to address the threat of global warming. This has committed all developed countries to maintaining their CO<sub>2</sub> and other greenhouse gas emissions levels at 1990 levels in the year 2000.

## III. The Greenhouse effect

The Earth and its surrounding atmosphere absorb

Figure 1. UK CO<sub>2</sub> emissions by sector

around 70% of the  $1.7 \times 10^{14}$  kw of energy which reaches it from the Sun<sup>9</sup>. Indications are that complex atmospheric processes are occurring which are responsible for measurable climate changes. One observed change is that average temperatures appear to be increasing, so-called 'global warming' caused by the 'greenhouse effect'<sup>9</sup>,

**Table 1. Thirty countries with the highest emissions of greenhouse gases, per capita, 1989, ranked by World Resources Institute. (Data excerpted from World Resources Data Base, 1992, World Resources Institute, Washington, DC.)**

Rank	Country	Relative per capita emissions*
1	United Arab Emirates	15.7
2	Qatar	12.4
3	Luxembourg	10.5
4	Côte d'Ivoire	10.4
5	Bahrain	10.2
6	United States	9.8
7	Brunei	9.8
8	Australia	8.8
9	Canada	8.6
10	Trinidad and Tobago	7.6
11	Guinea-Bissau	7.2
12	Kuwait	7.1
13	Czechoslovakia	6.4
14	USSR	6.2
15	Ecuador	6.2
16	Germany <sup>†</sup>	6.1
17	Norway	6.1
18	Nicaragua	6.1
19	Japan	6.0
20	Paraguay	5.9
21	Singapore	5.7
22	Liberia	5.7
23	Columbia	5.6
24	New Zealand	5.6
25	Malaysia	5.6
26	Saudi Arabia	5.5
27	United Kingdom	5.5
28	Gabon	5.5
29	Belgium	5.4
30	Ireland	5.2

\*1.00 = world median.

<sup>†</sup>Data for Germany include both the former Federal Republic of Germany and the German Democratic Republic.

**Table 2. Thirty countries with the highest industrial emissions of carbon dioxide, 1989. (Data excerpted from World Resources Data Base, 1992, World Resources Institute, Washington, DC.)**

Rank	Country	Total CO <sub>2</sub> emissions (million metric tons)
1	United States	4 869 005
2	USSR	3 804 001
3	China	2 338 613
4	Japan	1 040 554
5	Germany*	964 028
6	India	651 936
7	United Kingdom	568 451
8	Canada	445 530
9	Poland	440 929
10	Italy	389 747
11	France	357 163
12	Mexico	319 702
13	South Africa	278 468
14	Australia	257 480
15	Czechoslovakia	226 347
16	Korea, Rep.	221 104
17	Romania	212 193
18	Brazil	206 957
19	Spain	203 227
20	Saudi Arabia	173 776
21	Iran, Islamic Rep.	166 074
22	Korea, Dem. People's	151 488
23	Indonesia	137 726
24	Yugoslavia	132 901
25	Turkey	126 078
26	Netherlands	124 990
27	Argentina	118 157
28	Bulgaria	106 989
29	Belgium	98 104
30	Venezuela	95 887

\*Data for Germany include both the former Federal Republic of Germany and the German Democratic Republic.

thought to be the result of a build-up of certain gases in the atmosphere. The gases which contribute most to the greenhouse effect are shown in Figure 2 in their relative percentages.

#### IV. The carbon cycle

Although the carbon cycle is probably one of the most significant of the biogeochemical cycles affecting climate

