Drivers and Barriers to Industrial

Ecology in the UK

Steve Harris

Doctor of Philosophy
The University of Edinburgh
2004

Abstract

Drivers and Barriers to Industrial Ecology in the UK

Industrial ecology (IE) is developing as the science of sustainability. The field is highly interdisciplinary and its scope, as yet somewhat undefined, is potentially huge. Industrial ecology is the study of how modern industrial society can live within the carrying capacity of the natural surrounding system by emulating (and integrating with) the cyclical eco-systems in nature.

Central to this thesis is: How can IE be implemented in the UK? There are generally two paths or routes (which need not be separate) to IE: product based analysis and industrial symbiosis (IS). This thesis concerns itself with the drivers and barriers to industrial ecology, focusing primarily on the symbiosis route. Although forms of IS have occurred throughout history, the implementation of IS networks on a regional or industrial park basis is emerging as potentially the main driver for IE. The research examines several system levels (national, regional, network, company) and combines research from:

1. Action research – implementation of an IS network and case study research of the local process industries.
2. Desk based research – examination of regional and national policies
3. Lessons and experiences from the UK National Industrial Symbiosis Programme; and findings from meetings and collaboration with BCSD-UK, the programmes facilitators.

The thesis examines how at the local and regional level IS networks can be successfully implemented by building on regional strengths in terms of cooperation and networking; and also building on policies and strategies. It examines how at the national level industrial ecology can incorporate and build on strategies and policies including: clusters, innovation, regional development, waste and sustainable development.

It is argued that for IE to succeed it has to be learnt by the main actors at all levels (company, regional and national), otherwise barriers will hinder IE's evolution. A technology transfer model is adopted to help understand and demonstrate how this learning and evolution could occur.

The research shows that it is usually a complex combination of small barriers that hinder IS development because the incentives are insufficient. Therefore, although some specific barriers are identified (such as the legislative label of 'waste'), it is suggested that it is more important for policy to focus on drivers.

The ability of IE to fit within, and indeed to unify policies and strategies, is seen to be the biggest driver. But the framework demonstrates the importance of *association* and hence how policy can induce a behavioural/cultural shift by targeting the *association* of key players. Importantly, drivers should concentrate on IE (the wider system perspective) because IS applied without wider system considerations can develop less favourable outcomes.

Declaration of Authenticity

I hereby declare that this thesis is entirely my own work and that the work has not been submitted for any other degree or professional qualification except as specified.

Contents

Chapter 7 Conclusions   **167**

List of Tables and Figures

Abbreviations

BCSD-UK   Business Council for Sustainable Development – United Kingdom
BPS   By-product Synergy
CCL   Climate Change Levy
CHP   Combined Heat and Power
DETR   Department of the Environment, Transport and the Regions
DFE   Design-for-Environment
DIET   Designing Industrial Ecosystems Tool (US EPA)
DTI   Department of Trade and Industry
EA   Environment Agency
EIP   Eco-industrial Park
ELV   End-of-Life Vehicles
EMAS   Eco-Management and Audit Scheme
EMS   Environmental Management System
EPR   Extended Producer Responsibility
EOP   End-of-Pipe
EPA   Environmental Protection Agency
EU   European Union
FaST   Facility Synergy Tool (US EPA)
FGD   Flue Gas Desulphurisation
GDG   Grangemouth Development Group
GIS   Geographical Information System
GWUG   Grangemouth Water Users Group
ICC   Inter-Company Cooperation
IE   Industrial Ecology
I-O   Input-to-Output
IPC   Integrated Pollution Control
IPPC   Integrated Pollution Prevention and Control
IS   Industrial Symbiosis
JIT   Just-in-Time manufacturing
LCA   Life Cycle Analysis
LEC   Local Enterprise Companies
LIES   Learning Industrial Ecology Strategy model
MFA   Materials Flow Analysis
NDPB   Non-departmental Public Bodies
NISP   National Industrial Symbiosis Programme
OECD   Organisation for Economic Cooperation and Development
PBA   Product Based Approach
PBI   Product Based Improvements
R&D   Research and Development
RDA   Regional Development Agency
SEPA   Scottish Environmental Protection Agency
SME   Small and Medium-sized Enterprise
TQM   Total Quality Management
USEPA   United States Environmental Protection Agency

Acknowledgements

This thesis has been a testing one, both on a personal and intellectual level. In such a young field with an enormous and as yet undefined scope, it was difficult at best to maintain the margins of focus. I have been fortunate to have the support of my supervisor and those close to me.

Firstly, I'd like to thank my supervisor Dr Colin Pritchard for all his help, support, patience, and perseverance.

The majority of the companies I contacted were extremely helpful and friendly, and I'd like to thank all those who helped in this research: in particular thanks to Mervyn Jones of BP.

Thanks to Peter Laybourn of BCSD-UK for his help and kindness: I wish you continued success with NISP.

I would also like to thank members of the IE community, in particular Murat Mirata (for his friendship, discussions and company over the odd pint).

A big thank you to all my Kernow family members for their support and encouragement and comments like: '*Gaw, abbent yew finished yet?*' Thank you: mum (party on!), dad (right on!), nana and papa (special thanks for helping me with the paper); and Maddie.

Thanks to my friends, dotted in various places around the world: Tim, Mat, Camille and Andreas.

Last and certainly not least: a big, big thank you to '*min lilla alskling*', Sara Jonsson, for her unfaltering support, energy, enthusiasm and love.

Chapter 1 Introduction

1.1 Industrial Ecology Introduction

Industrial Ecology is an emerging concept that compares the ideal sustainable society with that of natural ecosystems. The following words penned by Leonardo da Vinci some 500 years ago in one of his manuscripts (unnamed), eloquently contain the essence of Industrial Ecology (da Vinci, 1500):

'Although human genius through various inventions makes instruments corresponding to the same ends, it will never discover an invention more beautiful, nor more ready, nor more economical than does nature, because in her inventions nothing is lacking, and nothing is superfluous.'

Industrial Ecology (IE) has yet to find a single definition but is adequately expressed by Graedel (1995):

'It is a systems view, in which one seeks to optimise the total materials cycle from virgin material, to finished material, to component, to product, and to ultimate disposal. Factors to be optimised include resources, energy and capital.'

This thesis has beginnings in the following basic question: How can industrial ecology begin to be implemented in industrial society? How can industrial ecology be applied in the UK to make progress in sustainability? The task of achieving sustainability is enormous as is the range of issues that need to be considered in a field that requires a highly interdisciplinary approach (see Figure 1).

As will be discussed in Chapter 2, industrial ecology's scope is potentially huge, but to date research has predominately been in two areas:

- Flows of materials in nations, regions and companies; and the analysis of these.
- Symbiosis/ synergies between companies, utilising the 'waste=food' idea, that one company's waste can be used as another's input.

The second area, known as industrial symbiosis, is probably the most easily accessible component in terms of explaining to the layman what industrial ecology is. It is also the area that can most easily achieve improvements in resource productivity.
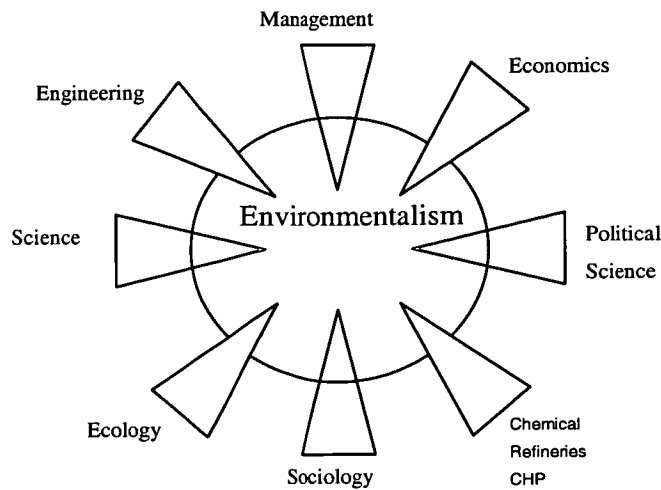
Figure 1.1: The Cross-disciplinary Aspect of Environmentalism (source: Hoffman, 1997:184)

This thesis concentrates on the business aspect of IE because, put simply, it is companies that supply products, which require the resources and create the waste. But the path towards a sustainable society will only be achieved by a holistic approach from many quarters of society. The transition to a sustainable society (Indigo,2003) will require design at the level of:

- Products
- Services
- Processes
- Materials and energy flows
- Facilities
- Business organisations/missions/strategies
- Non-Governmental Organisations and grassroots strategies
- Inter-company and inter-stakeholder relations
- Community and regional planning and infrastructure
- Societal institutions and policies

1.1.2 Industrial society, manufacturing and waste

The increase in the worlds' population (the root of the majority of the environmental problems) to more than 6 billion has made the earth's finite limits startlingly apparent. The world can no longer be seen as an unlimited resource. The anthropogenic system and its' manufacturing of numerous products, has vast effects on the world's environmental health in terms of resource use, energy use, waste and general pollution. The need for improvements in the present production system is therefore apparent from both ends – dwindling resources and a growing waste problem. Particularly in the UK the waste problem has been receiving increasing attention in recent years, due partly to European legislation, but also to the diminishing available space for landfill sites. The total mass of waste produced in the UK is estimated to be 434 million tonnes per annum (DEFRA, 2003). Figure 2 shows the break-down by sector.

United Kingdom

■ Agriculture

▨ Minerals (mining & quarrying)

■ Sewage Sludge

▤ Dredged material

▥ Municipal waste

▨ Commercial

▨ Industrial

□ Demolition & construction

Estimated Total = 434 million tonnes
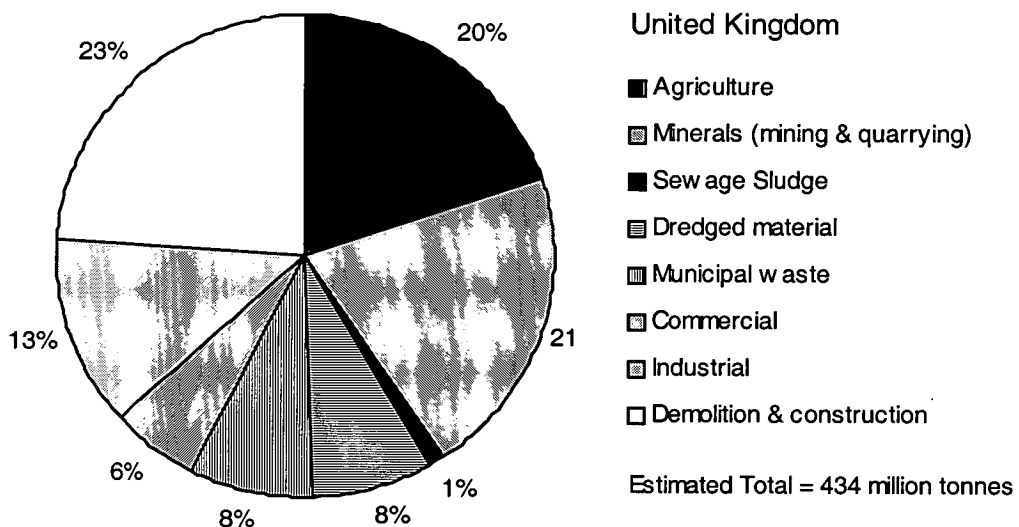
Figure 1.2: Estimated total annual arisings by sector (source: DEFRA, 2003)

A study by the World Resource Institute (WRI, 2000) looked at the material outflows from 5 industrial economies: Austria, Germany, Japan, The Netherlands and the United States. Its' key findings were:

- Industrial economies are becoming more efficient in their use of materials, but waste generation continues to increase.

- One half to three quarters of annual resource inputs to industrial economies are returned to the environment as wastes within a year.
- Outputs of some hazardous materials have been regulated and successfully reduced or stabilised, but outputs of many potentially harmful materials continue to increase.
- The extraction and use (or import) of fossil energy resources dominate output flows in all industrial countries.
- Physical accounts are urgently needed, because our knowledge of resource use and waste outputs is surprisingly limited.

The second finding is made more ominous when you consider it alongside the fact that we currently use ten tonnes of raw materials to produce one tonne of goods (not including water or air) sold to the final consumer, an efficiency of less than 10% (WRI, 2000).

Industry is a large part of the problem and must therefore be a large part of the solution. Equally, though society's consumption habits must change. How can industrial society begin to change? Industrial society must be adapted to fit within the cycles of nature and within the earth's carrying capacity (resource limits and pollution limits). This is known as 'sustainability' and the path to get there is known as 'sustainable development'. The definition of both these terms has attracted much debate, but one of the most quoted is that of The World Commission on Environment and Development, which has said that sustainable development is:

'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WECD, 1987).

In order to be physically sustainable society's material and energy throughputs would have to meet the following three conditions (Daly, 1991):

1. Its rates of use of renewable resources do not exceed their rates of regeneration.
2. Its rates of use of non-renewable resources do not exceed the rate at which sustainable renewable substitutes are developed.
3. Its rates of pollution emission do not exceed the assimilative capacity of the environment.

How can manufacturers begin to alter their behaviour and make real change? Large corporations have in the past, received the majority of the criticism regarding environmental damage. However, the problem does not lie entirely on the shoulders of manufacturers, who in essence merely operate within the present economic system: it is the system that must also change. There is little doubt that legislation has been the greatest driver causing manufacturing companies to make environmental improvements (Green et al, 1994; Irwin & Hooper, 1992; Newman, 1992; Hunt, 1995). In the foreseeable future this important influence is likely to continue. Past legislation has prompted an 'end of pipe' (EOP) response that has often been viewed as an expensive approach. The EOP (or clean-up response) controls the release of pollutants by capturing and cleaning up waste streams before releasing them in smaller quantities or in a more dilute form into the environment. An example of this is flue-gas desulphurisation (FGD) that reduces the risk of acid rain by removing sulphur dioxide from the chimney gases of metal smelting plants, etc.

With global recognition of the environmental problem, pressure for improvement now often comes from international agreements and EC legislation. The UK government's Kyoto Protocol target is a 12.5% cut in the basket of six greenhouse gases from the 1990 level by 2010. The target for carbon dioxide emissions is even more demanding, being 20% below 1990 levels by 2010 (DETR). As we will discuss later in the thesis, there is a growing emphasis from policy and government strategies, on waste issues and resource productivity.

In recent years attention has turned to waste minimisation techniques and energy reduction. These not only save businesses money, but also improve the environmental impact of participating companies. Environmental management schemes are also becoming more popular. When correctly implemented, they have the potential to integrate environmental thinking into the company at all levels, but have received significant criticism (ENDS Report, 353, 2004). Only when manufacturers integrate environmental considerations at all levels of their business can we consider that we are on the road to sustainability. It is here that such concepts as industrial symbiosis and industrial ecology can help manufacturers to adjust to the requirements of sustainability, both as individual companies and as an industrial system.

1.3 Thesis Structure

Chapter 2, the literature review, will look at the history of industrial ecology before discussing some of the projects that have emerged around the world. It then moves on to look at a range of issues that are important for the application of IE.

Next Chapter 3 presents the research design and discusses the various paths and contexts that were considered to undertake this research thesis. Chapter 4 then discusses the project development and presents findings from the study in the Forth Valley on existing and potential synergies. It describes and discusses the predominant barriers and drivers to these synergies. The chapter continues by analysing the related regional and national policies and strategies that, it is proposed, lay appropriate foundations for IS networks and IE strategies.

In Chapter 5 a conceptual framework of technology transfer is adapted that helps to understand IE as an evolutionary and learning process. Chapter 6 then utilises the adapted framework to reassess the drivers and barriers, and illustrate how the key actors at the system levels of company, region and nation can learn IE. The chapter then uses this analysis to suggest appropriate policies.

Finally Chapter 7 presents the conclusions of this research and makes several suggestions for future research.

Chapter 2 Literature Review

2.1 Industrial Ecology

2.1.1 History of Industrial Ecology

Many authors quote Frosch and Gallopoulos (1989) as the pioneers of industrial ecology, in a seminal article they stated:

'The traditional model of industry activity, in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of, should be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimised and the effluents of one process serve as raw materials for another process.'

As will be discussed, the last sentence really describes Industrial Symbiosis (IS), an important component of IE. Although IE has struggled for a precise definition, the comparison of the industrial system with natural ecosystems is an inspiring vision. Such a vision is precisely what is needed in these troubled environmental times, as Paul Hawken (1993) wrote in 'The Ecology of Commerce':

''The transition from immature ecosystems is called ecological succession. What we must now create is commercial succession. Rather than argue about where to put our wastes, who will pay for it, and how long it will be before toxins leak into the groundwater, we should be trying to design systems that are elegantly imitative of climax ecosystems found in nature... Business needs more than criticism. It needs a plan, a vision, a basis –a broad social mandate that will turn it away from the linear, addictive, short-term activities in which it is enmeshed and trapped''

Erkman (1997) identified several instances where IE activity existed well before the concepts emergence. For example, the idea was clearly present in the writings of Odum (1955), although not explicitly named. In addition to what Erkman documented, certain industry sectors, such as the iron and steel sector, have long established recycling loops; and other instances have occurred in agro-ecosystems.

Other noteworthy, early research identified by Erkman (1997) occurred in Belgium and Japan. In Japan the Ministry of International Trade and Industry (MITI) commissioned a

study that in 1971 resulted in an Industry-Ecology Working Group. The Group was commissioned to further develop the idea of a reinterpretation of the industrial system in terms of scientific ecology (Erkman, 1997). The idea behind the Belgium study (Billen et al. 1983) was to produce an overview of the Belgian economy on the basis of industrial production statistics, but to express these in terms of materials and energy flows rather than the traditional abstract monetary units. The work clearly has IE connotations:

'To include industrial activity in the field of an ecological analysis, you have to consider the relations of a factory with the factories producing the raw materials that it consumes, with the distribution channels it depends on to sell its products, with the consumers who use them... In sum, you have to define industrial society as an ecosystem made up of the whole of its mean of production, and distribution and consumption networks, as well as the reserves of raw material and energy that it uses and the waste it produces... A description in terms of circulation of materials or energy produces a view of economic activity in its physical reality and shows how society manages its natural resources' (Billen et al, 1983).

Frosch and Gallopoulos (1989) are generally considered the modern pioneers of IE, and certainly the authors who grabbed the attention of a wider audience. At about the same time Ayres (1989) introduced the concept of 'industrial metabolism', which has come to be regarded as a sub-component of IE. Industrial metabolism is defined as the process by which mass and energy (exergy) flows are handled or transformed by the economy (Seager and Theis, 2002). It is basically an application of the materials-balance principle aimed at understanding the circulation of the materials and energy flows linked to human activity. IE goes further because it aims to understand how the industrial system functions and how it can be made to interact more compatibly with the natural world.

2.1.2 Lessons from the Natural World

Industrial ecology exploits ecosystems as a metaphor, one such as "the industrial world is an ecosystem" (Lifset, 1997). Using a systems description Gradel and Allenby (1995) compare the evolution of ecological systems to that of industrial systems. In the proposed "Type I" system the flows of materials are linear, analogous to life on primitive earth where resources were turned into waste. These systems eventually evolved to the "Type II" (Figure 2.1.2) system where a large degree of recycling and material and energy cascading took place. This Type required limited energy and material input and produced limited waste, although the actual flow of materials within the system could have been quite large. The ultimate sustainable system is represented by the Type III system and is the desired end state of the

field of IE for the anthropogenic system. Biological systems have evolved to be almost completely cyclical, where waste and resources are undefined and the only input to the system is solar radiation.
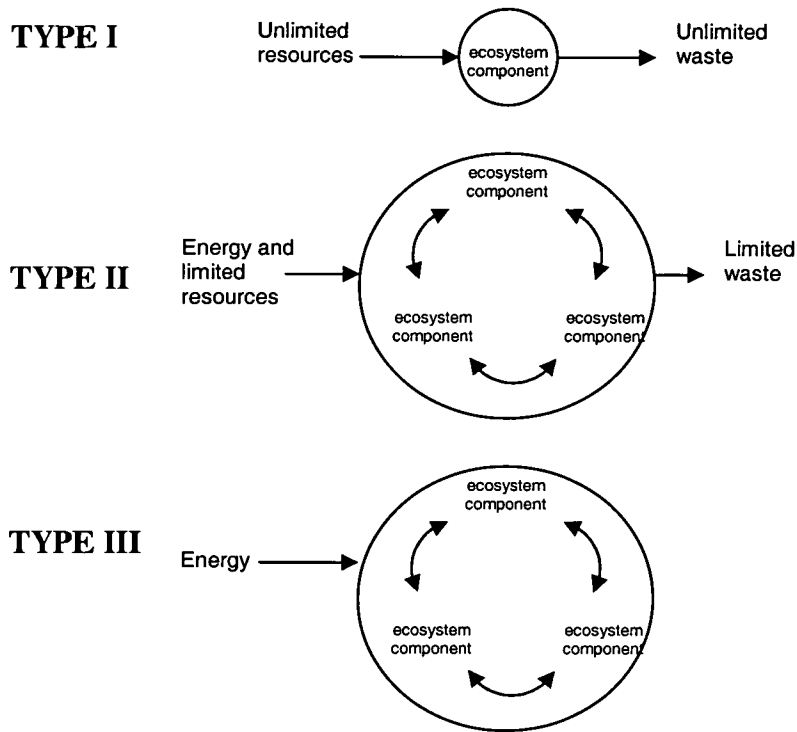
Figure 2.1.2: Type I system with linear materials flows, Type II with quasicyclic materials flows and Type III with cyclic materials flows (source: Graedel, 1995)

Humankind has always learnt directly from nature and continues to do so. The field of IE has yet to fully explore other lessons from ecology studies that could be applied to the field. However, there are some easily understood rules that nature adheres to, that industry could potentially benefit from (Thompson, 1999):

- Use waste as a resource
- Diversify and co-operate to fully use the habitat
- Gather and use energy efficiently
- Optimise rather than maximise
- Use material sparingly
- Don't foul nests
- Don't draw down resources
- Remain in balance with the biosphere
- Run on information and shop locally.