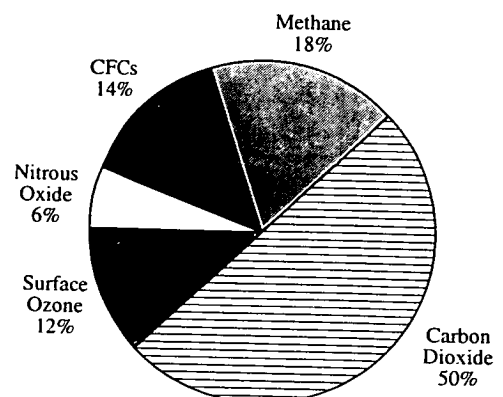


Figure 2. Relative contribution to greenhouse effect

change, understanding of it is very limited. To determine the role of the oceans and the biosphere as sinks for  $\text{CO}_2$  will require more accurate definition of the carbon budget than presently possible. For example, estimates of the amount of organic carbon in world soils range from 700 000 billion tonnes to 3 000 000 billion tonnes and the range of estimates of  $\text{CO}_2$  released from soils is significant compared with the release from fossil fuel burning, approximately 800 000 million tonnes compared with 5 billion tonnes per annum<sup>10</sup>.

The largest contributor to global warming is the emission of  $\text{CO}_2$ . It has been estimated that a doubling of pre-industrial levels of  $\text{CO}_2$  could result in an overall temperature rise of between  $1.5^\circ\text{C}$  and  $4.5^\circ\text{C}$ <sup>11</sup>. This in turn could lead to a rise in sea-level of between 25 cm and 140 cm which would result in widespread flooding of low-lying regions and the displacement of around 300 million people<sup>11</sup>.

## V. The sulphur and nitrogen cycles

Precipitation is naturally acidic, with background acidity from natural sources of atmospheric carbon dioxide, sulphur and nitrogen compounds and formic and acetic acids, which are weak organic acids. Man's activities which are associated with the combustion of fossil fuels have altered the chemical composition of precipitation from weak acids to the strong acids, sulphuric and nitric.

The atmosphere acts as a complex chemical reactor, transforming the pollutants produced by the combustion of fossil fuels as they interact with other substances and moisture. Under the right conditions, emissions of sulphur dioxide and nitrogen oxides are chemically transformed into sulphuric and nitric acids, respectively. If their concentrations are high enough, they can have a deleterious effect on wildlife, buildings and human health. So far these acids have caused damage to forests in many parts of North America, Scandinavia and other parts of Europe. Hundreds of Scandinavian lakes are now reported to be too acidic to support aquatic life, over half of the former West Germany's forests are dead, dying or in decline and in Switzerland a third of the forests are dying. Although generally around two thirds of the sulphur dioxide emitted in the UK every year is 'exported' to other countries<sup>9</sup>, in 1984 black snow, which was as acidic as vinegar, fell at Aviemore in Scotland.

Apart from its role in acid deposition, sulphur has an important part in the biogeochemical system. Human activity has more than doubled the total amount of sulphur entering the atmosphere and, since we still have little understanding of the role of sulphur from natural

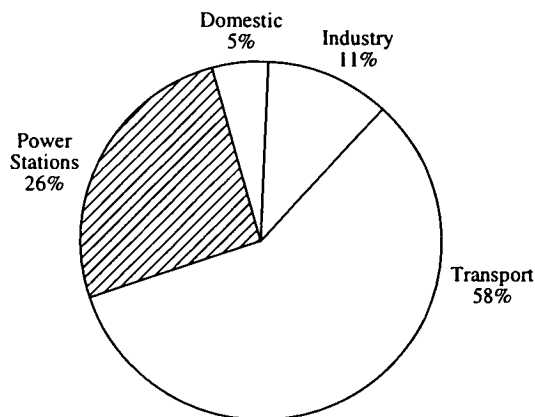


Figure 4. UK nitrogen oxides emissions by sector

processes this could have a significant effect on the environment through acidification.

Nitrogen produces highly reactive oxides in the atmosphere which react with other elements and, in the case of nitrous oxide, acts as a greenhouse gas.

As an example of the significance of fossil-based generation in the problem of acid precipitation, Figures 3 and 4 indicate that the ESI is responsible for about 70% of the total emissions of sulphur dioxide and 42% of the emissions of nitrogen oxides in the United Kingdom alone.