2.1.3 Refining the defining

Industrial Ecology has been described as 'The Science of Sustainability' (Allenby, 1999; ISIE Conference, 2001) but has struggled to find one clear definition. Graedel and Allenby (1995) state:

'Industrial Ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to component, to product, and to ultimate disposal. Factors to be optimised include resources, energy and capital'

Industrial Ecology is both an emerging field and an end (or desired) state of the anthropogenic system. A collection of definitions is given in Table 2.1.3.

- The means by which a state of sustainable development is approached and maintained, consisting of a systems view of human economic activity and its inter-relationship with fundamental biological, chemical and physical systems-Allenby (1992)
- The totality or the pattern of relationships between various industrial activities, their products and the environment-Patel (1992)
- A recognition that manufacturing and service systems are in fact natural systems intimately connected to their local and regional ecosystems and the global biosphere, with the goal of bringing the industrial system as close as possible to being a closed-loop system with near complete recycling of all materials-Lowe (1993)
- A large-scale, integrated management tool that designs industrial infrastructures as if they were a series of interlocking artificial ecosystems interfacing with the natural global ecosystem-Hawken (1993)
- A largely analytic framework that serves mostly to identify and enumerate the myriad flows of materials and technological artefacts within a web of producers and consumers-Ehrenfeld (1994)
- The design of industrial infrastructures as if they were a series of interlocking man-made ecosystems interfacing with the natural global ecosystem. Industrial ecology takes the pattern of the natural environment as a model for solving environmental problems, creating a new paradigm for the industrial system as a process-Tibbs (1992)

Table 2.1.3: Industrial ecology, as envisioned by key researchers and authors (Adapted from Cote & Smolenaars, 1997).

Erkman (1997) noted that whatever the varying definitions all authors more or less agreed on at least three key elements of the industrial ecology/metabolism perspective:

1. It is a systemic, comprehensive, integrated view of all the components of the industrial economy and their relations with the biosphere.

2. It emphases the biophysical substratum of human activities, i.e. the complex patterns of material flows within and outside the industrial system, in contrast with current approaches which mostly consider the economy in terms of abstract monetary units, or alternatively energy flows.
3. It considers technological dynamics, i.e. the long term evolution (technological trajectories) of clusters of key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem.

A working paper produced for the consulting firm Arthur D Little, by Hardin Tibbs, (Industrial Ecology: an environmental agenda for industry) essentially reproduces the ideas of Frosch and Gallopoulus but presents them in the language of the business world. In subsequent published revisions of the paper Tibbs (1992) outlines six principal elements of industrial ecology:

1. Industrial Ecosystems - Fostering cooperation among various industries whereby the waste of one production process becomes the feedstock for another.

2. Balancing industrial input and output to the constraints of natural systems - Identifying ways that industry can safely interface with nature, in terms of location, intensity, and timing, and developing indicators for real-time monitoring. Consideration of recovery time is a crucial aspect.

3. Dematerialization of industrial output - Striving to decrease materials and energy intensity in industrial production.

4. Improving the efficiency of industrial processes - Re-designing production processes and patterns for maximum conservation of resources.

5. Development of renewable energy supplies for industrial production - Creating a world-wide energy system that functions as an integral part of industrial eco-systems.

6. Adoption of new national and international economic development policies - Integrating economic and environmental accounting in policy options.

In addition to the definitional disparity, IE has not yet reached a definite scope and terminology (Chiu & Yong, 2004). One approach is to characterize the elements of IE on various spatial scales. Lifset and Graedel (2002) suggest dividing IE activities into those that focus "at the firm or unit process level, at the inter-firm, district or sector level, and finally at the regional, national, or global level." Figure 2.1.3 depicts this division of IE activities into these different scales.

```
                    ┌─────────────────┐
                    │ Sustainability  │
                    └────────┬────────┘
                             ▼
        ┌────────────────────────────────────────┐
        │           Industrial Ecology           │
        └────────────────────────────────────────┘
         ◄───────────        ▼         ───────────►
```

Firm Level
- design for environment
- pollution prevention
- eco-efficiency
- green accounting

Between Firms
- eco-industrial parks (industrial symbiosis)
- product life cycles
- industrial sector initiatives

Regional/Global
- budgets and cycles
- materials and energy flow studies (MFA)
- dematerialisation and decarbonisation
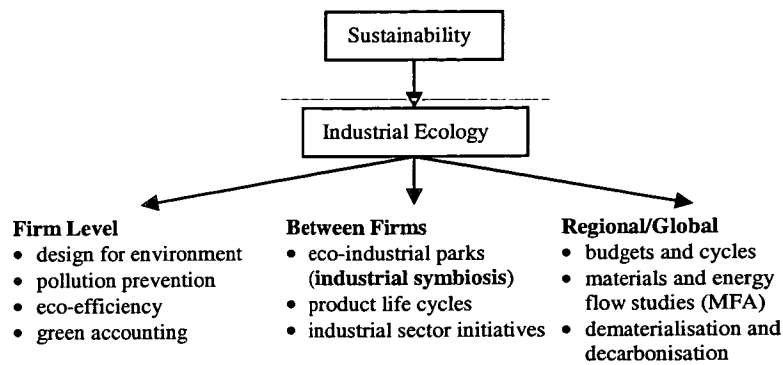
Figure 2.1.3: The elements of industrial ecology seen as operating at different levels (source: Lifset and Graedel, 2002)

Others have noted IE's worth as a model and a vision. According to Cohen-Rosenthal (2004) the end concern of IE is:

'actually fairly easy to state. The goal, at the minimum, is to generate the least damage in industrial and ecological systems through the optimal circulation of materials and energy. Highest value use with the least dissipation of resources forms the core of systematic application of industrial ecology.'

The term "Industrial Symbiosis," a central component of IE, was originally coined by Valdemar Christensen, a manager at Kalundborg, Denmark. According to him it is: *'a cooperation between different industries by which the presence of each... increases the viability of the other(s), and by which the demands [of] society for resource savings and environmental protection are considered'* (Quoted in Engberg, 1993).

The biological definition of 'symbiosis' is *'The living together in more or less imitative association or even close union of two dissimilar organisms'* (Webster's Revised Unabridged Dictionary, 1996). But it is sometimes used as an umbrella term to cover three distinct types of inter-species relationship: *parasitism*, where one organism benefits from the relationship to the detriment of the other organism(s) involved; *commensalism*, where one organism benefits with no significant detriment or benefit to the other organism(s); and *mutualism*, where both (all) species benefit from the relationship (Taylor, 1999). This classification seems to cover most business relationships! Interestingly, symbiosis has been developed as a third avenue of evolution, in the theory of 'symbiogenesis'. This theory sees the creation of new forms of life through permanent symbiotic arrangements as the principal avenue of evolution for all higher organisms. This echoes a possibly fundamental lesson for businesses who wish to survive: they must develop co-operative relationships.

A number of terms have thus emerged based around the idea of industrial ecology: industrial metabolism, industrial symbiosis and also eco-industrial park or network. The development of eco-industrial parks (EIPs) is a similar approach to creating networks and exchanges but on an industrial park scale. The EIP approach is often to design a park from scratch; but there have also been attempts to convert an existing industrial park. A popular definition for an eco-industrial park/network is provided by Lowe et al (1995):

'A community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environment and resource issues including information, energy, water, materials, infrastructure, and natural habitat. By working together, the community of businesses seeks collective benefit that is greater than the sum of the individual benefits each company would realise if it optimised its individual performance only.'

In an attempt to provide conceptual clarity in understanding nature as a model under IE, Isenmann (2003) presents a framework based on 5 characteristics of IE (Figure 2.1.4)
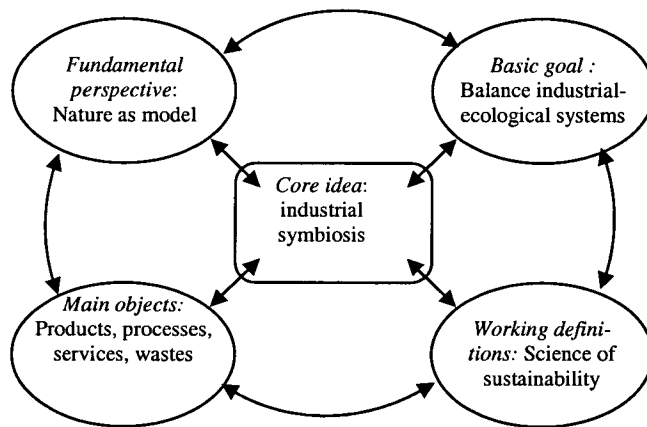
Figure 2.1.4: Five characteristics of industrial ecology (source: Isenmann, 2003)

However a fundamental flaw in this proposed framework is that the *core idea* of IE is industrial symbiosis. IS is the most easily appreciated aspect of IE but not the core idea. If there is a 'core idea' it is more probably, and more fundamentally 'symbiosis' or co-operation; between many actors of industrial society. IS concentrates on symbiosis between companies, whereas IE considers the wider system, most importantly post-consumer flow and not simply utilisation of wastes by another company.

Another concept of note, and strongly related to IE is that of Zero Emissions (ZE). Compared to IE, Zero Emissions (also termed Total Resource Management (Environ, 2001)) has a more explicit focus on the use of 100% of resources in the manufacture of products. As with industrial ecology, ZE sees industry's ultimate, sustainable aim as a closed loop emulating the cycles evident in the natural world. The ZERI foundation gives the following definition for Zero Emissions (ZERI):

'Zero Emissions envisages all industrial inputs being used in the final products or converted into value-added inputs for other industries or processes. In this way, industries will reorganise into "clusters" such that each industry's wastes / by-products are fully matched with others' input requirements, and the integrated whole produces no waste of any kind.'

The concept of ZE has been embraced in Japan by government and industry alike (Pauli, 1998). ZE research can be separated into two main approaches:

- those working with major industry and looking at maintaining the momentum of improved eco-efficiency;
- and those who work on projects that centre around more 'natural ' and readily biodegradable resources.

In essence ZE is waste 'utilisation'; questioning how we view waste:

'Zero emissions is not waste minimisation... this is waste 'utilisation' to achieve more with less. The competitive advantage in the new millenniums will be total productivity - zero waste, zero inventory, zero defects and zero emissions' (Breakthrough Technologies, 2000).

Many practitioners have noted that a cultural shift is needed in the way waste is viewed (Bontoux L and Leone F, 1997; DEFRA, 2003a; Pongracz E and Pohjola VJ, 2004). Some sectors such as the chemical industry often use the term by-products. When waste is reconsidered and waste utilisation becomes more common, or where the situation demands it, some interesting ideas can emerge. The people of a small fishing town on the north-east coast of Iceland have come up with an intriguing waste disposal scheme - importing crocodiles (BBC News, 2003). The crocodiles would be used to consume the waste of the fishing industry, but they may develop several spin-off roles. In addition to providing a tourist attraction the crocodiles themselves have potential end uses such as meat and attractive handbags!

Industrial ecology therefore can be said to influence thinking from a number of directions:

> - the raw material – sourcing renewable, post consumer or post company resources,
> - the production – designing out waste by redesigning processes,
> - the waste end – encouraging companies to reconsider the concept of waste,
> - the consumption – reducing the consumption of energy and materials.

2.1.4 The Developing Science – tools and techniques

Industrial ecology, as defined and analysed by various authors, broadens the scope from cleaner production within companies to cooperation within and between chains of companies (cascading, facility sharing and so on) (Bass, 1999). Boons and Bass (1997) focused attention on the coordination of activities of different economic actors in an industrial ecology concept. That coordination can be elaborated via the product or material life cycle, a geographical area, a sector or miscellaneous relationships such as bilateral constructions. Korhonen (2002) makes a useful contribution by dividing IE into two paths: product based systems analysis (involving for example life cycle analysis) and geographical based analysis. Boons and Baas have made the most important contributions to the IE literature on organisational relationships and have highlighted its significance. Whether the relationships exist on a supply chain basis or in a sector network, management of IE projects should make use of the relationship (Boons and Baas, 1997).

The field of IE is somewhat divided into two spheres. Perhaps in an attempt to develop IE as a 'sound science' based on mathematical certainty, there appears to be too much emphasis in the literature, and at IE conferences, on concepts such as 'material flow analysis' and 'life cycle assessment' (discussed below). Although both of these are extremely useful concepts, the most difficult aspects of industrial ecology in the real world are the decisions to be made, the negotiations that take place amongst stakeholders and the necessary regulatory framework needed to effect positive change.

The Society of Environmental Toxicology and Chemistry defines the LCA process as follows:

'The life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and

material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use/re-use/maintenance; recycling; and final disposal' (SETAC, 1993).

Other than LCA, the other most promising analytical method for IE is systems analysis (Seager and Theis, 2002). Both are sensitive to how the boundaries of study are defined. LCA relies on the metaphor of a product or process 'lifetime'; whereas systems analysis is more flexible and amenable to any scale: the single product or process, an entire industry or geographical region. LCA is primarily comparative (and thereby descriptive), while systems analysis is aimed at optimisation and decision making (and thereby prescriptive). Seager and Theis (2002) provide a useful comparison (see Table 2.1.4).

Characteristic	Life cycle assessment	Systems Analysis
Purpose	Descriptive	Prescriptive
Boundaries	Cradle to cradle/grave	Scalable
Data requirements	Broad	Focus on decision
Emphasis	Materials cycling	Any uniform metric (e.g dollars)
Applicability	Industrial Metabolism	Industrial Ecology

Table 2.1.4: Summary comparison of LCA and systems analysis (source: Seager and Theis, 2002)

A wide variety of approaches has been used, but LCA typically follows a four-step methodology: scoping, inventory analysis, impact assessment and improvement assessment (see Gradel, 1998; SETAC, 1993; or USEPA, 1993).

Materials Flow Analysis (MFA) is a method of investigating flows of specific materials through an economic system in a specific geographic area during a certain period of time (Ayres and Ayres, 1998; Baccini & Brunner, 1991; Kytzia et al, 2004). These flows are defined in mass units per time period. The main field of application is evaluation of environmental policies ranging from emission control to promotion of technological changes and to consumer information (Kytzia et al, 2004). Substance Flow Analysis is similarly defined, but places the emphasis on investigating flows of substances rather than materials. Both of these methods however are limited to examining physical components of the industrial system, which is driven by cultural, social and economic factors.

2.2 Examples of Projects

This section gives a brief overview of projects from various parts of the world. It starts with the flagship example of Kalundborg in Denmark, which is the most quoted example to date. Other projects discussed are mostly in embryonic form, the field of IE being young, but its application even more so. Of course, the lessons of application will take a few more years to fully emerge and will help develop the theory more fully. As will be discussed later this gives all the more reason to draw parallels with, and learn from, other fields such as clusters, inter-company relationships & collaboration, regional environmental management and development.

2.2.1 The 'Industrial Symbiosis' of Kalundborg, Denmark

The most famous and most quoted example of IE is the 'industrial symbiosis' of Kalundborg, in Denmark, which shows that such an approach is both practical and economically viable. The symbiosis evolved during the past twenty-five years. The network principally consists of the local authority and five large companies: Asnaes power station, the plasterboard manufacturer Gyproc, the pharmaceutical company Novo Nordisk, the Statoil refinery, and the soil remediation company Biotekniks Jordens. The companies exchange by-products such as: steam, hot water, refinery gas, gypsum, biomass, sulphur, fly ash and sludge; and thus attain a high level of environmental and economic efficiency. Figure 2.2.1 shows the network of exchanges at Kalundborg.

The trading of by-products has offered its participants several advantages:

- Reuse of by products - the by-product of one enterprise becomes an important raw material for another.
- Reduced consumption of resources, e.g. water, coal, oil gypsum, fertiliser.
- Reduced environmental impact in the form of lower emissions of CO_2 and SO_2, smaller discharge of wastewater and less pollution of watercourses etc.
- Better utilisation of energy resources. For example the refinery's surplus gas flare has been reduced to a night light because of internal use and because Asnaes Power Station uses gas when available in place of coal and oil.
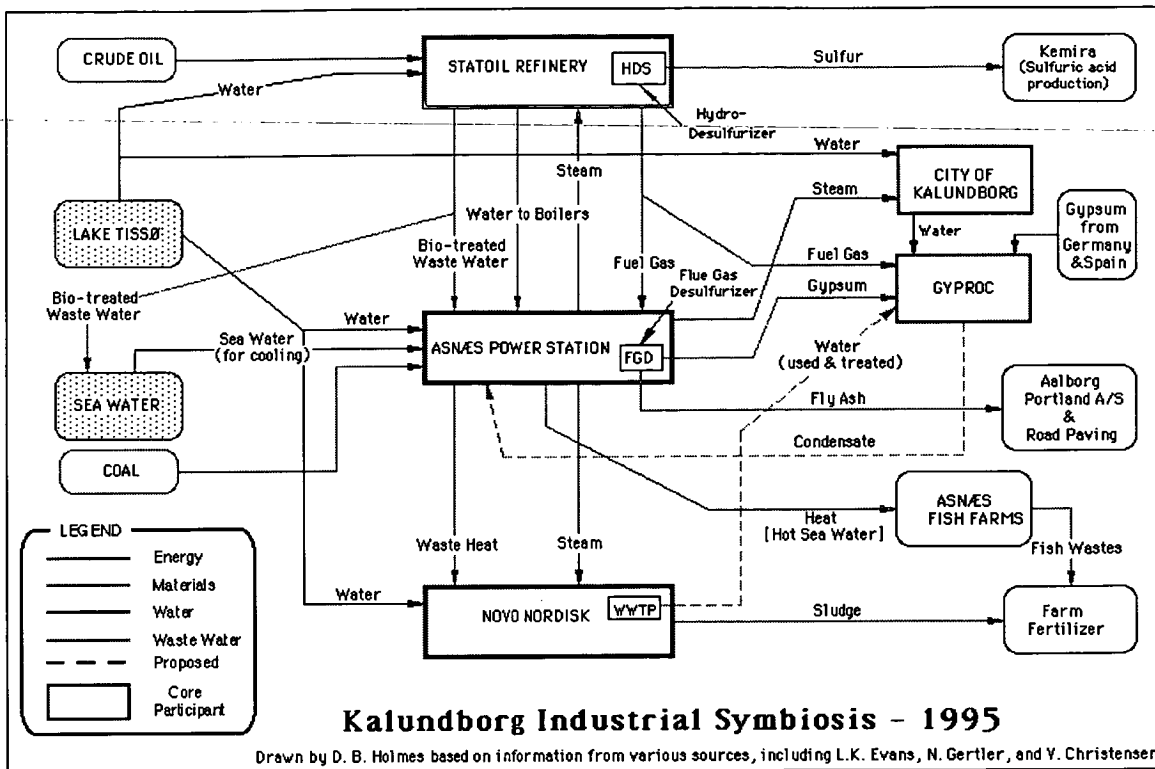
Figure 2.2.1: Kalundborg industrial symbiosis. (Source: Indigo Development, 2001)

Examples of annual resource savings, production and environmental improvements due to the symbiotic partnerships are shown in Table 2.2.1.

Reduced ground water consumption	1.9 million m^3
Reduced surface water consumption	1.0 million m^3 (~30% total savings)
Reduced oil consumption	20,000 tonnes (~50%)
Reduced coal consumption	30,000 tonnes (~2%)
Industrial gypsum production	200,000 tonnes
Sulphur production (from FGD, sold to make H$_2$SO$_4$)	2,900 tonnes
Fly ash reuse	64,000 tonnes

Table 2.2.1: Annual resource saving examples from IS at Kalundborg (source: .

From its beginning in the early seventies up to 1993, the $60 million investment in infrastructure (to transport energy and materials) produced $120 million in revenues and cost-savings. Kalundborg's success is largely due to the town's small size, which allowed companies to become aware of opportunities through informal meetings. As one of the managers involved stated 'You need to know what is going on in your neighbour's business

to be able to take advantage of any opportunities. In this small town people know each other and we are always talking' (Financial Times, 1990).

2.2.2 Other Eco-industrial Developments

In other parts of the world there has been a steadily growing interest in eco-industrial development. Within Europe, the next most documented case after Kalundborg is a region of Austria known as Styria. The amount of waste treated within the recycling structures of Styria totalled 1.5 million tonnes per year (Schwarz and Steininger, 1997). As with the case of Kalundborg however, the system of exchanges evolved over several years and ultimately their development was triggered by cost calculations (Schwarz and Steininger, 1997). In a case study of 968 Austrian manufacturing companies, cooperative exchange structures were dominant over those developed under purely market conditions (Strebel et al, 1996).

There are numerous other examples of eco-industrial development but they are relatively immature and hence limited published results are available. Examples are given in Table 2.2.2.

The US approach has been to create 'eco-industrial parks', of which 25 have appeared within the past five years (Indigo Development, 2001). A variety of software has been developed to assist the process. In a number of cases GIS systems are used to give a visual representation and linked to databases to locate suitable input-output relationships within a certain radius. The Environmental Protection Agency of the US support and sponsor such eco-industrial relations. Under its XL initiative, the EPA exempts the eco-communities from environmental regulations on condition that the consequent environmental benefits are greater than they would be under the regulations alone (USEPA, 2001).

The Bechtel Corporation developed software called the Industrial Materials Exchange (IME) analyser that links large numbers of regional industries in a network of materials exchange (USC, 2001). The IME maintains a database of more than 350 industry profiles, specifying typical production input and output; a search-and-match system that identifies feasible exchanges among existing and prospective regional businesses; and a procedure that uses material quantities and costs to pinpoint economically and environmentally sound matches (USC, 2001). It was developed from petroleum complex planning software. Using the

software to find links among 150 companies, it found 29 companies within a 15-mile radius that could profitably create by-product synergies. These were primarily chemical producers converting solvents, carbon dioxide, plastics and other waste streams into construction materials, fuel, shoe soles and other products

Site	Characteristics
Rotterdam Harbour Industrial Ecology Project, Netherlands(ENIS)	Project to explore the potential of creating by-product exchange amongst 60 companies; training for participating companies (Lowe et al. 1998)
Ecopark Moerdijk, Netherlands	Redeveloping an existing industrial site - decontamination of polluted ground (Carstensen 1999)
Eco-Industrial Park Karlsruhe, Germany	Virtual Eco-Industrial Park; about 40-50 companies; exchange network for organic and mineral by-products, information and communication networking; dematerialization chains (Hiessl1998 / Schön et al. 1999)
Verwertungssystem Ruhrgebiet, Germany	Highly evolved recycling network; steel plant, power station, building material industries and different other companies exchanging by-products, steam and energy (Schwarz 1996)
Bioenergie und Rohstoffzentrum Dormagen	Virtual Eco-Industrial Park; by-product exchanges and energy cascades, information and research entity; extended collaboration between companies, university and public entities (Denaro,1999)
Gewerbegebiet Henstedt- Ulzburg/ Kaltenkirchen, Germany	Eco-Industrial Park project; inter-firm material and energy exchanges, common water treatment approaches, public and private entities collaboration and co-financing (Großmann et al. 1999)
Fujisawa Factory Eco-Industrial Park, Japan	Combination of industrial, commercial, agricultural, residential and recreational components, including technologies and features in energy conservation and cascading, renewable energies, solar greenhouses, waste water treatment using wetlands and reuse of treated water, conversion of wastes into cement and ceramics, reuse and recycling of materials etc. (Côté & Cohen-Rosenthal 1998)

Table 2.2.2: Eco-industrial development examples (source: adapted from Fleig, 2000)

A further study in the US, the "Triangle J Project", studied 182 companies and discovered 'probable or possible partners for cost-effective sharing of materials water or energy' for 48% of the companies (Kincaid, 1999). They discovered that the most important element in developing an industrial ecosystem infrastructure was the presence of a 'facilitator' or 'product champion' to make the links and encourage collaboration.

The U.S. Business Council for Sustainable Development developed several projects under the banners of By-Product Synergy (BPS), which is "the synergy among diverse industries,

agriculture and communities, resulting in profitable conversion of by-products and wastes to resources promoting sustainability (USBCSD, 2001)."

During the first two years of this research thesis, the research and development of IE in the UK seemed to be lagging behind that of its Western counterparts. Before the development of the National Industrial Symbiosis Programme (discussed later in Chapter 4) projects in the UK with an IE flavour were developed under the Zero Emissions name. A definition given in 'Signposts from the future, a summary of emerging themes', Foresight, Nov 2000, is:

"The concept of 'industrial ecology' is suggested as the next stage in the evolutionary development from end-of-pipe or preventative environmental improvements. Linking green chemistry and clean technologies, industrial ecology takes an integrated, systemic approach. It connects the inputs and outputs of one process, including material, energy, products, emissions and wastes, with those of others, to produce an integrated industrial estate with 'zero emissions'."

Over the past few years a number of waste exchanges have appeared on the Internet, and there are now at least 12 operating in the UK (ENDS, 307, 2000). However, there is a startling difference between IE and 'waste exchanges', and often a danger in IE projects that companies may link the two and fail to see the wider benefits of IE.

In a comparative study between IE systems in The Netherlands and in the US, Heeres, et al (2004) conclude, based on initial results, that Dutch IE projects appear to be more successful than their US counterparts. This difference in success is attributed to the fact that the US projects were initiated by local and regional governments while the Dutch projects were usually initiated by the companies themselves (Heeres et al, 2004).

2.2.3 Zero Emissions Projects

ZE is the brainchild of European industrialist Gunter Pauli, who saw that achieving ZE requires developing critical technologies and reinventing the regulatory climate that now impedes innovation in environmental risk reduction. The main differences that appear between industrial ecology and zero emissions are that, while IE concentrates on creating networks and industrial symbiosis, ZE concentrates more on 100% utilisation of natural materials. ZE projects to date have mostly targeted the sectors that are most open to such an approach and can gain more immediate financial benefit. An example is the brewery in

Namibia, where they increase the use of all materials, as shown in Figure 2.2.3. The ZERI projects have chiefly involved the use of biodegradable and alternative materials (such as compostable plastics), whilst IE places its hope on technological innovation.
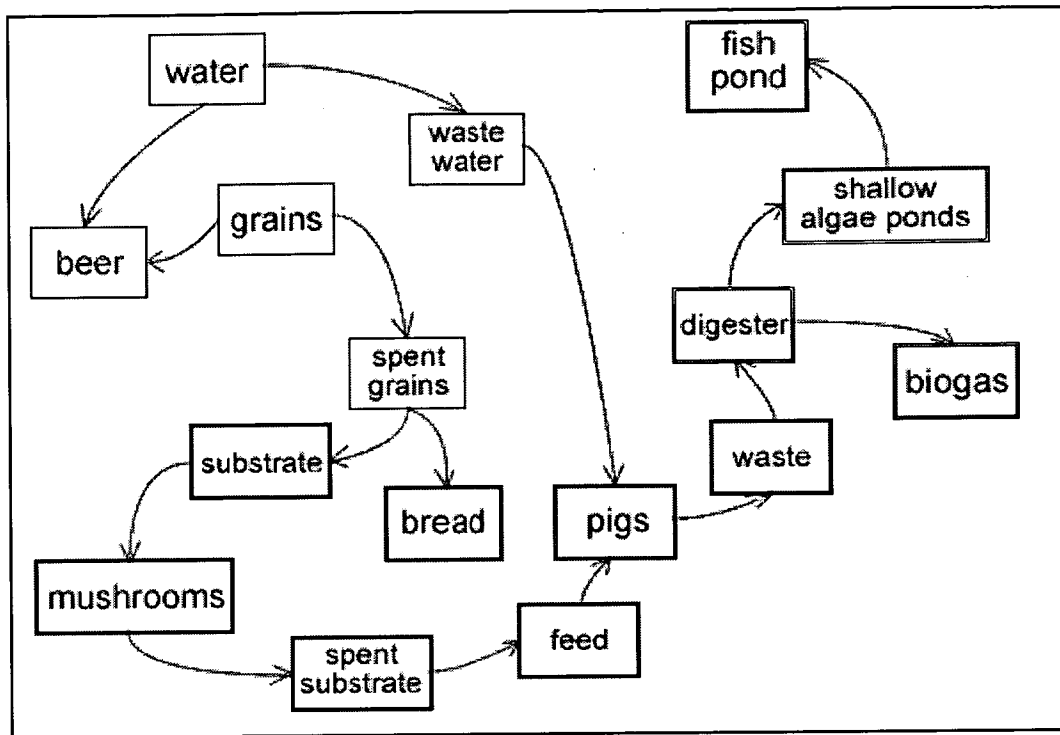
Figure 2.2.3: The ZERI Brewery. (Source: www.zeri.org)

In terms of real moves towards zero emissions in industrialised countries, Japan has led the way, where ZE is taking on the status of national policy (Pauli, 1998). Industry and government are working with universities and making a concerted effort to develop a national zero emissions strategy. There have been a number of examples that could be described as moves towards ZE within companies. NEC recently claimed to have achieved 'zero emission' status (Fabtech, 2002). However, this generally refers to the fact that the company has found routes for its by-products other than disposal, although from a systems perspective the company may still be unsustainable.

2.3 Methods and Strategies for Industrial Ecology

> Where there is no vision, the people perish. *Old Testament, Proverbs 29:18*

The approaches to industrial ecology can be summarised into product based and geographical analysis (Korhonen, 2002). Korhonen (2002) concludes that when the basic vision and the overriding goal is the local industrial ecosystem, the product-based approach can serve as an inventory tool to support the project. Used separately however they could support conflicting decisions for environmental policy and management. Creating a vision and an understanding of the overall goal is increasingly recognised as important in studies from innovation (Kass, 2000) through to regional and sustainable development (DETR, 1998; DTI, 2003a). An evolutionary approach is therefore needed (Ehrenfeld and Chertow, 2002)

Through their analysis of Styria, and other regions, Schwarz and Steininger (1997) concluded that 'recycling structures' must exist in many regions even when not explicitly recognised as such. The task now for many IE practitioners is to stimulate these exchanges by the creation of EIPs and regional industrial ecosystems. There are two basic philosophies to the development of eco-industrial projects: the self organised system approach and the engineered system approach (Fleig, 2000). In the former approach emphasis is on facilitating connections between companies by providing appropriate fostering conditions. The engineered systems approach is based on obtaining and analysing data for the material and energy flows of companies within a region. It more or less assumes that intelligent companies will thereby actively engage in adopting the opportunities identified. Fleig (2000) identified a number of models and starting points that have been used in the implementation of eco-industrial parks, and which can also be useful to consider from a regional context (see Table 2.2.4).

The scope for IE collaboration between companies goes beyond material and energy exchanges to include many areas for efficiency improvements, as illustrated in Table 2.2.5. The importance of communication and interaction amongst the respective companies, thereby creating an 'atmosphere', is recognised throughout IE literature (Schwarz and Steininger, 1997; Boons and Baas, 1997; Thoresen, 2001). Trust between parties is fundamental and hence the building of informal relationships is advocated (Boons and Baas, 1997; Thoresen, 2001; Gray 1989).

Type of model	Approach	Initiators
ex-nihilo model	Designing an Eco-Industrial Park on a green field and "out of nothing"	public entity developer
anchor tenant model	Identifying an already existing and interested "core-company" and designing an Eco-Industrial Park complementing this "anchor" by establishing a network of businesses needed to supply materials and use by-products	public entity developer company
business model	Attracting a number of tenants in order to develop a certain area and then facilitate network linkages	developer
stream model	Analysing different material/resource flows in an existing industrial system and creating a (Virtual-) Eco-Industrial Park by networking the users of complementary streams	public entity developer companies
business-stream model	A combination of the above-mentioned ones: analysing flows in an existing system, networking users and attracting additionally needed businesses to an available development area	public entity developer companies
redeveloping model	Analysing material and energy flows, communication gaps and possibilities of collaboration in a fully established industrial park, enhancing environmental per-formance, cleaning up past pollution, presenting possibilities of improvement and facilitating communication and collaboration (Lowe et al. 1998)	public entity companies, park management

Table 2.2.4: Starting Points for EIPs (according to Chertow 1999 and Lowe et al. 1998)

Summary

This chapter has already highlighted the central importance of companies in IE development. The next sections will show how industrial ecology has emerged at a very appropriate time in industrial society's evolution (it could even be described as a natural progression). The next sections will cover the following points:

1. Evolution of environmental legislation
2. Evolution of environmental innovation and manufacturers response to legislation
3. Evolution of organisational factors
   a. Manufacturing techniques
   b. Cooperation – networks and clusters
   c. Management techniques – e.g. supply chain management
   d. Organisational culture – e.g. a move to a 'flat' hierarchical structure

Materials	Energy
• Common buying • Customer supplier relations • By-product exchanges • Creating new material markets • Common waste management/ treatment	• Green building • Energy auditing • Cogeneration • Spin-off energy firms • Alternative fuels
Transportation	**Marketing**
• Shared commuting • Shared shipping • Common vehicle maintenance • Alternative Packaging • Integrated logistics • Inter-regional transportation	• Green Building • Accessing green markets • Joint promotions (e.g. advertising, • Joint ventures • Recruiting new value-added companies
Human Resources	**Environmental, H&S**
• Human resource • Joint Benefit packages • Common needs (payroll, maintenance security) • Training • Flexible employee assignment	• Accident prevention • Emergency response • Waste minimisation • Multimedia planning • Design for Environment • Shared environmental information systems • Joint regulatory permitting
Information / Communication Systems	**Production Processes**
• Internal communication systems • External information exchange • Monitoring systems • Computer compatibility • Joint MIS system for regional management	• Pollution prevention • Scrap reduction and reuse • Production design • Common subcontractors • Common equipment • Technology sharing and integration
Quality of Life / Community connections	**Others**
• Integrating work and resources • Co-operative education opportunities • Volunteer Community programs • Involvement in regional planning	• Shared workshops

Table 2.2.5: Possible Areas for Eco-industrial Networking (source: adapted from Cohen-Rosenthal, 2000)

2.4 Evolution of Environmental Legislation

To date the greatest driver causing companies to make environmental improvements has been legislation (Hunt, D, 1995). Past legislation has caused concern amongst industry and there has generally been a feeling that environmental goals oppose economic ones. It is therefore important to examine in detail the development of legislation and its current state as driver and barrier.

2.4.1   Recent History of Legislation

If we include laws to protect the rights of individuals to clean water, environmental legislation has a long history in most countries (Hunt, 1995). The majority of laws in the past were made to control the direct effects of pollution, which were usually clearly observable. They were put in place to protect the health of the surrounding population, as well as the environment. Only within the past 30 years or so have the global significance of human activities emerged and legislation begun to emerge in response.

The 1960's and 1970's saw historically high levels of government regulatory activity. The 'energy crisis' of 1973-74 saw decreased rates of economic growth, high rates of inflation and high levels of unemployment. Governments saw innovation as a means of breaking out of the recession and a general consensus emerged that high levels of regulatory activity have a negative impact (Hunt, 1995). The United States led the way in a series of deregulatory moves, which were later matched in Britain during the years of Margaret Thatcher, who privatised and deregulated the public utilities. However, studies of the interactions of government regulations and industrial innovation between the 1960's and the early 1980's, have shown that the presence of regulations didn't necessarily mean negative impacts on industrial innovation (Rothwell, 1992). In fact it was the actual nature of the regulation and the behaviour of the regulatory agencies which often caused the greatest problems.

The important influence of legislation on industry is likely to continue. Historically, command and control regulation has been the main style used, but has recently come under attack as being overly rigid and may have the potential to impede innovation. Indeed there is much criticism of this 'end of pipe' thinking, in that it does not induce preventative measures which can be implemented in the design stage (Fiksel J, 1996). It also provides an incentive to transfer pollution from one medium to another, and this has been recognised in the Environment Pollution Act 1990 and by the E.U. in its Directive in Integrated Pollution Prevention and Control (IPCC). Such standards and controls are now more often complemented with other types of instrument, involving direct financial incentives or deterrents, so called 'Market Based Incentives'.

2.4.2   Current Legislation

There is now clear recognition that the scale of environmental pollution has increased to a global scale. Effects of pollution are no longer merely confined to a local region but effect the global environment. Consequently treaty obligations and various international organisations now influence UK law. In the area of environmental law, treaties are often concluded under the auspices of international organisations such as the United Nations. In recent years the emphasis of international law has moved from liability for environmental damage to a greater emphasis on preventative regulation. An example of a recent and significant international treaty is the 1987 Montreal Protocol that sought to phase out substances that depleted the ozone layer (such as CFCs; the agreement was substantially amended in 1990 and 1992). Another is the United Nations Conference on Environment and Development, held at Rio, Brazil in 1992, resulting in conventions on biodiversity and climate change, and in the Kyoto Protocol.

Since joining the European Community in 1972, a number of Community treaties and obligations have been brought into existence in the UK's domestic law. Within the European Commission, the Directorate General (DGXI) has specific responsibilities for environmental matters. Community legislation can be introduced in the form of regulations, directives and decisions. Since the 1970's, community developments on the environment have probably been more considerable than any other aspect of Community policy. There are over 300 Directives, regulations and decisions currently in force covering such diverse areas of the environment as pollution control and wildlife. Recent Directives which will have direct implications on the UK and its' manufacturers include the Waste Electrical & Electronic Equipment (WEEE) 2000 Directive, and the End-of-Life-Vehicles Directive. Table 2.4.2 provides further examples of environmental legislation affecting Scotland.

2.4.3   Shifting Legislation

Emerging legislation is becoming more radical and directed. For example the latest forms of legislation are moving away from simple EOP control, and are placing more responsibility on the manufacturer for their products and waste. The Producer Responsibility Obligations (Packaging Waste) Regulations 1997 (the UK's response to European Environmental legislation) aims to minimise waste by reducing the quantity of packaging used and entering

the waste stream. Furthermore it spreads the burden of responsibility across all those involved in the packaging chain, from manufacturer to final seller. This burden increases as a business descends the packaging chain, with the largest burden on the final seller of the packaging.

Sewage Scotland Act 1968	Prod. Resp. Packaging Waste Regs. 1997
COPA 1974	Waste Minimisation Act 1998
Health & Safety at Work Act 1974	Groundwater Regulations 1998
Wildlife & Countryside Act 1981	Prod. Resp.(Essential Req.) Regs 1998
Environment Protection Act 1990	COSHH 1999
EP(Duty of Care)Regulations 1991	Contaminated Land (Scotland) Regulations 2000
Clean Air Act 1993	Air Quality (Scotland) Regs. 2000
CHIP2 1994	Town & Country Planning Act 1990, T&P (Scotland) Act 1997
Environment Act 1995	Finance Act 1996, 2001: Climate Change Levy, Landfill Tax
Waste Management Licensing Regulations 1995	WEEE Directive 2003 (Waste Electric and Electronic Equipment)
Special Waste Regulations 1996	Sustainable Urban Drainage (SUDS)

Table 2.4.2: Examples of Environmental Legislation in Scotland (source: Burton, 2003)

The Landfill tax and the increasing costs of waste disposal are designed to encourage manufacturers to consider waste more carefully. Locally landfill tax costs Forth Valley Councils over £2.2 million every year (SEPA, 2001). Legislation in the pipeline, such as the End of Life Vehicles Directive for car manufacturers and the WEEE directive, make producers (importers and manufacturers) responsible for financing the collection, recycling and safe disposal of their product. It thus places responsibility for the product over its entire life cycle on the manufacturer. Producer responsibility strongly supports industrial ecology ideas and is a possible way to embed industrial ecology (Nicholas, 1998).