## VI. Emissions legislation

As mankind became increasingly aware of the potential effects of gaseous emissions, legislation was introduced in an attempt to control or limit their level. Early legislation was (and still is in many instances) based on a command/control model, where pre-set levels were agreed and any emissions above these levels attracted a fine by the authorities<sup>4</sup>.

This form of legislation is somewhat crude and limited in effectiveness. Those responsible are now addressing the question of which form of legislation should replace it. Should countries be forced to reduce their overall emissions, regardless of the type of industry they support or should any restrictions be introduced with the national economies of the countries involved and their position in supplying world markets in mind? Legislators, policy makers and engineers must now rationalize the rising demand for electricity with the desire to be more energy efficient and to protect the environment. Two suggestions are carbon taxation and tradeable emissions permits<sup>5</sup>.

### VI.1 Carbon taxation

Carbon taxation first gained widespread attention in 1989. The idea was that by applying a tax to gaseous emissions of the oxides of carbon they would be discouraged and the economic standing of low-carbon processes would be improved. In June 1990, the EU heads of state agreed to limit the emissions of greenhouse gases as part of an action for 'sustainable development' and within a few months the Energy/Environment Council had undertaken to stabilize  $\text{CO}_2$  emissions in the EC at 1990 levels by the year 2000. Without this action, it is forecast that levels could rise by about 14%<sup>6</sup>. The European Commission has developed a strategy for achieving this target which includes:

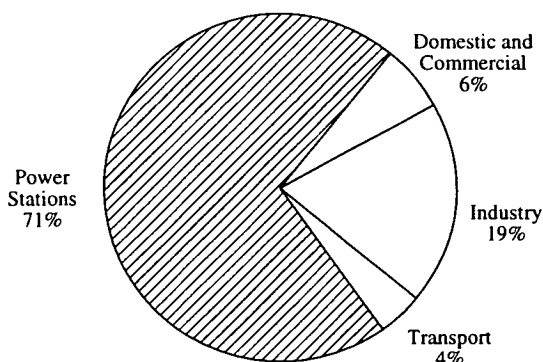


Figure 3. UK sulphur dioxide emissions by sector

- R & D programmes and technical measures;
- measures to help member states with the greatest problems of abating emissions or economic constraints;
- tax measures, including the possibility of a specific CO<sub>2</sub> energy tax.

The tax is not intended as the sole measure against increasing emissions but as part of a strategy to increase energy efficiency. In a broader sense this tax is seen as part of a policy for protecting the environment that deals with air acidification, transport, nature protection and other relevant issues. The energy, or carbon tax should be offset by tax incentives for firms and individuals, the aim being to promote new investment in improving the efficient use of energy and limiting CO<sub>2</sub> emissions.

The EC Environment Commissioner suggested that the money raised from the taxation should be used to finance research and development programmes into reducing carbon emissions<sup>4</sup>.

Such a tax is a politically convenient way of raising money for environmental research because the source is directly linked with the problems being addressed. It is not a tool for affecting fuel choice or encouraging fuel efficiency. Table 3 shows the revenue which would be raised by a tax of 0.4\$/tC (dollars per tonne of carbon) applied to all fossil fuels. The figures amount to more than \$300M/yr in Western Europe and over \$2bn/yr if applied worldwide.

So far, unilateral introduction of a carbon tax has been rejected because of the increased burden of higher energy prices it would impose on national industries. To meet this complaint the draft directive explicitly includes a clause stating that the tax arrangements cannot be applied in the member states until other countries of the OECD have introduced a similar tax, or measures which would have an equivalent financial impact. The EC Economic Policy Committee has agreed that the proposals are compatible with the objectives pursued and with economic efficiency.

An international agreement on domestic carbon taxes would not involve handing over resources to international control. However, such an agreement would not address the question of resource/technology transfer to developing countries. The fixing of a domestic rate would need to take into account the fact that certain economies depend on more energy intensive industries than others. Domestic subsidies could also offset the tax burden.