Climate change is receiving increasing attention in policy and legislation. As part of its' Kyoto Protocol commitment the UK has a target of 12.5% cut in the basket of six greenhouse gases by 2010. The target for its carbon dioxide emissions is even more demanding being 20% below 1990 levels by 2010 (DTI, 2004). The Energy White Paper set a longer term strategic framework for the UK's energy policy and committed the UK to reduce carbon dioxide emissions by 60% by 2050 (DEFRA, 2003c). The Climate Change Levy came into effect in 2001 and applies to energy used in the non-domestic sector (industry, commerce, and the public sector). The aim of the levy will be to encourage these sectors to improve energy efficiency and reduce emissions of greenhouse gases.

With regard to waste, the EU Commission is preparing a 'thematic strategy on the prevention and recycling of waste' as part of the EU's Sixth Environment Action Programme (ENDS Report 341, pp 53). It identifies waste prevention and management as one of four top priorities, with the primary objective being to decouple waste generation from economic activity. Following consultation on the new communication, it must produce final proposals and secure the agreement of Member States and the European Parliament by mid-2005.

In the absence of additional policy measures, waste generation in the EU is likely to increase. The 6th EAP includes targets to cut the total quantity of waste going for disposal by 20% by 2010 and by 50% by 2050 from 2000 levels, and to reduce hazardous waste arisings by 20% by 2010 and 50% by 2020 (ENDS Report 328, p50).

The best means of promoting recycling is the use of economic instruments, says the European Commission (ENDS Report 341, pg 53). But these have been impossible to agree at EU level and the paper warns that if they "*are not acceptable or feasible, for either political or technical reasons*", it will propose prescriptive measures such as landfill bans or obligatory source separation of specific wastes (EU Commission, 2003).

Thus far the approach to waste prevention has not been comprehensive with ELVs and WEEE directives only representing approximately 1% of total waste arisings. Also, EU legislation requires recycling of paper and board packaging but not of paper from other sources, such as office paper or newsprint. The principle of producer responsibility will continue to be important to EU recycling policy, in particular for end-of-life products, it will need to be complimented by other instruments to promote recycling of important waste streams (ENDS Report, June 2003).

2.5   *Evolution of environmental innovation and manufacturers response to legislation*

This section examines the most significant approaches to environmental manufacturing and illustrates the evolution of manufacturing from a linear process to a more cyclic process (albeit slowly). The present process of manufacturing, illustrated in Figure 2.5.1, can be expressed as a linear process:
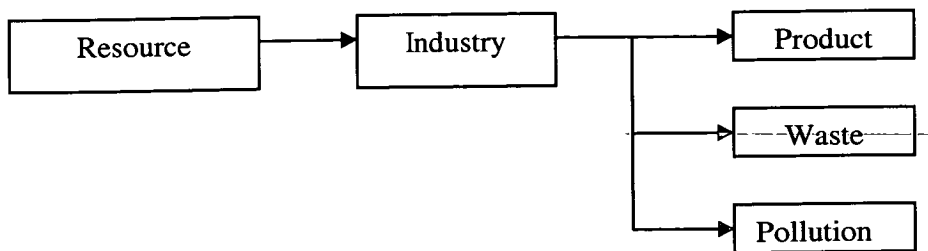
Figure 2.5.1: The linear process of industry

In a study of companies across a range of industry sectors and different countries, Clayton et al (1999) found a range of responses existed to regulatory pressure:

- *end-of-pipe solutions* (typically waste water treatment plants), sometimes combined with internal recycling or sludge reuse;
- *improved techniques/working practices;*
- *internal recycling* (where waste materials are reintroduced into a production process);
- *external recycling* (where waste materials are reintroduced into a production process);
- *incremental change in process technology;*
- *radical change in process technology;*
- *changes in products;*
- *product chain management* (where environmentally oriented change takes place across a supply chain).

Their survey found only one example each of the last two categories. They hypothesised that these kinds of cleaner approach are very difficult to achieve, at least in the short term, as they involve coordination between a wider range of players (suppliers and customers). A diversity of outcomes in individual cases was put down to the interaction between an array of economic, technical, political and cultural factors. They grouped the main influences under three broad headings: regulation, economic factors and organisational factors.

2.5.1   End of Pipe (EOP)

As mentioned in section 2.4.1, past legislation has mainly set standards on emissions that had been judged in hindsight to be detrimental to the environment. Manufacturers saw EOP responses as the easiest and quickest way to meet these standards. Overall EOP responses are often a costly approach and globally an unsustainable one. After increasing their standards

for several decades, some manufacturers, primarily the larger ones, are beginning to make product and process changes to avoid relying on EOP responses.

2.5.2   Cleaner Manufacturing

The next stage on the road to sustainability after EOP, are techniques that come under the name of *Cleaner Manufacturing*. Jackson (1994) provides a useful definition, '*an operational approach to the development of the system of production and consumption, which incorporates a preventive approach to environmental protection'*. Cleaner manufacturing represents a more complete approach to minimising the environmental effects of production and consumption. It takes on board environmental management systems and technologies that minimise waste and pollution.

2.5.3   Eco-efficiency

Eco-efficiency can be defined as 'The ability of a managed entity to simultaneously meet cost, quality and performance goals, reduce environmental impacts, and conserve valuable resources' (Fiksel, 1996).

Eco-efficiency and 'design-for-the-environment' (DFE) are concerned with the management of material and energy resources. Hence there is movement away from the linear system to the process illustrated in Figure 2.5.3. The concepts also suggest emphasis on the provision of services as a way of meeting the challenge of sustainable development.
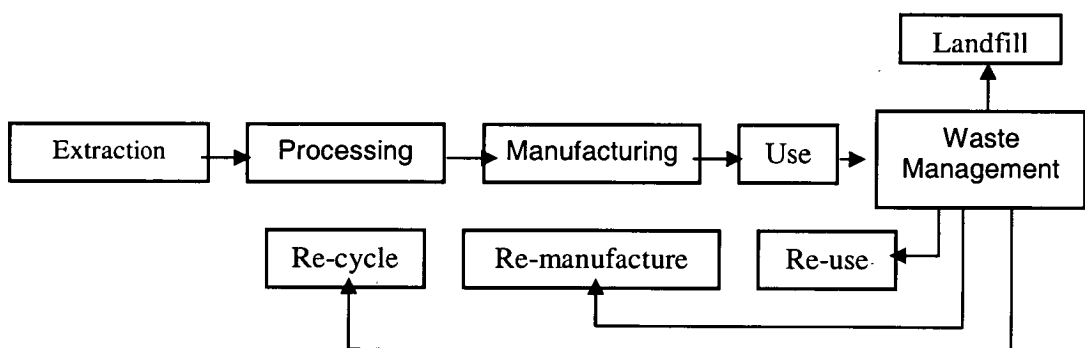
Figure 2.5.3:   Materials management (adapted from Thompson, 1999)

The concept of Eco-efficiency is similar to cleaner production and seven objectives can be identified (Ayres et al 1995):

1.   Minimise the material intensity of goods and services
2.   Minimise the energy intensity of goods and services
3.   Minimise toxic dispersion
4.   Enhance material recyclability
5.   Maximise sustainable use of renewable resources
6.   Extend product durability
7.   Increase the service intensity of goods and services

There are numerous advantages of materials reduction or 'dematerialisation'. There is a reduction in the consumption of raw materials, a reduction in pollution associated with extraction and refinement of the material, a reduction in pollution and energy consumption during the subsequent manufacturing phase, and a reduction in the volume of material entering landfills.

One of the major challenges with DFE and LCA is being able to determine if one product is more 'environmentally friendly' than another. Is one material, which requires more energy to extract but can more easily be recycled, 'greener' than another with lower extraction costs? Current LCA techniques have been criticised as unreliable scientific tools subject to quantitative and qualitative errors (Ayres, 1995; Owens, 1997; Nash et al, 1994).

The results can change depending on where the system boundaries are drawn. As an example consider the common light bulb. The conventional bulb is highly inefficient since 95% of the energy is wasted as heat. The modern fluorescent bulb consumes 75% less energy to provide the same lighting. However, the fluorescent bulb contains mercury and so in the context of heavy metal pollution, is not as 'green' as the conventional bulb. But if the system boundaries are expanded to include the power production then a different story is told. Mercury is a trace element in coal and so if the power production is derived from coal the overall mercury emission over the lifecycle can be higher for the conventional light bulb. The analysis is dependant on which indicators or metrics are used and considered important.

The World Business Council for Sustainable Development has recently completed a two-year project into how businesses can measure the eco-efficiency of their operations (ENDS,

307, 2000). It concluded that due to the diversity of businesses, companies should be allowed to tailor analysis and reporting to their individual activities. It suggests that only a limited number of indicators can be used, but a company of any size or sector can use them:

- Product/service volume.
- Net sales.
- Energy consumption.
- Materials consumption.
- Water consumption.
- Greenhouse gas emissions.
- Ozone depleting substances emissions.

It emphasised the need for flexibility due to the diversity of business and is adamant that this does not undermine the compatibility of this framework with efforts to standardise corporate reporting on sustainability. Other industry groups are beginning to construct guidelines and indicators for members in an effort to address sustainable development (and perhaps to prepare the ground for impending legislation). The Institution of Chemical Engineers (IChemE) has recently produced a set of indicators designed to measure sustainability performance across the three pillars of sustainable development (IChemE, 2003). The metrics have been designed to present a view of an operation, company, industry or regional. They can even be used for a group of plants, part of a supply chain, a whole supply chain, a utility or other process system. The purpose is to '*help engineers address the issue of sustainable development, and learn about the broader impact of company operations. They will also enable companies to set targets and develop standards for internal benchmarking, and to monitor progress year-on-year*' (IChemE, 2003).

2.5.4 Evolution of approaches

Hence the response of manufacturers to environmental issues continues to evolve. Building on past experience, the latest and most holistic approach is Industrial Ecology. In summary, the control and reduction of emissions from industrial pollution sources has gone through three phases (and in many cases continues to evolve) (Ayres, 1997):

1.   End-of-pipe pollution control technologies and practices dealing with wastes and emissions after they have been created.

2.   Cleaner Production - application of integrated preventive environmental strategies to processes, products and services to increase efficiencies and reduce risks to the environment and humans. The goal is to avoid generating pollution in the first place and thus reduce costs and risks.

3(a).   "Product-to-Service Transformation" -- a considerably more radical and far-reaching generation involving end-user changes as well as altered production technologies, which individually and collectively can move toward greatly reduced inputs and resource consumption.

3(b).   Zero Emissions - altered production technologies and approaches (including computer modelling and design of integrated industrial clusters), which individually and collectively can move business toward greatly reduced inputs and resource consumption.

Figure 2.5.4 shows schematically how these concepts or stages relate to each other. It illustrates that there is a maximum efficiency of resource consumption for the various techniques.
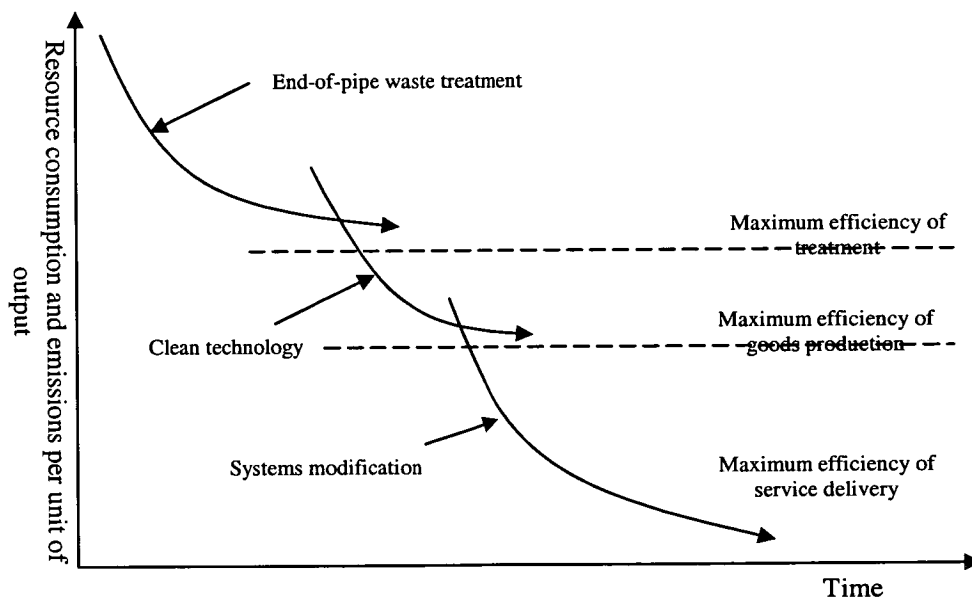
Figure 2.5.4: Illustration of efficiencies of environmental compliance techniques (Ayres 1997).

2.6 Evolution of organisational factors

Understanding how organisations work both internally and externally is of central importance for IE. Companies work within a complex system of economic, social, cultural and technological influences (see Figure 2.6; Michaelis, 2003). For the purposes of IE it is pertinent to understand which types of companies, their structures and cultures, respond best to the pressures to become sustainable. Hence the conditions for innovation towards sustainability are of fundamental interest.
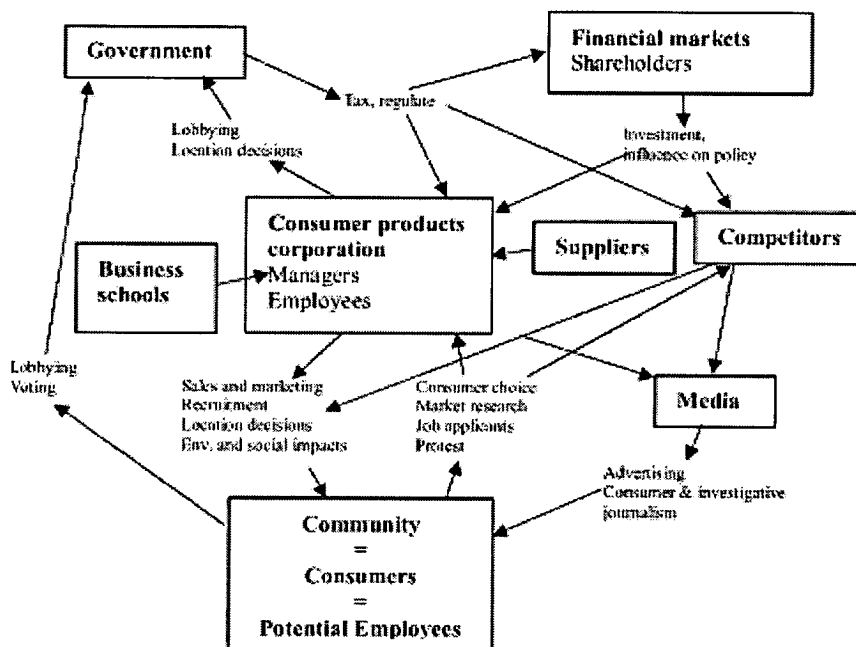
Figure 2.6: Influence map for the consumer products corporation: caught in a web? (Michaelis, 2003)

Several theories have developed over the past century on how best to view and conceptualise organisations, with varying degrees of success. One of particular relevance for IE is that of contingency theory. Contingency theory argues that the analogy of a biological organism is appropriate for the study of complex organisations (Dunkerley, 2001). The theory uses an open systems perspective, emphasising the importance of the environment within which the organisation exists. It therefore recognises the interdependence between an organisation and its environment. Burns and Stalker (1961) observed two distinct systems of management termed 'mechanistic' and 'organic' types. Each is more appropriate to a particular environment. The characteristics of organic structures are adaptability, flexibility and loose

structure, whereas the mechanistic structure is more bureaucratic and rigid. An organic structure is more appropriate in practice to organisations that need to be innovative. The pressure of innovation fosters a flexible and loosely defined structure that can respond to environmental variations. Additionally the organisation tends not to be too formalised and roles not too closely structured. Conversely, when the environment is stable a mechanisitic structure is more relevant (Dunkerley, 2001).

How we view the organisation is key to understanding how it functions, what its needs are and how it responds and interacts with the environment. If we view IE as an action concept (the prescriptive versus descriptive debate is only now beginning to be discussed in the literature) then the organisation (although perhaps the most important element) is simply an organism which responds to external criteria in order to survive. In essence if we change the external environment and the conditions in which it operates (i.e. the market place) the organisation must adapt to survive.

2.6.1 Manufacturing Techniques

The industrial revolution began in the United Kingdom with craft production techniques. Frederick Taylor's experiments on the organisation of labour laid the foundation for the mass production systems (Wallace, 1998). Later, Henry Ford was the pioneer of the mass production assembly line, and the current dominant model of industrial production is 'lean manufacturing.' This system (also known as just-in-time (JIT)) was led by Japan, again in the car manufacturing sector where a series of management innovations led to more flexible production and working patterns. The aim is to reduce inefficiency and waste with a just-in-time inventory control, 'right first time', zero defects, worker cells and worker control of the pace of the assembly line. Figure 2.6.1 represents the evolution of the dominant forms of industrial production.

Numerous other concepts have emerged designed to increase the productivity and efficiency of their operations including: Total Quality Management, Inventory Management, Supply Chain Management and Concurrent Engineering (for an explanation see Krajewski, 1999). Some of these are discussed below.
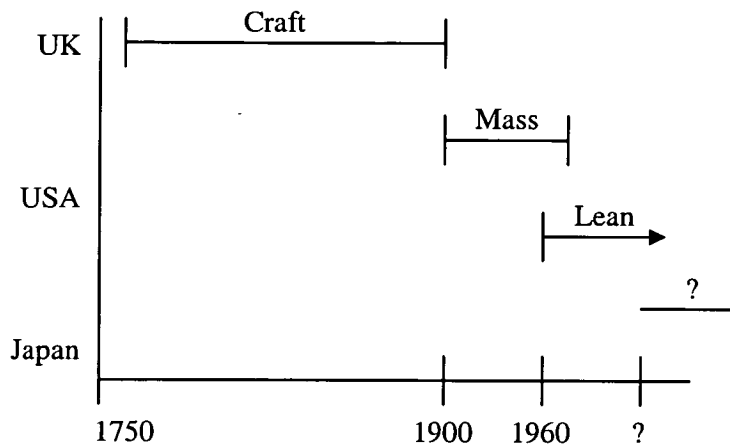
Figure 2.6.1: Evolution of Production Systems (source: Wallace, 1998)

In recent years attention has turned to waste minimisation techniques and energy reduction. These not only save businesses money but also improve the environmental impact of participating companies. Environmental management schemes have become more popular. When correctly implemented they have the potential to integrate environmental thinking into the company at all levels. Companies that more readily integrate environmental considerations into their core business generally have the greatest rewards (Shrivastava, 1995; Harris, 2000).

2.6.2 Organisational culture and management techniques

Managers have shifted their metaphors from hierarchies to networks and have come to realise that partnership – the tendency to associate, establish links, co-operate and maintain symbiotic relationships – is one of the hallmarks of life'. (Capra 2002)

The world of management is fast paced and new terms arrive often. Analysis of publications shows that there is approximately one new management fashion per year (Grint, 1997). Peters and Waterman (1982) wrote one of the most influential management texts of modern times. In their study of 62 top performing American companies they identified eight attributes of excellence, one of which was 'stick to the knitting'. This basically involves limiting activities to what the company does best and avoiding diversification into unknown territory. But increasingly (especially within the last decade in the UK as a result of privatisation) companies are diversifying – e.g. electric and gas providers offering both services; British Telecom and British Gas offering insurance and loans; and Tesco, the food

supermarket selling clothes and other goods. Companies are building on strengths in one market to break into other markets, gaining a range of skills and looking beyond traditional boundaries.

The concept of the 'boundaryless organisation' was coined by Jack Welch of General Electric in the 1960's. Boundaries can exist between layers within an organisation (classic example: military organisation) which can cause innovation problems e.g. someone in a lower layer has a useful idea; how do they get the idea recognised by appropriately senior representative? Similarly, boundaries can exist between the organisation's functional units where each unit has a single function. A common problem associated with this is that each unit seeks to maximise their own goals, but not the overall goal of the organisation. Horizontal boundaries can also cause communication problems between departments. External barriers between the organisation and the outside world (customers, suppliers, other government entities, special interest groups, communities) can cause companies to loose sight of the customer needs and supplier requirements. Customers are the most capable entity in identifying major problems in the organisation and are interested in solutions. Geographic barriers can exist, for instance among organisation units located in different countries, and can cause isolation of innovative practices and ideas. Boundaries will always exist to some degree, but the 'boundaryless organisation' seeks to loosen the boundaries and make all of these barriers much more permeable

As Capra (2003) noted, people don't like to be forced to change. However people *can be influenced by giving impulses rather than instructions. Force or energy are not the issue; the issue is meaning.... Meaningful disturbances will get the organisations attention and will trigger structural changes*' (Capra 2003). Employment relations are seen as moving away from bureaucratic hierarchy and 'low trust' industrial relations, towards securing real commitment (Guest, 1987; Legge, 1989).