## VI.2 Tradeable emissions permits

An alternative to carbon taxes is marketable emission permits, already in limited use in the United States. The idea is that emissions are controlled through a system of permits, which can be interchanged between various parties without central direction. The approach seems to offer many attractions, but whether such benefits are realized will depend partly on the form the system takes.

First, governments would need to negotiate a global target for emissions. The arduous process of allocating emission restrictions among countries would be replaced by the allocation of permits. Allocations based on current emissions, GNP and land area have all been suggested but the most practical basis would be a capacity-based one, as implemented in the USA (see below). Such an allocation would result in a definite transfer of resources and technology from developed to developing countries.

Secondly, the question of whether the permits should be tradeable or leasable would need to be agreed upon. One suggestion is that permits be periodically 're-issued' according to the initial allocation system. This would amount to a system in which permits are leased but never sold, overcoming many of the objections associated with the overall question.

Finally, the currency of trading would need to be agreed upon, although most economists are likely to argue that it should be unrestricted.

In the United States tradeable emissions permits have already been introduced to help the electricity utilities halve their annual emissions of sulphur dioxide. The Environmental Protection Agency (EPA) has distributed 5.3 million one year permits, each corresponding to an allowance to emit 1 ton (imperial) of sulphur dioxide into the atmosphere, to the 110 worst polluters<sup>7</sup>. By the year 2000 it is planned that a total of 9.5 million permits will be available to all utilities. In March 1993 some 150 thousand tons of pollution rights were auctioned by the Chicago Board of Trade for around \$21 million<sup>8</sup>. Since then the purchase price for emissions permits has fluctuated between \$125 and \$450 each. Like all other stocks, pollution can now be bought, sold and auctioned by anyone who is interested in it. Indeed, some environmental groups have purchased permits and shelved them with a view to reducing atmospheric pollution.

**Table 3. Revenue raised by 'fund raiser' carbon tax**

Fuel	Carbon content MtC/Mtoe*	Western Europe consumption		World consumption	
		Mtoe	MtC	Mtoe	MtC
Coal	1.07	263	281	2428	2600
Oil <sup>†</sup>	0.81	594	481	3038	2460
Gas	0.61	199	121	1631	984
Total (MtC)			883		6044
Revenue @0.4\$/C (\$M)		353		2417	

\* MtC = million tonnes of carbon; Mtoe = million tonnes of oil equivalent.

<sup>†</sup> Oil figures allow for non-energy applications.

## VII. Modelling emissions

Traditional ESI dispatch of generation plant to meet a given demand is based mainly on economic factors and annual emissions restrictions. The introduction of legislation such as Carbon Taxation or Tradeable Emissions Permits would require the dispatch engineer to consider the full generation cost incurred and a different generation merit order might result. To estimate the financial penalty applied to a particular generation mix, it is necessary first to determine the levels of associated gaseous emissions.

A PC-based, emissions simulator is described below which determines the level of emissions released into the atmosphere by a fossil fuelled plant. The results are considered accurate enough to be used, for example, in estimating the relative merits of different future generating options in terms of associated gaseous emissions. The model is designed to calculate the levels of CO<sub>2</sub>, SO<sub>x</sub> and NO<sub>x</sub> and the particulate emissions of ash from coal-, oil- and gas-fired power stations.

The model makes it possible to calculate the emissions for the different types of power stations operating from part- to full- load for specified time periods. The constituents of the fuel may also be specified for different types of coal, oil and gas.

### VII.1 Assumptions made in the development of the algorithms for emissions calculation

The combustion of fuels for the production of electricity is highly complex and it was necessary to make several assumptions to allow the development of a preliminary model.

#### VII.1.1. Combustion processes

The assumptions made in the development of the algorithm used in the emissions simulator are as follows.