Corporate culture can be defined as the way that management mobilises combinations of values, language, rituals and myths (Thompson and McHugh, 2001). Its aim is to unlock the commitment and enthusiasm of employees. Although it has not been replaced, corporate culture is certainly less prominent now as other panaceas such as business process reengineering and TQM take centre stage (Thompson and McHugh, 2001). Business process reengineering (BPR) has particular overtones for IE. Davenport, an exponent and author on BPR writes:

'In the face of intense competition and other business pressures on large organisations in the 1990s, quality initiatives and continuous, incremental process improvements, though still essential, will no longer be sufficient. Objectives of 5% or 10% improvements in all business processes each year must give way to efforts to achieve 50%, 100% or even higher improvement levels in a few key processes. Today, firms must seek not fractional, but multiplicative levels of improvement – 10x rather than 10%. Such radical levels of change require powerful new tools that will facilitate the fundamental redesign of work.'(Davenport, 1993)

The key elements of process innovations are said to be (Thompson and McHugh, 2001):

- a 'fresh start',

- a process view rather than functional view of the whole organisation.

- cross-functional solutions.

- step change.

- the exploitation of information technology

- attention to work activities on and off the shop floor.

- adoption of a customer's view of the organisation/producing value for customers.

- processes must have owners.

Industrial Ecology can build on the key elements of BPR by providing a vision for change and encouraging the company to look beyond the normal boundaries.

Viewing the business as a 'process' starts with an analysis of the value adding activities and follows with an attempt to identify and eliminate the non-value adding components. This way of analysis is claimed to be very far reaching in its implications for organisational structures and human resource management. Hammer and Champy (1992) (the originators of the "business re-engineering" concept) claimed *'everything that has been learned in the twentieth century about enterprises applies only to task-oriented organisations, everything must be rethought'*. The central idea is that in order to survive under the new competitive conditions, companies must re-orient themselves around their core processes – the start to finish sequence of activities which create customer value.

In a nutshell, increasing affluence, more discriminating consumers, competition from the Far East, and developments in information technology has meant companies have had to be more innovative and flexible. Hammer (1996), talks bluntly about the *'end of the organisation chart'*. In the new kind of organisation people are valued *'No matter how well designed a*

process is, it's the people who make it work' (1996:117). Empowerment of the employee and adjusting reward schemes means supervision is not supposed to be required. There are no departments or departmental managers and very little hierarchy.

2.6.3 Cooperation – networks and clusters

Recent years have seen a great deal of interest in forming new sorts of structures which reach out to engage associates, partners and even competitors in the wider marketplace. The arrangements have been of various forms but most prominent are joint ventures, strategic alliances, networks and outsourcing arrangements (Mabey et al, 2001). Several authors have written about the 'breaking' of organisational boundaries (Quinn 1990; and Ashkenas et al 1995). Alliances, partnership and networks are seen as increasingly important.
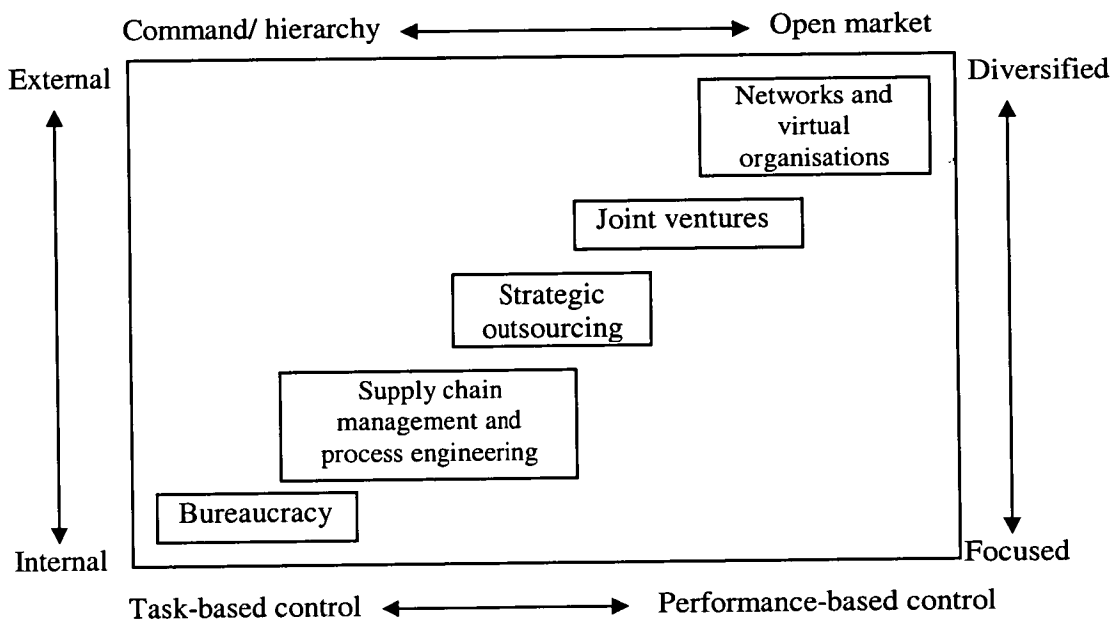
Figure 2.6.3: A spectrum of relationship structures beyond conventional organisational boundaries (source: Mabey et al, 2001).

Many observers assert a definite trend in the direction of the top-right of Figure 2.6.3. Mabey et al (2001) however, state that "the evidence does not entirely point in one direction. Moreover, a historically informed perspective on organisational studies would caution that apparent 'trends' are often more like 'cycles'." They do however admit that at least that the

general thrust seems to be in this direction. For example, BT alone has more than 70 joint ventures and overseas distribution arrangements (Mabey, 2001).

2.7 Summary of the evolution and convergence of environmental and business techniques

It is important to recognise the trends illustrated above. Not only do they indicate that IE has a place and that it can help to simultaneously tackle a number of difficulties, it also highlights the platform on which IE must build. Knowledge of the history and evolution is important in the next stage of fostering the movement to a sustainable anthropogenic system. In this fostering, knowing the 'natural' trends can help avoid unnecessary conflict between a range of drivers and barriers. Hence all the factors are important and have laid appropriate foundations on which, with care, IE can develop successfully.
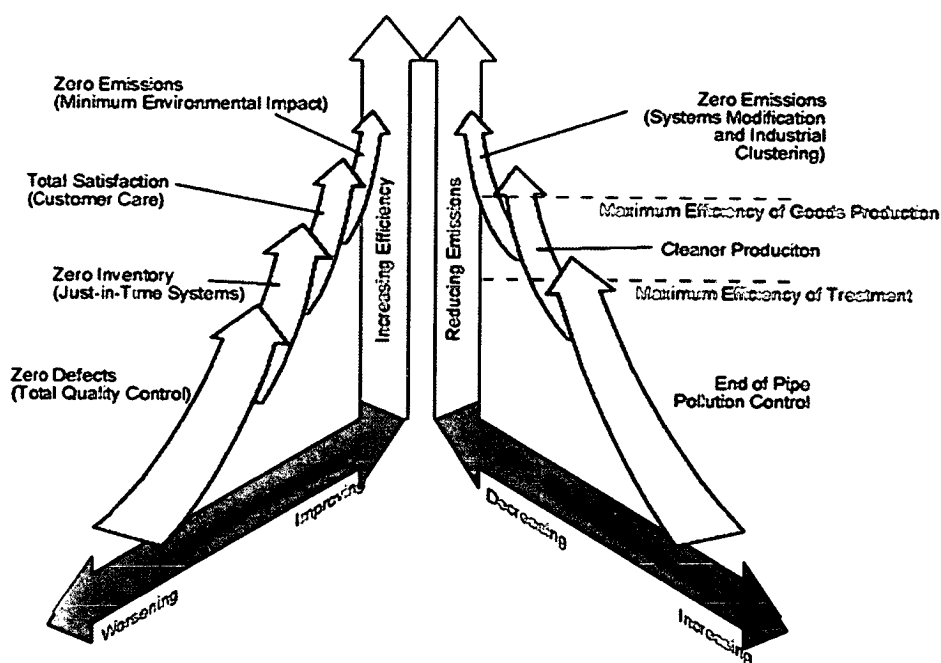
Figure 2.7: Zero Emissions – towards increased efficiency and reduced emissions. (source: UNU ZE Forum, 2001).

Environmental regulation in the 1970's and 1980's provoked an 'End-of-Pipe' response that proved costly to industry and required the use of additional resources for clean-up. There has since been an evolution of both regulation and industry's methods of coping with

41

environmental constraints. Recent advances in waste minimisation and energy reduction have saved both money and resources. Simultaneously many companies have adopted business concepts designed to increase the productivity and efficiency of their operations, such as Total Quality Management, Inventory Management, Lean Manufacturing, Just-In-Time, Supply Chain Management and Concurrent Engineering. Figure 2.7 illustrates how IE / Zero Emissions can encompass these concepts and has the potential to continue the drive towards increased efficiency and reduced emissions.

2.8 Drivers and barriers

If we accept IE as the science of sustainability then generally the drivers and barriers of IE will be the same as for those of sustainability. As discussed earlier a central component of IE is innovation. To achieve sustainability innovation of products, processes and organisations and their relationships, will need to occur. Hence in general terms drivers and barriers to environmental innovation are also important for IE.

2.8.1 Barriers

Definition of waste

Both the concept of waste and the definition itself within EU and UK legislation has been noted as a barrier. Recycling companies and manufacturers often find the definition of waste an obstacle to environmental protection (Pongracz, 2004). In their opinion, as long as someone is prepared to purchase material, it is inaccurate to label it 'waste' (Bontoux and Leone, 1997). Table 2.8.1 provides a number of definitions for waste.

The main problem is that the label of 'waste' in law does not necessarily mean that the thing is ultimately a waste, rather that those dealing with it are legally required (under the duty of care imposed by the Environmental Protection Act 1990) to treat it as a waste (and so take 'reasonable and appropriate steps in relation to it'). In simple terms this usually translates to an additional expense with the requirement to label wastes appropriately and use licensed operators when handling them.

EU	Waste shall mean any substance or object in the categories set out in Annex I which the holder discards or is required to discard (European Council, 1991)
OECD	Wastes are materials other than radioactive materials intended for disposal, for reasons specified in this Table (OECD, 1994)
UNEP	Wastes are substances or objects, which are disposed of or intended to be disposed of or are required to be disposed of by the provisions of national law (European Council, 2004)

Table 2.8.1: Definitions of waste (source: Pongracz, 2004)

Barriers to Cleaner Production

If we consider that IE is a continuation of the general industrial evolution, then barriers to cleaner production are also relevant. In a US study of more than 60 pollution prevention (P2) programs across the US the by the National P2 Roundtable (2003), 70 percent of respondents said that they had a lack of resources to implement P2 and 40 percent complained of the high rate of staff changes and a lack of management commitment. Other barriers cited listed in order were the most commonly cited among survey respondents.

1. Lack of man-hours to devote to P2 implementation.
2. Perceived high cost of P2 implementation.
3. Low priority among business owners.
4. Lack of awareness and interest of P2 success and programs in general.
6. Lack of regulatory enforcement.
7. Lack of strategic direction and organizational structure to help implement P2.

Another barrier facing the P2 community is the erroneous idea that all of the "low hanging fruit" opportunities are already explored. But as stated in a report by the United States General Accounting Office's (USGAO, 2001): *"not only is low hanging fruit going unpicked, some is rotting on the ground .... a representative from the Illinois Office of Pollution Prevention remarked that state engineers rarely visit a facility without finding fairly simple pollution prevention opportunities to suggest."*

The importance of barriers at the organisational level to both innovation and more sustainable practices are continually mentioned in the literature. Commenting on barriers to

cleaner production Zilahy (2004) states: *"it can already be stated, that concentrating only on technical terms (i.e. the technical feasibility of CP options) and purely economic considerations (e.g. the rate of return of the projects) is not adequate without the consideration of organisational barriers to cleaner production measures within companies."*

The lack of a market for many materials is an additional barrier to recycling and waste reduction. A report by AEA Technology (1999) on the creation of markets as a driver for recycling looked at the following possible options to tackle the barriers to increased market demand:

- standards for recyclate and recycled content products;
- guidelines for industry on best practice, and on using recyclate to make new products;
- recycled content agreements with industry;
- buy-recycled initiatives;
- waste exchanges, and recyclables exchanges;
- economic instruments;
- design for the environment, and
- use of eco-labelling.

The report noted that although some of these options are likely to have a greater impact than others, good co-ordination between government departments and also between government and industry would be beneficial in achieving any targets which may be set by the new national waste strategy.

2.8.2 Drivers

Economic and efficiency incentives

After legislation, a direct financial incentive is the next major reason why manufacturers make improvements. Waste minimisation is the most common environmental improvement to date (Connell & Flynn, 1999). Financial gains can be felt with simple modifications to processes and the consideration of business operations in a new light.

Large multinational companies such as 3M have already shown the financial benefits of implementing some of the most basic industrial ecology tools. In 1988 it announced that its 'Pollution Prevention Pays' programme saved $420 million (Allen, 1994). They have continued to change their organisational structure and internal attitude, and adopt such concepts as 'design for the environment.'

Examples of companies that have benefited from simple changes by considering the environmental effects of operations are becoming more common. The electronics company Intel changed its solders and fluxes to make washing with CFC solvents unnecessary, thereby reducing its contribution to ozone layer depletion and the greenhouse effect and saving $1 million per year (Meadows, 1992). In the North West of England a two-year project to wake up small and medium enterprises to the benefits of improving their environmental performance has led to annual savings worth £2.8 million for its 81 members (ENDS, 293, 1999). Companies are beginning to make more fundamental changes, but overall progress is still slow. The majority of advances remain with large companies who have the financial capabilities to invest in changes and R&D.

To enhance consumer relations and market potential

Research suggests that consumers are becoming more environmentally conscious and that they indeed prefer environment-friendly products and packaging (Shrivastava, P, 1995). As consumers become more knowledgeable of environmental matters they are increasingly likely to choose ecologically sound products.

Although Eco-labelling is currently undeveloped (particularly in the UK), it has enormous potential to produce a world of environmentally friendly products if used in conjunction with well-developed life cycle analysis theory. Its implementation and promotion would further the knowledge of consumers who would demand environmentally friendly products. In fact if policy was correctly developed and promoted it could allow home products to be more competitive than foreign products whose policies didn't consider long term effects. In its twenty year vision, the Environment Agency has recently proposed that, with its key objective of reducing waste, product licensing '*will make producers responsible for end-of-life fate of their products,*' and the price of goods will reflect their full environmental costs (ENDS, 304, 2000).

Pressure groups have become increasingly influential in persuading public (and consequently commercial) attitudes and often hold more trust than the regulators or regulated. As was shown in 1995 with the Brent Spar oil-drilling platform, environmental groups can influence consumer preferences both nationally and internationally. Companies that take deliberate steps to make environmental improvements are more likely to be held in favour with such groups who can ultimately influence consumer fashions.

Partnerships and Collaboration

As discussed in section 2.6.3 there has been a general trend towards collaboration and outsourcing amongst manufacturers. The emergence of lean manufacturing and the just-in-time approach has lead to efficiency improvements (increasingly also environmental improvements) along the supply chain. Environmental Management Systems can additionally lead to sustainability improvements along the supply chain. Table 2.8.2 lists a range of drivers for collaboration, the responses that often emerge and the intended impact of those collaborative responses.

Since IS networks are intrinsically related to networks and clusters, it is prudent to examine these fields in more detail and extract what can be learnt and applied with regard to IS and IE. Therefore section 2.9 builds on the discussion of section 2.6.3 and looks at the place of networks and clusters in the UK.

2.9 Networks and Clusters

'In a globalised and technologically advanced world, businesses are increasingly gathering together to generate competitive advantage. This phenomenon - clustering - can been seen around the world.' (DTI, 2003)

The term clusters has been well defined by Porter:

"Geographic concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions (for example universities,

standards agencies, and trade associations) in particular fields that compete but also co-operate." (Porter,1998)

Incentive	Collaborative Response	Intended Impact
Economic and technological change	Inter-firm joint ventures	Stimulate innovation Minimise risk
	Business-university consortia	Exchange expertise Expand market access Reduce competition
	Public-private partnerships	Cope with economic decline Stimulate socioeconomic revitalisation
Declining productivity	Labour-management committees	Improve productivity Increase worker input into planning
	Inter-functional collaboration	Facilitate introduction of new technology / new product designs
Global interdependence	Multilateral collaboration (nations / NGOs/ multinationals)	Facilitate world preservation Facilitate global management of resources / technology Prevent violence
Indistinct boundaries	Labour-management committees	Create broader collective bargaining agenda Increase worker input into planning
	Policy dialogues (business /government/communities/ interest groups)	Resolve policy disputes Develop broad consensus on new policies
	Intergovernmental collaboration	Resolve policy disputes Speed decisions
Shrinking federal revenues	Public-private partnerships	Cope with economic decline Stimulate socioeconomic revitalisation
Dissatisfaction with courts	Policy dialogues	Overcome impasse
	Regulatory negotiation	Settle conflicts
	Mediated site-specific disputes	Improve solutions

Table 2.8.2: Impact of incentives to collaborate (source: Gray, 1989)

Well known examples of clusters in the UK are the IT cluster in Silicon Valley or the financial services cluster in the City of London. A study by the DTI in 2001 showed that there were clusters throughout the UK: aerospace in the North West, textiles in the East Midlands, and IT around the M4 (DTI, 2001). The idea of clustering is receiving attention across a number of sectors and by a number of bodies, in particular Scottish Enterprise Forth Valley, the CIA, DTI and the Foresight programme:

47

'The impact which we envisage following on from a co-ordinated Chemicals cluster approach will be to ensure that the industry remains competitive in Scotland and globally through improved linkages to academia, increases in the SME basis as a key part of the industry and the potentially greater linkage between training and industry needs' (Foresight Programme, 2000).

The DTI noted that clusters produce a wide range of benefits to both business and the wider economy. These include (DTI, 2001):

- Increased levels of expertise. This provides sourcing companies with a greater depth to their supply chain and allows for the potential of inter-firm learning and co-operation.
- The ability of firms to draw together complementary skills in order to bid for large pieces of work that as individual units they would be unable to compete for.
- The potential for economies of scale to be realised by further specialising production within each firm, by joint purchasing of common raw materials to attract bulk discounts or by joint marketing.
- Strengthening social and other informal links, leading to the creation of new ideas and new businesses.
- Improved information flows within a cluster, for example, enabling finance providers to judge who the good entrepreneurs are and business people to find who provides good support services.

The development of successful clusters requires several important factors which can be divided into critical and contributory factors (DTI, 2001):

The three 'critical success factors' identified are:

- The presence of functioning networks and partnerships;
- A strong innovation base, with supporting R&D activities where appropriate; and
- The existence of a strong skills base.

The four contributory factors for successful cluster development are:

- An adequate physical infrastructure
- The presence of large firms;
- A strong entrepreneurial culture; and

- Access to sources of finance.

The DTI study noted: *'In the long run, establishing inter-relations between firms helps tie together the economic fabric and increases the potential for firms to adapt to new markets and changed economic conditions.'* Several lessons were established from a decade of networks:

- Firms will and do co-operate.
- Networks can be accelerated by facilitators.
- Incentive grants are of limited value, networks so started rarely survive beyond the life of the grant.
- Social capital has been vastly under-rated.
- Learning is a sufficient benefit for companies to network

At the centre of networks and clusters is a complex web of human relations. Thus with the recognition of the importance of clusters for economic competitiveness, the importance of social factors in industry which has been traditionally dominated by engineers and a technical emphasis has grown. Thoresen (2001) identified the following aspects that can facilitate effective relationships between network participates and companies (although Thoresen refers primarily to eco-parks, the factors are equally applicable to other networks):

- The creation of arenas for information, communication and feedback through e.g. steering group participation, partnering sessions, intra-company thematic working groups on selected topics, person-to-person dialogue.
- Systematic use of feedback information loops to spread results from working groups to involved companies and organisations.
- Identification through involvement e.g. by developing common service facilities, web-pages, use of local media and development of common eco-park grounds.
- Learning by doing. Active participation is required in mapping, problem solving and exploitation of potentials in the individual companies and in the project groups.
- Focusing on part-responsibility of each group participant for successful group results.
- Involvement of external resources for introduction of working concepts and as drivers for initiation and maintenance of the eco-park co-operation.