- (1) *The combustion is complete and the fossil fuels release the full amount of energy per kilogramme as indicated by the calorific value.* This is felt to be a valid assumption since the plant is designed for maximum energy levels.
- (2) *The fuel being burned may be completely defined on an elemental basis.*
- (3) *The constituents of the fuel will react according to this elemental definition.* In the case of the emissions occurring in relatively large quantities, such as CO<sub>2</sub> and SO<sub>2</sub>, it may be interpreted as reasonably valid.
- (4) *All elements of the fuel will be completely oxidized, where applicable, to form gaseous emissions.* This is a valid assumption since the combustion of fossil fuels occurs in excess air, giving negligible concentrations of unburned constituents in the exhaust gas<sup>12,14</sup>.
- (5) *Moisture will be emitted as a vapour.*
- (6) *The ash component of coal and oil will be completely emitted as a particulate pollutant.* In the case of coal this assumption is valid for horizontally and tangentially fired pulverized systems, where up to 90% of the total ash is taken off by the flue gas.
- (7) *No pollution abatement apparatus is in use.*

The authors consider that the seven assumptions are reasonably valid and simplify the model substantially. Overall accuracy is estimated at  $\pm 15\%$ .

### VII.2 Combustion chemistry

This section describes the chemical reactions associated with the constituents of fossil fuels and the emissions that their combustion yields.

#### VII.2.1 Coal oil reactions

In the combustion of coal and oil some assumptions are made. These are as follows.

- (1) *The constituents of coal are carbon, hydrogen, oxygen, nitrogen, sulphur and ash.* These substances constitute more than 90% of the coal used in power stations. The composition of a typical coal, Pennsylvanian anthracite, can be summarized as follows:

Carbon—79.7%  
Hydrogen—2.9%  
Oxygen—6.1%  
Nitrogen—0.9%  
Sulphur—0.8%  
Ash—9.6%.

- (2) *The constituents of oil are carbon, sulphur, hydrogen and ash.* These substances constitute more than 99% of the oil used in power stations<sup>13,17</sup>. A typical composition for fuel-oil would be:

Carbon—84.6%  
Sulphur—3.95%  
Hydrogen—11.4%  
Ash—0.05%.

- (3) *All carbon in the fuel is completely oxidized to give CO<sub>2</sub>.* In the presence of excess air negligible levels of carbon monoxide (CO) are emitted<sup>13</sup>.
- (4) *All sulphur in the fuel is completely oxidized to give SO<sub>2</sub>.* With sulphur trioxide (SO<sub>3</sub>) only forming approximately 10% of SO<sub>x</sub> emissions<sup>14,15</sup>, this assumption is reasonably valid.
- (5) *Fuel nitrogen is completely oxidized to nitric oxide and that this is the only source of NO<sub>x</sub> emissions.* This assumption disregards any contribution to NO<sub>x</sub> emissions by the thermal mechanism, which is very temperature dependent<sup>13</sup>. However, with no flame temperature being specified it may be taken that, for a typical pulverized coal-fired system, approximately 80% of nitric oxide (NO) emissions are due to fuel bound nitrogen<sup>14</sup>. Despite its short lifetime, nitric oxide forms 90–95% of NO<sub>x</sub> emissions<sup>16</sup>.
- (6) *Any hydrogen present within the coal or oil reacts to form water, adding to the moisture already present in the fuel.*

#### VII.2.2. Gas reactions

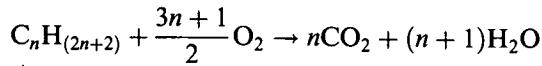
In the combustion of gas the following is assumed.

- (1) *The constituents of gas are methane, ethane, propane, butane, pentane and hexane.* This is valid since these account for over 98% of the total, with all other components present in percentages of less than 0.001. A typical composition of fuel gas is as follows:

Methane—91.98%  
Ethane—4.5%  
Propane—1.38%  
Butane—0.25%  
Pentane—0.03%  
Hexane—0.01%



- (2) The alkanes which make up the gas will all be completely oxidized to give carbon dioxide and water vapour. In the presence of excess air, negligible levels of carbon monoxide (CO) are formed. Corresponding to the general reaction formula below:



- (3) There is no formation of  $NO_x$  emissions from the oxidation of nitrogen in the atmosphere. That is, the effects of increasing the temperature of combustion are not taken into account<sup>12</sup>.

Although the model is not accurate enough for detailed quantitative estimation of emissions for dispatch it can be used for comparison purposes to identify the dependence of the level of emissions on fuel type and station output.

### VIII. The algorithm

The algorithm required to calculate the emissions can be followed through a number of steps.

- (1) The first stage is to calculate the mass of fuel which will be burned to meet the demand for electricity, taking into account the efficiency of the plant. The efficiency of the plant is found from data which are entered by the user in a series of figures for combustion, boiler, generating efficiencies for various load factors. The calorific value used is entered by the user as part of the fuel data entry screen for the selected fuel.
- (2) The second stage is to divide all masses of constituents by their corresponding molecular weights. This is necessary because the reaction equations use molar quantities.
- (3) The third stage is to calculate the number of moles of gaseous pollutants emitted per kilogramme of fuel. These values are multiplied by the molar quantities for each product and the total mass of fuel burned per hour to give hourly emissions levels.
- (4) The final stage is the calculation of the oxygen required to oxidize one kilogramme of fuel, and hence, the mass per hour required at the selected operating factor.

### IX. Results

To illustrate one use to which the simulator can be put, time-duration curves will be considered. This can be done for any gas described above: the example is shown for  $CO_2$ .

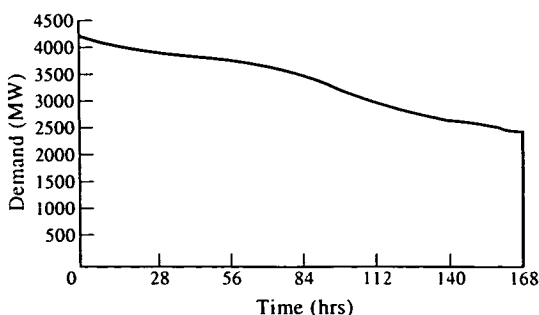


Figure 5. Load-duration curve

Table 4. Stations in a power system

Station code	Capacity (MW)	Average load factor	Merit order position
Nuclear 1	600	1.00	1
Thermal 1	600	1.00	2
Thermal 2	400	1.00	3
Hydro Gp 1	200	0.80	4
Hydro Gp 2	200	0.65	5
Hydro Gp 3	200	0.55	6
Hydro Gp 4	200	0.50	7

#### IX.1 Emissions duration curves

Electricity demand is traditionally represented by a 'load duration curve' such as that shown in Figure 5. A week is considered and the numbers of hours within the week for which each demand level was exceeded is shown.

If a power system consisting of the stations described in Table 4 is available to meet this demand, the plant usage might typically be as shown in Figure 6.

Using the emissions software, the equivalent gaseous output may be determined. This can also be plotted as a duration curve such as the one shown for  $CO_2$  in Figure 7.

The area under the curve quantifies the overall emissions from the electricity generating plant and it is this area that, under new EU legislation, electricity planners must endeavour to reduce.

Other dispatch schedules can be simulated and the corresponding emissions duration curve produced. These can be taken as absolute values, with error ranges, and can be used to estimate operational costs.

Alternatively, the results of several options could be compared and a decision made on the relative attractiveness of each in terms of environmental impact and possible cost to the generator in taxation.