In the literature on how groups of organisations evolve, there have been several suggestions that they go through different phases that can be conceptualised as a life cycle (Baas and Boons, 2004). Shearman and Burrell (1987) provide a model with four phases:

- Community: this first phase is the industry in its embryonic state. There is a strong sense of common fate, but this is more shared by individuals than by organisations. Typically, these individuals work in close geographical proximity, and frequently change their organisational affiliation. The level of trust is high, and competition is low. Silicon Valley in its first stage is a good example;

- Informal network: this stage is demarcated by the development of a distinct—set of— products and technologies. As a result, the bonding to a limited geographical area is less important, allowing geographical distribution. This implies that organisational boundaries become more important. Specialisation between organisations develops;

- Formal network: this phase is the industry in its maturity. It displays a high level of competition, low level of trust, and the distinction between core and periphery in the network;

- Club: due to ingrained ways of perceiving and acting, adaptation to environmental changes becomes more difficult. This results in defensive behaviour, coupled to a social structure that resembles a club with exclusive membership; eventually, an industry meets with crisis.

The life cycle metaphor links to the literature on institutionalisation, where due to processes of isomorphism, the members of an 'organisational field' develop similar ways of thinking and acting (DiMaggio and Powell, 1993). This is similar to the concept of 'atmosphere' discussed in section 2.3. The network and its members can develop momentum through a shared mission and conversely are effected and learn from each other.

2.10 Innovation

Innovation is increasingly recognised as a complex process involving a range of actors including governments, academia, industry and others (Smith and Skea, 2003; Seaton and Cordy-Hayes, 1993; Trott et al 1995). Knowledge is transferred amongst these actors through collaborative networks.

Innovation as discussed above is an important component in the implementation of IS and IE. It is therefore important to understand how the process of innovation happens. In the turbulent and competitive modern world the ability to change and adapt is essential for a manufacturer's survival. Trott (1998) provides a useful framework that illustrates innovation as a management process. Figure 2.10 illustrates that while the interactions of the functions inside the organisation are important, so too are the interactions of those functions with the external environment.

Interaction will occur between scientists and engineers of one company and scientists and engineers of other companies, associations, as well as universities. The marketing function will also need to interact with suppliers, distributors, customers and competitors. Senior management and business planners can have links to a number of external organisations and institutions. Hence the company gains its information and knowledge through a variety of paths that make the whole process of information transfer a complicated network. Internally, the interaction of the various functions and the facilitation of the flow of knowledge between them are the important factors (Trott, 1993).
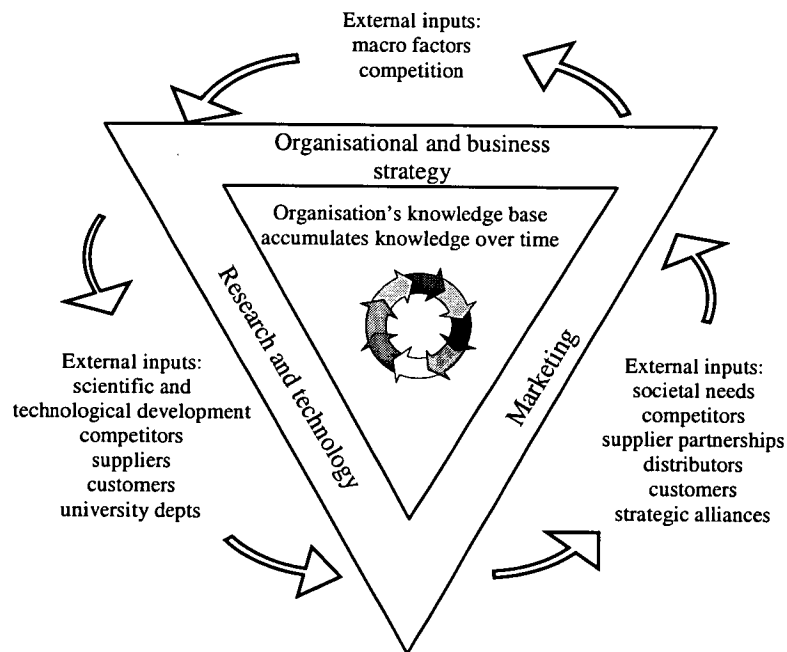
Figure 2.10: Innovation management framework. (source: Trott, 1998)

Of course, not all companies are equally innovative. Kroonenberg (1989) in a study of 3000 firms concluded that small and medium enterprises could be classified into one of three groups, reflecting the responsiveness of organisations to take up externally developed technology:

1   technology-driven SME
2   technology-following SME
3   technology-indifferent SME.

The benefits of innovation and its importance in taking industry forward to a new era of competitiveness and environmental efficiency have been discussed. But there are a number of barriers to innovation (Kass, 2000).

- *Innovation culture* and the perceptions of the risks of innovation relative to the benefits
- *Legal framework* especially the treatment of intellectual property 31 and business failures
- *Macroeconomic conditions* such as inflation, interest rates, and their impact on stability
- *Management of company priorities* and how innovation fits into these (particularly product development, demonstration and marketing)
- *Artificially high and unsustainable levels of R&D*
- *Lack of awareness of government support* and the complexity of the 'maze' of schemes that are often still embedded in the now discredited linear model of innovation
- *Regulation* that hampers information exchange within innovation networks.

As previously mentioned, two basic responses to environmental pressures exist, end-of-pipe technology and cleaner technology. How a manufacturer might respond and which technology they decide to use is influenced by a number of factors (Kass, 2000):

- meeting basic legal and regulatory requirements
- reducing raw material and waste disposal costs to achieve overall cost-savings
- realising strategic business advantage from innovation and sustainable development
- preconceptions, perceptions of risk and attitudes to change
- investment time-scales for capital expenditure (e.g. new or replacement equipment)

The various paths of information transfer and the knowledge acquired by a company can all have an influence. The factors that are mentioned in Section 2.3 are all big drivers. Despite this it is the companies overall 'attitude' that will determine the approach to manufacturing objectives and environmental compliance. Those firms responding by simple compliance are most likely to adopt EOP technologies merely to meet existing or future legislative standards on existing plant (Kass, 2000). At the other end, those responding to broader societal concerns related to environmentally sensitive development may seek to adopt cleaner, resource and energy efficient technologies as new plant is being planned and installed. Manufacturers can rarely, if ever, afford to invest in new plant until the life span of the old is drawing to an end – unless for instance, new legislation forces them to, or makes the running of the plant too costly. Other companies may be seeking cost-savings or responding to supply chain pressures and may adopt either approach, depending on the circumstances.

Finally one aspect of innovation, for which the debate still continues, and which is relevant for IE, is the question of incremental or radical innovation. Weizsäcker (1997) is a proponent of radical innovation claiming that *'achieving big savings requires leapfrogging, not incrementalism. Advanced resource productivity requires integration not reductionism – thinking about the design challenge as a whole, not as a lot of disjointed pieces'*. In contrast a recent study on resource productivity concluded that evidence shows that the *'great potential for incremental innovation suggests that continuing with gradualist approaches remains an appropriate course of action'* (Smith and Skea, 2003). The study continues by advocating the existing UK government initiatives that seek to promote practices like waste minimisation. Further, policy approaches should only be formulated after further research and evidence into how and why radical innovation occurs.

2.11 Policy Tools

In previous sections it has been noted that regulation has to date, been the greatest driver causing companies to make environmental improvements. Past legislation has been mostly standard enforcing, but recently other approaches have been implemented. There are a number of instruments available for governments to bring about the desired change in environmental standards, pollution taxes through to direct financial incentives such as R&D subsidies. Studies have shown that a mixture of instruments is required depending on

specific factors and circumstances of the companies and sectors involved (Howes et al, 1997; Kemp, 1997; Gouldson & Murphy, 1997). The possibilities are summarised in Table 2.11.2.

Instrument	Example	Characteristics	Effect	Application
Technology-based environmental standards	Readily achieved numerical limits on emissions of pollutants from industrial facilities	- Effective when enforced - Inefficient across many industries	Helps incremental innovation in, and diffusion of, end-of-pipe technologies	Marginal costs of pollution abatement small Economically feasible solutions available
Technology-forcing standards	More challenging, longer-term numerical limits that force new technology (e.g. catalytic converters on vehicle exhausts or 'lean-burn' engines)	- Effective in focussing attention - Forces industry to invest in overly expensive sub-optimal technologies - Low credibility	Stimulates technological innovation	When low cost opportunities available
Taxes	Carbon tax	-Efficient - Industry response uncertain - Danger of weak and indirect stimulus - High costs to industry - Limited political support	Helps incremental innovation in, and diffusion of, end-of-pipe technologies	Where many options available and polluters are willing to respond to price signals
Tradeable pollution permits	US sulphur emission trading	- Effective Cost-effective (environmental benefits achieved at lowest cost)	- Helps diffusion of existing technology - Stimulates innovation	As with taxes, and also where monitoring and transaction costs are not too high
Covenants and voluntary agreements	Reduction of greenhouse gas emissions by the chemical industry	- Compliance uncertain - Possible need for sanctions - Low costs of administration	Helps diffusion of existing technology	Where there are many polluters and techno-logical options. Also where monitoring performance would otherwise be expensive
R&D subsidies	Tax credits for R&D investment	- Danger of funding poor projects - Danger of windfall gains	Stimulates technological innovation	No markets for environmental technology and future policy uncertain. Also where problems over appropriation of benefits
Investment subsidies	Discount on gas-condensing central heating boiler or cavity wall insulation	- Conflicts with polluter pays principle - Danger of windfall gains	Helps diffusion of existing technology	When industry suffers disadvantage due to less strict overseas regulations
Communication	Environmental Technology Best Practice Programme	Focuses attention on problems and availability of solutions	Helps diffusion of existing technology	Where there is a lack of awareness and information
Networking ('match-making')	Business Links programme	- Solutions can be tailored to specific needs - Understanding of processes and products necessary	- Helps diffusion of existing technology - Stimulates innovation	Where there are information failures

Table 2.11: Effectiveness of the environmental toolbox (source: Kemp, 1997)

Since the 1970's the popularity and deployment of so called 'New Environmental Policy Instruments' (NEPIs) has grown significantly. Jordan et al (2003a) use a fourfold categorisation of these instruments:

1. regulatory instruments
2. Market Based Instruments (MBIs)
3. Voluntary Agreements (VAs)
4. informational devices

These instruments are shifting the emphasis from government to *governance*. In their recent cross country study Jordan et al (2003b) concluded that currently these instruments were still limited to supplementing traditional command and control regulation, rather than supplanting it.

2.11 Summary of Chapter 2

This chapter has reviewed the literature on industrial ecology and the concepts and techniques which are relevant to its application. It began with a brief overview of the history of IE and discussed the problems the field has faced regarding terms, definitions and the fields scope. Several examples of IE projects in various parts of the world were discussed. Although the majority of these are still young, several lessons were discussed. The trends of industrial society, legislation, manufacturing techniques and organisational factors, were shown to be complementary for the emergence of IE. Related fields such as innovation, networks and clusters were reviewed and lessons drawn. Finally the available policy options that may aid in the fostering of IE were presented.

The next chapter presents the research design and lays the conceptual foundations for the research.

Chapter 3 Research Design

3.1 Introduction

This chapter describes the evolution of the research design. The project scope and focus was relatively undefined to begin with, but had the general aim to investigate a component of the emerging field of industrial ecology. The main desire of the author was to make an original and worthwhile contribution to the field of IE and to the task of sustainability.

The next section begins with an overview of the background to this research thesis. It then describes several software programs that were examined with the aim of utilising and applying them within the local industry. Subsequently, the project development and the evolution of the ideas behind this thesis are discussed. Next the developed research proposal is described, along with the aim and objectives of the research. The action research method of investigation and the reasons of the approach are then described. Finally, the chapter develops a conceptual framework, which helps to further define the scope of investigation and to provide a basis for the analysis.

3.2 Research Background

The research started with the intention of investigating the application of the 'zero emissions' concept in the local industry of the Forth Valley, Scotland. We considered the concept of ZE to be intimately linked to the field of IE. The initial research basis was to model a zero emissions network in the Forth Valley. Some initial project ideas were:

1. To identify the optimum environmental and economic network of material and energy exchanges.
2. Identify and model possible input-output matches. These could be material, energy or water.
3. Identify uses for by-product materials that currently have no use locally (or have no known use) and (as a last resort) investigate possibilities for converting these in to useful materials.

4. Identify possible clusters in the region, and suggest companies that would be suitable to encourage into the area to close the system.

The chosen method would ultimately depend on the type of data available and the number of companies that were willing to participate.

It was therefore recognised that there were potentially a number of software that could aid the project ideas above. Several software programs were identified from the literature and through internet searches. The initial research hence concentrated on using and investigating the following software:

- GaBi life cycle engineering software
- GIS evaluation
- FaST, DIET software
- PIMS software
- Waste exchange software

These software programs are now described below in the context of their potential use for this research.

3.2.1 GaBi Life Cycle Engineering Software

The GaBi software developed by IKP University of Stuttgart has been described as a tool to *'assess technology and ecology of different options, e.g. the materials choice for a new instrument panel or the use of recyclate for thermoset resin parts. The effects of the different options are assessed over the whole life span ('cradle-to-grave' analysis) regarding aspects like technological feasibility costs, or environmental aspects like global warming and acidification, toxicity to man and environment or the use of non-renewable resources[1]'.*

GaBi's main uses are in performing a life cycle analysis of a company or group of companies and visualisation of material and energy flows. It has an ability to save groups of processes, as a plan, which can in turn be used as a 'process' to build another plan, and thus build up a hierarchy of systems and sub-systems. GaBi's database allows the user to perform

a LCA to show the environmental effects of different set-ups of processes etc., and display it in terms of a number of different parameters such as CO_2 greenhouse potential.

The GaBi software is more suited to projects involving a small number of companies, or facilities (5-6). In particular closely located clusters of companies where energy exchanges can also be investigated along with the associated costs and savings. Generally large amounts of data are required on the processes, material and energy flows, to produce a Sankey diagram mapping the flows of energy and materials. The more in-depth company data that is gathered and used the fewer the number of companies that can be included (only due to time constraints and not those of the software).

ZE projects need to take a systems perspective and consider a number of levels. GaBi does allow you to implement a systems hierarchy and thus map the flows from the company, cluster, regional and national perspective. It would be possible to deal with a larger number of companies by mapping them at a more superficial level, perhaps to show the major flows of the companies in a given region. GaBi allows you to map the flows of the individual companies and map any links between them. It could then be used at a later stage (given further in-depth data) to analyse and improve the environmental performance of the individual companies.

The GaBi software is more suitable for clusters and the examination of energy/steam networks. In a situation where companies are more spread out, like the Forth Valley, then the two things most needed from a software facility are a feature to find input-output matches and a feature to work out the corresponding economics. GaBi does not perform either of these functions.

The balancing facility of GaBi appears to be little more than a facility that allows the user to see how much of each input produces a known quantity of an output. Since the majority of chemical companies already use software to map and monitor their material flows, little could be gained by using GaBi. At present there is no facility that would allow the synthesis of GaBi with GIS software.

3.2.2 Geographical Information Systems

Geographical Information Systems (GIS) can perform a number of functions that could aid in the visualisation and modelling of a ZE network. GIS is a *computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations'* (USGS, 2003). GIS allows the user to lay several layers of data over each other. With a GIS you can "point" at a location, object, or area on the screen and retrieve recorded information about it from off-screen files. In a ZE type project the user could select a chemical company and the GIS could show its inputs and outputs, the transport routes, the economic delivery area of a by-product, and land-use (for example, built-up areas).

The usefulness of both GIS and GaBi in ZE projects will depend on precisely the kind of project it is being used for, the chosen methodology, the number of companies involved, the type of flows being investigated (energy, material or water), and of course the objectives of the project.

A study in the US of 182 companies discovered 'probable or possible partners for cost-effective sharing of materials water or energy' for 48% of the companies (Kincaid, 1999). For this study they used a survey, completed by companies across a range of industries, which identified common wastes and chemicals. They used a GIS map of the region to display the companies that replied to the survey. Other companies were highlighted in a different colour. Selecting a company on the GIS map would bring up a table of inputs and by-products. Highlighting a input or by-product would then bring up its' details. So for this project, the GIS facility was used mainly as a visual spatial aid.

Ozyurt & Matthew (2001) suggest an overall methodology for synthesising industrial ecosystems, consisting of four main steps:

1. Locate the existing sources and sinks of potential materials for exchange or upgrading,
2. Assess and filter the feasible exchange candidates, and locations for new infrastructure. This will be done using the concept of *feasibilty contours*, and spatial filtering,
3. Build a superstructure of possible connections between locations and generate a mathematical programming model to select the optimal structure from the superstructure,
4. Execute the mathematical programming model and perform post-solution analysis.

In this methodology, a company's output is chosen and then a program creates contours of a calculated radius on the GIS map to show the range that it can be economically transported. A more complex program would be required to take into account the cost differences of, for example, transporting on motorways as opposed to B roads. The next stage is to then attempt to find a suitable sink for the identified source within the contours. The GIS then allows you to select a company, from the map display, bringing up a table showing the company's inputs and outputs.

So in effect you start with an output and then try to identify an input that is economical, i.e. identify a sink within the contours. Alternatively, the system could be developed so that you start with an input.

3.2.3 FaST and DIET

An Eco-Industrial Park (EIP) can exist as a 'sited EIP' (where all participants are closely located on the same site) or as a 'virtual EIP' where the participants can be spread out around a region. Some of these have been planned from an early stage, while others have been 'converted' from standard industrial parks. To help collect and use the necessary data, the US Environmental Protection Agency developed three computer-based tools: the Regulatory, Economic, and Logistical Tool (Reality Check), Designing Industrial Ecosystem Tool (DIET), and Facility Synergy Tool (FAST). They are designed to function separately, or together as a package.

The FaST tool was identified as potentially the most useful of the three for this research. FaST is a data base tool that stores information of inputs and outputs of companies, and creates a list of possible matches when a search is performed. DIET creates scenarios that help policy-makers envision combinations of industries that would benefit from co-location at a specific site. It estimates the economic, environmental, and employment trade-offs of different scenarios. It also considers the availability of land, energy, water, waste disposal, and other resources, based on the type of facilities and their special needs. Reality Check provides regulatory, economic, and logistical information that relates to the trade of specific materials. For instance, it identifies specific legislative and legal issues in the United States associated with the use of chemicals. It can estimate feasible transport distances for

materials, based on their economic value, and it broadly identifies industry sectors that may serve as potential trading partners.

3.2.4 PIMS

A simple approach that could deal with a large number of companies and by-products would be to collect the input and output data of the companies and store this in a database. The database could then be queried for matches, which would then be investigated manually for economics and environmental effects. The Bechtel Corporation of the US, developed software to aid eco-industrial park planning (BCSD-GM, 1997). The preliminary research involved assembling a database of industries in the Brownsville area (USA) and identifying their input and output streams, production processes, disposal costs and utility requirements. This data base was used with a computer-planning model, developed by Bechtel, to match industries by linking feedstock requirements with by-products and waste streams. The planning model was used to search the database to identify multiple possible materials exchange links within the region. The database included both local existing industries (to identify current opportunities) and non-local industries (to identify potential opportunities that may attract new industries).

3.2.5 Resource Exchange Software

Finally a commercial resource exchange software that had been developed in Australia known as Retrade was investigated (see Retrade, 2002). The system is similar to the FaST software described above, in that it stores information on companies inputs and outputs and finds a list of potential matches when a search is performed. The Retrade software is designed to be internet based and has the advantage of having both a public and confidential search area. Therefore a degree of confidentiality could be maintained by the companies whilst not hindering the ability of the software to find matches.

3.3 Project Development and Consideration of Project Options

Without full knowledge of the complexity and extent of the data, it was difficult to fully commit to a methodology. BCSD-GM suggest collecting the following information on companies and their by-products:

- Estimated physical and chemical composition, including concentration of primary and trace components,
- Regulated components,
- Estimated energy content,
- Estimated throughput,
- Estimated physical properties, such as density, compressive or tensile strength,
- Geographic location, and
- Transportation options.