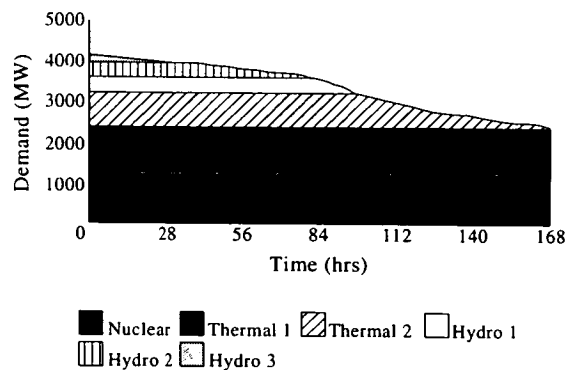


Figure 6. Load-duration curve showing plant usage

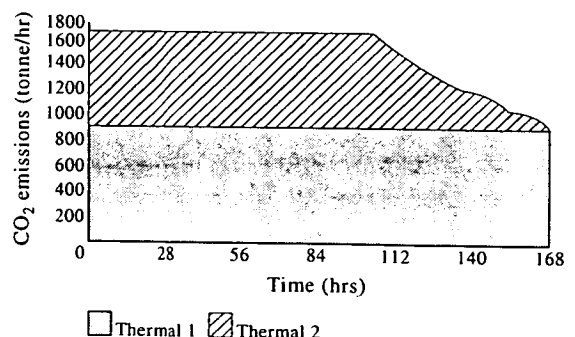


Figure 7. Emissions-duration curve

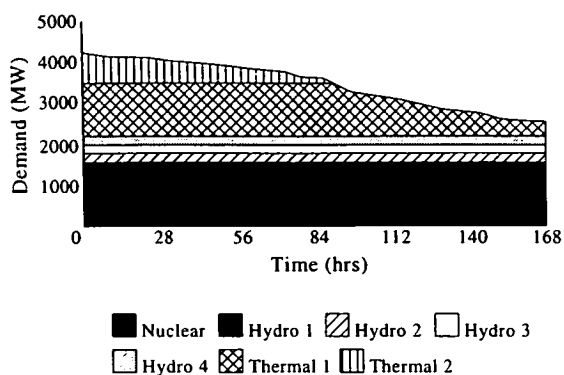


Figure 8. Alternative emissions-duration curve

Figure 8 shows the effect on the emissions duration curve of making this substitution of hydro for fossil-fuelled plant.

#### IX.2 Effect on CO<sub>2</sub> total emissions

By altering the merit order of plant considered from the traditional arrangements shown in Figure 6 to the revised arrangement shown in Figure 9, the quantity of carbon dioxide emitted for the same electrical energy delivered is reduced. The degree to which this reduction occurs can be seen by comparing Figure 7 and Figure 8.

The area under the curve defines the quantity of CO<sub>2</sub> emitted over the 168 hour period. By adopting the revised merit order a reduction of around 40% in carbon dioxide emission over the 168 hour period may be achieved.

### X. Conclusions

The Windows environment, in which the emissions simulator runs, is becoming almost standard for programmers today and the C language, in which the software is written, is widely used throughout industry. The database introduces flexibility for the user by allowing data to be entered, saved and edited as required. Thus, the software can be tailored to suit the individual user. Once the fuel composition and station efficiency information is entered no further knowledge of the combustion processes is necessary.

The emissions software has been successfully written and tested. The fuel data used for the preliminary calculations was supplied by the relevant fuel companies, while station efficiency levels were generalized for the purposes of testing. The completed software package calculates the hourly emissions levels for a selected fuel and power station, at a specific operating factor.

The 1990s has brought with it the prospect of a society caught between a rising demand for electricity, and a desire to save energy and protect the environment. The effects of the introduction of further emissions legislation in the EU would be the inclusion of an environmental value in the costs of electricity generation. This would require the utility operators to alter the dispatch algorithms used in determining the generating mix, involving the use of models such as this one to simulate plant emissions.

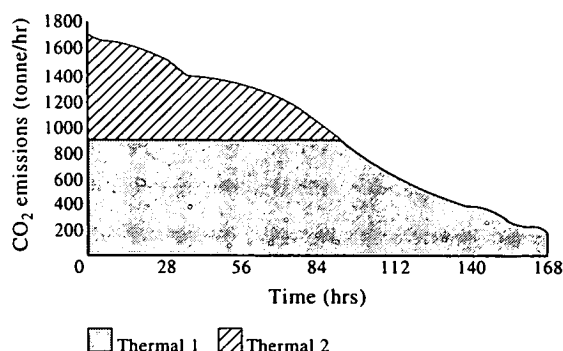


Figure 9. Alternative load-duration curve showing plant usage

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