It was anticipated that a database would need to be linked to a program that could perform a number of functions:

- Identify potential material input-output matches,
- Identify potential energy/steam/water exchanges,
- Transport options and costs. From the database it would also be able to calculate the difference from disposal costs or raw materials,
- Highlight any regulatory barriers.

However, from the literature and discussions with experts at international conferences (ERCP, 2001; ISIE, 2001) it was felt that there are severe limits as to what can be achieved by software. The Bechtel project (section 3.1.4) demonstrated it is possible to use software to perform some very useful work. However there may well be instances where matches have a better chance of being found manually, using tables and classifying materials. Chiu (2001) suggested that from the experience of the PRIME project in Asia they had found just as much success (if not more) from bringing together interested parties for discussion, than from using complex software such as Bechtel's PIMS. Further, Kalundborg, the most celebrated example of industrial symbiosis (section, 2.3), did not evolve because of software, but because of the close contact between managers.

To gain an idea of the kind of data that could be expected, the Scottish Environmental Protection Agency was visited, to examine the IPC records. The amount of useful data that could be gained from these records was limited however, because the documents were in an inaccessible form. Together with desk study research on company outputs, the opinion was formed that complex software was probably not needed. Additionally, companies have limited time to collect data: many would either not have collected such data, or would not be willing to spend the time doing so unless it could be demonstrated that the financial rewards were justified.

Evolution of the problem

Methods such as Ozyurt and Realff (see 3.2.2) are unnecessarily complex and unrealistic, because in reality the problem is due to other 'soft' factors. For example the trust between companies is of the utmost importance, and they cannot be forced to trade by-products. Unless companies all agree to 'go with the flow', and implement whatever the computer model says is the optimum solution (something which is very unlikely to happen in such a turbulent and unpredictable commercial world), then it is difficult to see the use of such a method.

The industrial world is not a mathematical problem, but based on relationships and culture. Kalundborg evolved on its own, as did Styria. The projects that are emerging now are an attempt to induce this evolution artificially. Software can be used as an aid, but the crux of the problem lies in the companies that make the products (and the waste) and the culture that demands such products. The real question of interest therefore began to emerge based around how a change in business can be fostered. What drivers and barriers are important for companies regarding industrial symbiosis? Why haven't more companies done this?

3.4 Research Proposal

The research proposal that emerged was to examine the influence of drivers and barriers in the UK on the implementation of industrial symbiosis and ecology. In order to achieve this, the research proposed to investigate influences across four main areas:

- economical: including economic instruments and the economic incentives
- legislation and its enforcement
- organisational: structure and culture of companies
- inter-company relations: affected by trust and openness

The research questions that stem from this are:

1. How can industrial ecology be implemented in the UK?
2. What are the most important drivers (if any) that are encouraging companies to move towards IE?
3. Is legislation and its enforcement a hindrance, or is it complementary to the development of industrial symbiosis?
4. How does the organisational strategy, structure and culture affect the company's ability to become involved with industrial symbiosis projects?
5. What other barriers and drivers are important with regard to industrial symbiosis?
6. To what extent has IE been implemented? Are companies working together?

Aim

The aim of the research is to analyse the influence of the drivers for and impediments to the implementation of industrial ecology in the UK; and provide feedback to relevant decision makers to facilitate the development of eco-industrial networks.

Objectives

The objectives of the project are:

1. Identify the positive drivers that are encouraging moves towards IE and cleaner production.
2. Identify the barriers and impediments to IE initiatives.
3. Identify the organisational aspects that are supportive for progress in IE.
4. Identify where legislation and regulation can be developed to improve effectiveness.
5. Identify other factors that contribute to movement towards IE.
6. Develop a conceptual framework which aids the analysis of the drivers, barriers and influences, affecting manufacturers.

7. Suggest optimum conditions for the evolution of industrial ecology to evolve.

Taking the classical approach of defining objectives can cause problems when dealing with the complexity of real world situations. Checkland (1999) gives a useful example:

"A current long-running example of the surprising difficulty in using the language of 'objectives' in human affairs is provided by the arguments which wax and wane over the Common Agricultural Policy (CAP) of the EEC. The Treaty of Rome boldly declares that the CAP has three equally important objectives: to increase productivity in the agricultural industry; to safeguard jobs in the industry; and to provide the best possible service to the consumer. No wonder the CAP is a constant source of never resolved issues: progress towards anyone of its (equally important) objectives will be at the expense of the other two!"

Particularly during research in real world situations such as those dealing with business, there is a high degree of unpredictability. There was a need therefore to be flexible and adaptive depending on the kind of data gained and the number and type of companies willing to participate.

3.5 Action Research Method

It was decided that action research methods would need to be used in order to achieve the objectives. The focus initially, would be on the waste streams of companies, in order to attempt to identify existing and potential synergies. To gain the necessary data on waste streams it would be necessary to visit companies, in addition to a desk study that would gather data from the public domain.

In Scotland there is no statutory duty to report waste streams. But some information is available at the office of the Scottish Environmental Protection Agency (SEPA) on companies that are subject to Integrated Pollution Control (IPC) regulation. Initially the focus was to be on the chemical industry for a number of reasons: the department already had several contacts in this sector, it represents the predominate industry of the area and the companies are also likely to generate large enough waste quantities for study. In order to visit the companies the following method was employed:

➢ Identifying a number of target companies

- ➤ Identifying a target representative within that company (usually the SHE officer or similar)
- ➤ Sending companies a letter and introduction to concept of Zero Emission
- ➤ Follow-up phone call to arrange a meeting
- ➤ Visit and meeting

Initially the larger companies of the region that had IPC permits were targeted for a number of reasons:

- ➤ It was anticipated that more information would be publicly available on the resource flows of these companies
- ➤ Large companies are generally keener to seek improvements
- ➤ The scale of existing and potential exchanges make them ideal showcases due to the material quantity and potential savings
- ➤ Larger companies generally have more resources in order to investigate and follow-up possibilities

The purpose of the initial meetings (known as the scoping study herein) was to gain an appreciation of the waste flows and identify any existing or potential exchanges. It was envisaged that, from the data gathered, a number of case studies to examine could be identified.

The scoping study was followed by semi-structured interviews where necessary, to gain additional information for the case studies. The project was later expanded to include a wider range of companies, thereby increasing the diversity and chances of finding matches. To encourage a larger number of companies to submit their data a 'Zero Emissions Network' was proposed. A website was developed to promote the project and in order to aid data collection suitable software was searched for. The software would also provide a firm basis for the project and help encourage companies to participate.

From the software discussed in section 3.1, the most appropriate was the Retrade resource exchange software. This was chosen because it could be internet based, was not overtly complex and had suitable functions.

3.6 Conceptual Development

Developing a Conceptual Framework for Investigation

This thesis is based on the question: How can IE be fostered or implemented? This thesis therefore analyses the barriers and drivers with the eventual aim being to suggest the most favourable conditions for the implementation of IE in the UK.

As discussed in Section 2.3, it is generally considered that there are two paths to IE: product based and geographical analysis. Another way of saying this is that progress towards IE can be made both through industrial symbiosis and product redesign. One of the key drivers for industrial symbiosis is a network or facilitator that fosters exchanges. Therefore this thesis is interested in drivers and barriers to IS, networks and IE. This thesis will concentrate on the application of IS (as illustrated by the right hand side of Figure 3.6.1), although the product based approach will in no way be ignored.
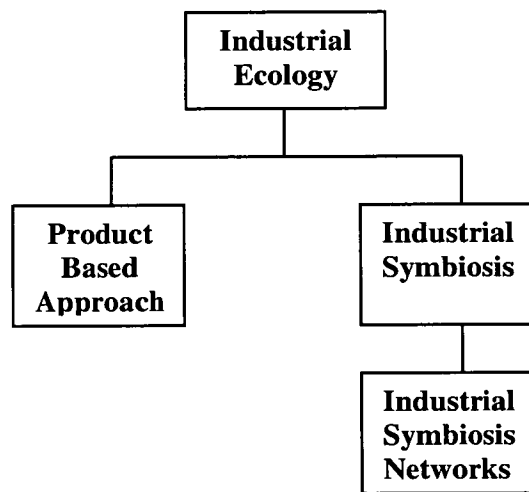
Figure 3.6.1: Paths to industrial ecology

IE is a systems approach and it will therefore be necessary to consider a number of interacting system levels simultaneously. Cote (1995) proposed a number of levels of integration for pollution prevention:

Process:	Most effective level for waste reduction, prevent with new technologies, reduce with new technologies and good housekeeping practices, reuse and recycle
Company:	Organisational environmental policy and guidelines for good housekeeping practices, recycle wastes from one process to another.
Industrial Park:	Municipal guidelines and regulations, waste exchange facilities, recycle wastes from one company to another.
Regional Area:	Federal, provincial / State guidelines and regulations, disposal (landfill, incineration etc) primary alternative
Global Perspective:	International regulatory and advisory agencies, least effective level for waste management, capacity of physical environment to absorb wastes.

Below (Figure 3.6.2) is a simple but useful way in which to begin conceptualising the problem and also the solution.
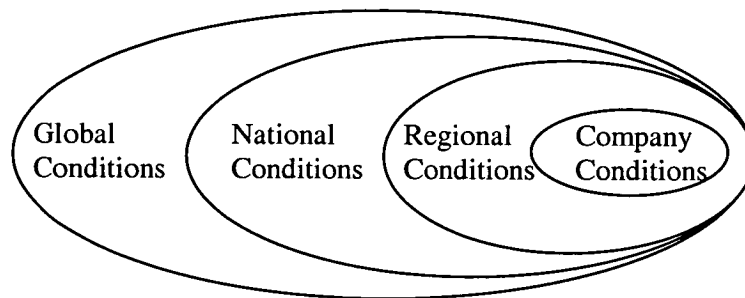
Figure 3.6.2: Conceptualising the system levels of importance.

This diagram represents how the various system levels interact and are affected by each other. All these levels are of relevance for both industrial symbiosis and industrial ecology. The 'company' could be affected by regional aspects, such as spatial (distance from potential partner); national such as legislative conditions; but also global such as trading conditions. Table 3.6 uses this framework to list some of the important influences that emerged during the literature review (and also several additional ones).

Individual	Company	Region	Country	Global
- Culture -Training -Education -Experience	-Culture -Strategy -Management techniques and systems, eg EMAS, TQM -Type of business -Sector groups/ initiatives and influences -Inter-site influences and networks - Market share /strength -Geographical location – distance from potential partners - Previous IORs – networks, alliances, clusters. - Funding from external sources - Training/ information from external sources	-Culture -Planning authority -Business and environmental initiatives -Facilitator -Regulator - Policies and strategies of key actors -History of industry - Skills of workforce - Funding from government etc.	-Culture -Legislation -Regulator - Policies and strategies of key actors - Politics: the need to please the voter	-Culture -Free markets -Stock market -Climate -Carrying capacity - Perception of other risks e.g. terrorism, global disasters.

Table 3.6: Important influences that can affect a company with regard to industrial ecology

3.7 Chapter Summary

This chapter has described the foundations of the research and its subsequent development. It has illustrated the initial focus of the research on using software for IE projects and how after the literature review, and conversations with practitioners from the emerging field of IE, the focus developed to examining the drivers and barriers to IE. This provides a wide scope in which to maintain flexibility, but the focus is primarily on synergies between companies and the importance of these for the progression of IE. Finally the chapter developed a conceptual basis for the development of the research.

Chapter 4 next describes the study of existing and potential exchanges within the Forth Valley area of study. Using the conceptual framework, it then goes on to examine the policies and strategies of key actors at the regional and national levels. Finally, it examines the latest IS development in the UK which emerged concurrently with this research – the National Industrial Symbiosis Programme. It discusses the early lessons from this venture that has brought the UK from a seemingly lagging position, to one that can provide many important lessons for IS/IE global development.

Chapter 4 Project Development and Discussion

4.1 Background of the Forth Valley

The area chosen for study is best described as the Firth of Forth area and is shown in Figure 4.1. It incorporates Edinburgh and the large industrial complex at Grangemouth (shown in Figure 4.2).

Figure 4.1: The Forth Valley, chosen area of study.

This area incorporates eight local authority areas: East Lothian, Mid Lothian, City of Edinburgh, West Lothian, Falkirk, Stirling, Clackmannanshire and Fife. Confusingly this area is covered by three Scottish Enterprise groups of Lothian, Fife and Forth Valley. Below is some information about the business strengths of the three areas (Scottish Enterprise, 2004).

Lothian

- Best known for financial services, Edinburgh is ranked the UK's second largest centre after London. The capital is also home to the Scottish Parliament.

- Other key industries are: biotechnology, optoelectronics, microelectronics, software, creative industries, government, tourism and education and training.
- Major employers in the area include: Agilent, Sun Microsystems, Quintiles, Epson, and Sky.
- Edinburgh and Lothian has a greater than average availability of labour and an abundance of well-qualified people.
- Lothian based companies achieved some £3.1bn of manufactured exports in 1998, some 16 per cent of the Scottish total.
- There were just over 21,100 enterprises in Lothian in March 2000, which includes all industries in the public, private and voluntary sectors. These represent 15% of the Scottish total.

Fife

- Most of the industrial and commercial activities are concentrated in the south-west of the region, in the area around Glenrothes, Kirkcaldy and Dunfermline.
- Dependency on mining and defence has been reduced with the introduction of electronics and financial services.
- Other important industries include: optoelectronics, oil & gas, biotechnology, chemicals, textiles and marine engineering.
- Major employers include: Guinness, Sky TV, Bank of Scotland Visa centre, and Marconi.
- Fife's exports during 2001 totalled £706m. Half of all exporters were in the engineering and IT sectors.

Forth Valley

- The deep-sea container port and oil refinery at Grangemouth are important contributors to the local economy. Other key sectors include: chemicals, tourism, distribution, and financial and business services.
- Major employers include: Prudential, BP Amoco, Avecia, United Glass, Thomas Cook
- The total number of residents with a job is estimated at 122,500
- More than 7,000 companies operate in Forth Valley, with about 90% having less than 50 employees while the few companies employing more than 250 employees represent 53% of total employment in the area
- The top export are chemicals, refined petroleum products, motor vehicles and basic metals

- Estimates on the impact of tourism on employment range from over 7,000 jobs directly employed with tourism to over 8,500 jobs created by both the direct and indirect employment from tourism

Figure 4.2: Grangemouth industrial complex.

4.2 Development of Research and Zero Emissions Network

4.2.1 The Scoping Study

The initial task was to gather as much information as possible from the public domain: the internet, authorities, trade associations and SEPA. The internet proved to be one of the most useful sources of information with various database type websites that provided a search facility and general information about companies. Organisations including the Institution of Chemical Engineers and the Chemical Industries Association were also contacted to find out whether similar studies had been done, and also in the hope of gaining information about some companies. The information gained from these organisations was however of limited use; the most useful information was an industry database website. The visit to SEPA provided very limited information, and the information that was available existed in a very inaccessible form.

Contacting the Companies

To obtain data successfully in the turbulent and unpredictable world of business it was necessary to maintain a high degree of flexibility. It was anticipated that some companies would not participate in the study or/and would supply only limited data. It also could not be assumed that the data gained would be of any use, or that any exchanges of interest would be found. The research developed into action research and the potential emerged to develop a Zero Emissions Network within the Forth Valley. It was also hoped that the act of proposing a Zero Emissions Network would ensure that more companies would recognise the benefits and participate in the study.

As well as companies, other organisations contacted in the initial stages of the study included Scottish Enterprise, who initiated a presentation at a meeting of the Grangemouth Development Group (GDG). GDG was formed in 1992 and consists primarily of the major companies at Grangemouth, the Local Enterprise Council, Forth Ports, and Falkirk District Council. Its' overall aim is to 'improve the competitiveness of the local chemical industry and create further jobs'

Zero Emissions Network Launch

The presentation to GDG that proposed a Zero Emissions Network for the Forth Valley took place on September 11th 2001. This demonstrated the advantages of the concept and gave examples of its growing success around the world. The overall response of the GDG representatives was very positive and two companies arranged meetings, whilst the others were willing to be contacted in the near future to arrange meetings. Through the GDG meeting and contacts within the University an initial 10 companies were contacted. This gave a good sample of the kind of response and data that we could expect from the companies.

4.2.2 Identifying Opportunities and Existing Exchanges

During the investigations of which software to use for data collection at the beginning of 2002, contact with BCSD-UK began. At the time BCSD-UK was overseeing three industrial

symbiosis programmes in the UK and had recently implemented a National Industrial Symbiosis Programme (NISP). In the latter part of 2002, BCSD-UK successfully gained financial backing from the Scottish Executive to implement a Scottish Industrial Symbiosis Programme (SISP) and was developing software in order to facilitate resource matches. The software would cover by-product materials and also other relevant factors such as spare human resource capacity. It was therefore seen as pertinent to collaborate with BCSD-UK, in order to avoid operating in direct competition with their government backed programme. The author participated in a launch event for SISP in March 2003 (see Appendix for presentation slides). This event proved enormously successful and involved 85 companies. The meeting included breakout sessions where companies discussed how they thought SISP could be taken forward and their anticipated drivers and barriers. The findings of this are discussed in Section 4.7. Following the workshop we collaborated with Thirdwave, the Edinburgh based consultancy running SISP for BCSD-UK, and visited further companies to introduce the software and SISP.

In carrying out the research and analysing the data, one of the most pertinent questions becomes – 'what really is *industrial symbiosis*?' Even Kalundborg, the most celebrated example of an industrial ecosystem, is only a limited number of "waste=food" type exchanges, and still represents a highly dissipative system. With the definition of 'symbiosis' in mind we must recognise that companies outsource and work together for general efficiency improvements (although sometimes for marketing purposes as well) and not necessarily for environmental ones. So although these forms may not be regarded as true 'industrial symbiosis', the important thing is that they are working together for mutual benefit and are developing IC skills for working together (trust, interpersonal skills, collaborating skills). Additionally, they are making efficiency improvements and are therefore embedding a culture of ICC together with recognition of the benefits of expanding the normal boundaries of the company. With increasing amounts of legislation and competition it is likely that there will be an increasing need for ICC. Therefore any ICC is of significance in the study of IS.

This research came at a time of great transition when government policies were being developed towards sustainability and waste strategy. Also a number of initiatives were underway in the UK aimed at helping companies become more energy efficient or reduce waste.

The number of companies participating in this research increased concurrently whilst the relationship with BCSD-UK developed and are shown in Table 4.2.2. The visits to these companies included presenting the idea of industrial symbiosis, data collection and a semi-structured interview. The purpose of this was to find potential and existing synergies that could be developed as case studies.

Company	Company	Company	Other Organisations
Alcan	GE Plastics	Scottish Power	BEP
Avecia	Macfarlan Smith	Scottish Water	CIA
Borden Chemicals	North British Distillery	Shanks ChemServices	Falkirk Council
BOC	Nychem	Shell	Forth Ports
BP Amoco	Plastic Polymer Processors Ltd.	Smith Anderson	GDG
Diosynth	Polymeri Europa UK	Syngenta	IChemE
Elementis	Rohm & Hass		Scottish Enterprise
EPR	ScotAsh		SEPA
Exxon	Scottish & Newcastle		WRAP

Table 4.2.2: Companies and Organisations initially contacted.

4.2.3 Opportunities and Existing Exchanges

The scoping study and the subsequent meetings revealed several existing and potential exchanges in the area. Overall the interviews with the companies showed that the companies are receptive to IS and can see its value. They are increasingly open to working with others and are aware of the benefits. Outsourcing, joint ventures and inter-company projects have all been found to exist. There is no way of comparing ICC with previous research (no previous studies have been found) but the majority of those found (shown below in Table 4.3.1) are very recent, suggesting the trends found in the literature are reflected in the area of study.

As would generally be expected at a large chemical complex such as Grangemouth, a number of IS type exchanges have developed over the years. In section 4.2.1 it was mentioned that there is close interaction of the major companies at Grangemouth, who meet regularly under the banner of the Grangemouth Development Group. GDG could be described as a type of embryonic IS network through its increasing emphasis on

sustainability issues. Some of the existing and potential exchanges found at Grangemouth are illustrated in Figure 4.2.3.
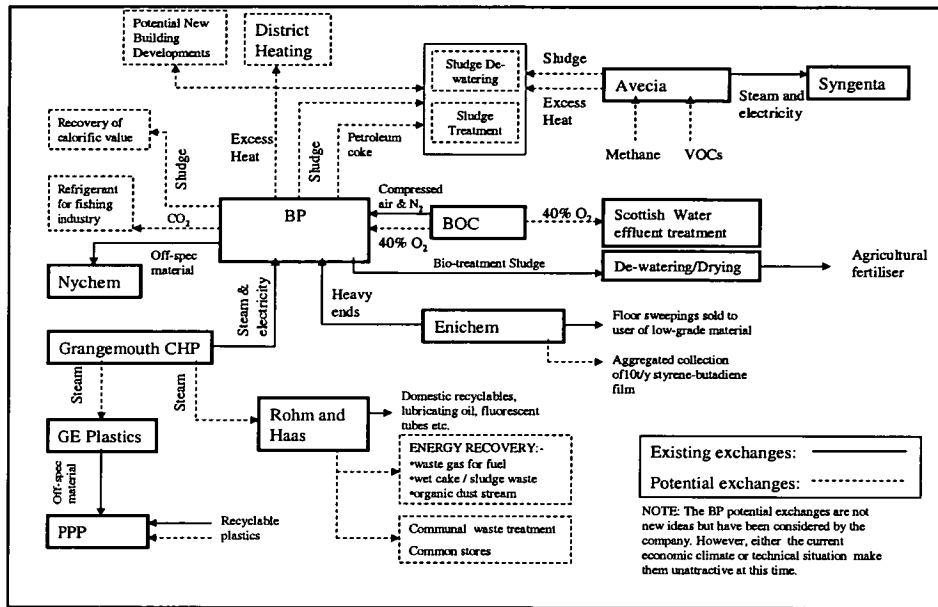
Figure 4.2.3: Examples of existing and potential Exchange in Grangemouth

Figure 4.2.4 shows some of the exchanges in the wider area of the Forth Valley which include a number of large commercial exchanges.
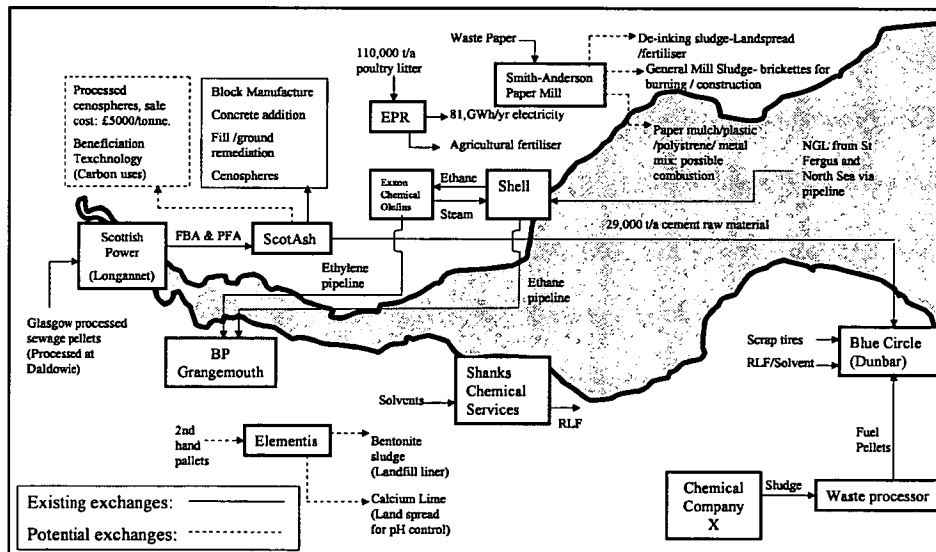
Figure 4.2.4: Existing and Potential Exchange in the Forth Valley

Some involve joint ventures such as ScotAsh, set up between Blue Circle and Scottish Power, to utilise the power station ash. Another example of ICC is Diosynth that works with its customers to recycle solvents, making a saving of £600,000 per year in production costs.

Two spin-off undergraduate projects were developed from the data gathered. These were 'Towards Zero Emissions: a Study of Waste From a Petrochemical Site' (Catherine Donneky) and 'Influence of Climate Change Levy, Carbon Taxes and Carbon Trading on the Market for Oxygen-enriched Air' (M. McCormack).

4.3 Company Level Analysis of Barriers and Drivers

The research has provided findings from a range of sources that can be used to illustrate and analyse the drivers and barriers to industrial symbiosis. The research will be presented in three main areas:

- Research and case studies of companies from the Forth Valley
- The National Industrial Symbiosis Programme (NISP)
- Collaboration with BCSD-UK and the Scottish Industrial Symbiosis Programme (SISP)

These will initially provide results for discussion of IS in the UK which can then be followed by a wider discussion on IE. The following tables display opportunities (Table 4.3.2) and existing IS behaviour (Table 4.3.3) against respective barriers and drivers. Because IS is not widespread or generally recognised as a concept (although easily understood in its simplified form as a waste exchange), it was necessary to identify any activity that may have facets of IS and analyse as much as possible. The table categorises the type of activity by industrial symbiosis (IS), inter-company cooperation (ICC) or both.

Companies involved	Description of Opportunities	Types of Activity	Drivers	Barriers
A	Outputs: • 100,000 tonnes red mud. Very small amount used in paint, investigated the use in bricks; fixes heavy metals-confidential ongoing research. This is a matter for waste utilisation research – company has already run several projects over many years.	IS	• On-site landfill lifetime 7-8 years • Large quantities	• On-site landfill tax only £2 / tonne - lack of incentive • Potential for Brick use but other materials are more suitable • Practically useless material
A	• Possible waste heat capture. Plans for CHP plant.	IS		• No data • No other companies in area • Limited land space
B	Potential Inputs: • VOC/ Methane combustion in CHP plant.	IS		• Any fuel would need to be economical and in bulk
B and others	Outputs: • Biological sludge – phosphorus recovery, drying with waste heat from Avecia and others.	IS & ICC	• Cost of disposal • Potential revenue from phosphorus	
B	Outputs: • Waste solvent as start up fuel for Longannet.	IS	• Cheaper alternative?	• Other fuel already used
B	• Incorporate waste solvents with heavy residuals to produce a synthetic crude oil which could be cracked/ pyrolisized.	IS & ICC	• Potential revenue from product • Disposal costs	• Research and capital outlay needed
B	Outputs: • Calcium sulphate/ 50% water.	IS		• No known use
C, Falkirk Council	Outputs: • Excess steam/ heat: district heating with Falkirk Council for sludge dewatering / BP office heating	IS & ICC	• Falkirk Council – improving social conditions / cheaper heating • Public relations	• Would need back-up MP steam plant • BP are unsure of long term steam availability • Company is considering heating their offices with the heat • Government grant needed for capital outlay
D	Output • 40% low pressure O$_2$ stream, could be piped to others, to increase combustion temp /efficiency or increase biological activity in wastewater treatment.	IS	• Increased efficiencies of combustion • Increased biological activity	• Cost of laying pipeline & compressors • Long term contract needed to cover cost of pipes
E	None identified – company would not participate.			• Perceived lack of benefit for perceived number of man hours required to examine possibilities.

Table 4.3.2: IS opportunities identified in the Forth Valley against respective barriers and drivers

Companies involved	Description of Opportunities	Types of Activity	Drivers	Barriers
F	*Outputs* o *20 tonnes of waste per product.*	IS	• Economics – have a six man team working on improvements • ISO14001	• Cost of transport if match found - £500 / tanker • Have tried waste exchange before with no success
G	*Potential Inputs:* o 2nd hand pallets	IS & ICC	• Purchase savings • A future waste exchange facility	• Finding reliable source
G	*Outputs:* o Bore hole water	IS	• Economics – sale profit	• (Re. Water) No factories within 300m – hence infrastructure costs outweigh cost of water which is generally considered cheap anyway.
G	*Outputs:* Sludge already has uses, but Elementis are open to better offers! o Bentonite sludge – landfill liner o Calcium sludge- land-spread	IS	• Economics – sale profit • ISO 14001 and Responsible Care Program	
H	*Outputs:* o Sludge – working with company to dewater it; and also looking at biomass treatment	IS	• Economics – financial savings • ISO14001	• Legislation – biomass treatment of sludge onsite would result in higher VOC emissions
H	*Outputs:* o Timber – considering recycling to make decorative chippings	IS	• Economics – financial savings onsite use instead of disposal costs • ISO14001	
H	*Outputs:* o Spent Caustic Soda o Inert carbon coke – possibly for filters o Excess heat – greenhouses	IS	• Economics – sale profit • ISO14001	• Did not want to become involved in project after initial meeting. Reason unclear, would not return contact.
I	*Potential Inputs:* o Investigated steam pipeline from CHP	IS	• Economics – financial savings	• Public opinion opposed after recent steam release accident involving member of public (and a dog!).
I	*Outputs* o Filter cake – 20-25% solids o Hydrocarbons – currently captured and incinerated	IS	• Have two projects, one to reduce at source and one to turn into a product • ISO 14001	• Internal network may hinder drive to communicate with others • Uncooperative HS&E manager
J	*Inputs:* o Recycled liquid fuels and other combustibles	IS	• Improvements under EMAS. Emission improvements	
J	*Outputs:* o Wooden drums	IS	• Reduce amount going to landfill • Improvements under EMAS	• Small quantities – drums land-filled as sink has not been found.
J	*Outputs:* o Bricks from kiln	IS	• Reduce amount going to landfill • Improvements under EMAS	

Table 4.3.2: IS opportunities identified in the Forth Valley against respective barriers and drivers (continued)

Companies involved	Description of Opportunities	Types of Activity	Drivers	Barriers
K	*Potential* • Possibility of using waste heat in nearby housing development	IS	• Economics – free heat, provider does not intend to charge	• Previous project was hampered by Railtrack who would not allow way-leave over nearby railway. • Housing would still require a back-up heating facility in case of plant shutdown.
L	*Outputs:* • 'Grey' water ~ 60-70C with small amounts of hydrocarbons	IS &ICC	Economics - increasing water prices may encourage other to use it. There has been a water use project in the area so this may find uses for the water	• Location - no potential user of 'grey' water near-by?
L	• Water treatment and recycling with third party	IS &ICC	• Economics - increasing water prices • Familiar with outsourcing – Polymeri are taking the view that their expertise is in the manufacture of butadiene products. So services e.g. utilities can best be supplied by others	
L	*Outputs:* • Small amount of styrene-butadiene film – currently landfilled	IS	• ISO 14001	• Landfill cheap • Very small amount of film would need communal collection
M	*Output* • Calcium sulphate in powder form	IS		• LaFarge use gypsum but crush it on-site and can't use powder in their process
N	*Outputs:* • Effluent treatment sludge - landfill • Filtrate from effluent • Organic dust – heat recovery by combustion • Waste gas	IS	• Landfill tax	• Organic dust needs correct (possibly custom) injection system
O	*Outputs:* • Kieselguhr (filtration medium) Glacier could potentially incorporat into raw materials for LaFarge	IS	• Technical – Dunbar cement works is a dry process and so it would have to be dried or transported to Glacier in Sheffield or south of England plants • Transportation costs • Catching up with competitors on sustainability	
P	*Outputs* • Run water with low concentration of Zinc contamination	IS	• Economics - financial savings • ISO14001	• Barrier to IE system solutions - Legislation /technical Run water is basically shipped away by another company and discharged untreated because they have bigger consent limits.

Table 4.3.2: IS opportunities identified in the Forth Valley against respective barriers and drivers (continued)

Companies involved	Description of Opportunities	Types of Activity	Drivers	Barriers
P	*IS Possibilities* o Sharing trucks and/ or offices.	IS	• Economics- financial savings • ISO14001	• Core business • Co-ordination • No champion
Q	*Outputs:* o General mill – high fibre content, Bricks for burning or construction o De-inking sludge – low fibre content, ash, chalk. Land spread, good fertiliser. o Pulper waste – pulp, plastic and metal mix. Possible combustion.	IS	• Economics - financial savings • Legislation	
R	*Outputs* o 5 types of solvents: Methyl acetate by-product is sold to paint industry; others are incinerated or go to RLF (can be a mixture of 1000 compounds) but are looking for better options	IS	• Economics – financial savings	• Technical – difficult mixture, incineration may be the only solution
R	*Outputs* o Waste heat is low grade – possible greenhouses on Jupiter (the community nature park).	IS & ICC	• Company image	• Capital investment
R	*Inputs* o Potentially: waste acids or alkalis to treat effluent.	IS	• Economics – financial savings	
R	*ICC* Sharing of lorries – 3000 tankers a year bring materials in. A lot of material goes to Hull and then the lorries are empty. A lot is also exported to Europe, could they be returned loaded?	IS	• Economics – financial savings	
Grangemouth companies	o Possibility of Grangemouth incinerator?	ICC	• Economics – difficult wastes • Legislation	• Capital • Emissions responsibility

Table 4.3.2: IS opportunities identified in the Forth Valley against respective barriers and drivers (continued)

Companies involved	Existing IS Activity	Types of Activity	Drivers	Barriers
GDG	Grangemouth Development Group – network to improve competitiveness of chemical industry	ICC	• Economics • Job creation in the area and other social aspects	• Perception of competitive environment
C and Falkirk Council	• District heating	ICC	• Social – cheaper heating for housing and improving conditions	• Capital needed • Technical - plant changes leading to uncertainties about the amount of low pressure steam available
C	• Grangemouth Water Users Group - partnership to find alternative sources of water and identify water saving opportunities	ICC	Water • Economics – financial savings • Rising water prices • Image of companies using large volumes (70Ml/day) of water • Landfill tax – and awareness of its increasing trend	• Some of these projects are not core business – others have taken priority
C, S	*Output* • Waste polymer was previously going to landfill and is now sent to Nychem, 100metres down the road	IS	• Cost saving on both sides	
F, T	• Work with customers and waste management company to reduce and reuse wastes.	ICC	• Economics (~20 tonnes of waste/ product batch) • 6-man waste minimisation team • ISO14001 • Waste is seen as *customer's waste*	• Need for high purity of products • Length of tests needed in recycling solvents(can be up to 1 year), to ensure product purity is not affected, and customers are happy with current process
F, T	• Worked with waste management company to abstract Al from waste stream which is then used in water treatment	ICC	• Economics • Pressure from customers	
F and customers	• Packaging is returned and recycled	ICC	• Economics • Legislation	• Cost of collection
H	*Outputs:* • Tar – currently blended offsite for cement kiln fuel	IS	• Economics	• Onsite production of fuel would incur higher SO₂ emissions and would need license to sell
U	Incineration of chicken waste to recovery energy value *Outputs* • 81 GWh/ yr of electricity • Ash for use as agricultural fertiliser	IS	• Change in legislation – SEPA were trying to stop the land-spreading of this waste. • Fertiliser is more environmentally acceptable for land-spread than poultry litter.	
J	*Current Inputs as fuel:* • Recycled fuels – paints, solvents • Tyres • Coal	IS	• Improvement in emissions and in Integrated Sustainability Index from use of tyres • Improvements under EMAS	• SEPA / Legislation (Substitute Fuels Protocol) , - New potential fuels have to go under extensive and costly tests to satisfy SEPA /EA. • Waste in small quantities – because of the need for tests (even if widely known to be harmless!)

Table 4.3.3: Existing IS activity identified in the Forth Valley against respective barriers and drivers

Companies involved	Existing IS Activity	Types of Activity	Drivers	Barriers
J	*Inter-company co-operation* ○ Sapphire Energy Recovery – joint venture with Michellin to source tyres at set rate ○ Glacier – set up to provide raw materials (based in Sheffield), source useful wastes.	IS & ICC	• Economics • Steady source of supply	
V	Solvents sent for recovery or incineration in cement kilns – Sheffield. Other recyclables are recycled by other contractors	IS		• High purity needed for products, so this deters using recycled inputs
K	○ *Existing*: Presently all products are sold: grain whisky, grain neutral spirit, CO_2, animal feed, whisky distillate	IS	• Economics	•
W	*Current Inputs:* ○ 'Floorsweepings' of polythylene & polypropylene	IS	• Business opportunity	• Only a taker of waste plastic pellets
X	*Inputs:* ○ Waste Plastic	IS	• Business opportunity	• Plastics must be segregated to process
L	*Outputs:* ○ Heavy ends go to C for heat recovery by combustion	IS	• Economics	
L	*Outputs:* ○ Floor sweepings – go to low grade user	IS	• Economics	
L	*Inter-company co-operation* ○ WH Malcom operate packing area ○ Elyo supply utilities at an agreed contract price	ICC	• Economics	
N	*Inter-company co-operation:* ○ Extracting value from domestic and chemical waste- project with Envirotech	ICC	• Economics • ISO 14001	
Scottish Power	*Inputs* ○ Sewage pellets from Scottish Water ○ Re-use coal from ScotAsh process *Outputs* ○ FBA & PFA (see ScotAsh) ○ Road spoil / waste	IS & ICC	• Landfill Tax • Economics	
Scottish Water	*Outputs* ○ Sewage sludge from Glasgow	IS & ICC	• Commercial venture	

Table 4.3.3: Existing IS activity identified in the Forth Valley against respective barriers and drivers (continued)

Companies involved	Existing IS Activity	Types of Activity	Drivers	Barriers
X	**Outputs** • Process solvents from pharmaceutical industry • Excess solvent goes into fuel blend • Recently introduced as part of the business: 'Managing Services' – a waste service offering advice on waste min. etc.	IS Servicizing	• Economics	• Technical -guaranteeing purity. Who should be responsible? • Price paid for recycled material is less, but usually more expensive to produce • Legislative label of waste
ScotAsh	**Outputs** • Un-burnt from ash	IS	• Economics – and landfill tax	• Legislation – 'waste' label
ScotAsh	**Inputs** • FBA & PFA from Longannet **Outputs** • PFA for cement, ground fill / remediation • FBA for block manufacture& drainage	IS & ICC (Joint Venture)	• Economics – commercial value adding company • ISO14001	
Shell	**Outputs** • Ethane to Exxon & BP (5%) **Inputs** • Steam from Exxon.	IS	• Economics	
R	**Inputs** • Steam and electricity from B	IS	• Economics	
R	**Outputs** • Cem-fuel - 5 types of solvents: Methyl acetate by-product is sold to paint industry; others are incinerated (can be a mixture of 1000 compounds)	IS	• Economics – cheapest disposal route • ISO 14001	

Table 4.3.3: Existing IS activity identified in the Forth Valley against respective barriers and drivers (continued)

4.3.1 Barriers at the Company Level

The evidence provided in Table 4.3.2 reveals that there are many differing individual barriers which usually depend on the unique circumstances of the company. It suggests that there is not usually one specific barrier which is of particular importance in hindering industrial symbiosis. Rather, a range of factors and circumstances combine that discourage focussing on such issues. Classification is difficult because of this but the following headings will be used for discussion:

- Economics
- Legislation and Regulation
- Technical
- Organisational
- Informational

Economic Barriers

Perceived return on the 'bottom-line' - projects can simply be seen as too expensive or the economic return not attractive enough. The latter is generally the case - when the potential added value and the management time necessary (that the companies envisage) is considered in comparison to the return on their core operations, it is simply unattractive.

Low cost of energy and utilities - in general has meant that progress in developing IS opportunities has been slow. This was expressed by companies in the Grangemouth area who admitted that there was little incentive to make improvements, particularly with water which is cheap (confidential dialogue with companies).

Capital – e.g. as in the case of district heating, there is an initial need of capital, and payback periods have to be closely considered.

Legislation and Regulation

Legislation is a common barrier both in this research and in the literature.

Legislative label of 'waste' - means that companies are often not allowed to handle a material deemed as a 'waste' and can only bag it for collection. In addition it cannot be sold easily for reuse unless the receiving party has the appropriate waste handling licence (BP, 2001). Another example of how legislation can frustrate agreements is the cement kiln example, where extensive and costly tests are needed for new fuels and materials. The cement kiln is only licensed for three types of fuels (coal, waste tyres, RLF); any others need the tests, whereas in France, for example, there is a list of acceptable, safe materials.

Time taken for legislative change – and the inflexibility of legislation and the regulator are common problems in many countries. When there are clear benefits for the companies and the environment there must be more flexible or easily changed legislation.

Poor and inconsistent regulation - was also highlighted by one company as a barrier that can frustrate advancements. As with the case of a company which reuses ash, officers are seen as inconsistent and inflexible.

Technical

Technical barriers arise in the following categories: material suitability, quantity, purity, consistency or reliability of feedstock.

Large quantities - for some of these companies the waste quantities are so large and the material so difficult that it has been an issue of concern (and expense) for a number of years. As for company 'A' they have had many separate waste utilisation or reduction projects. In cases like these, when we consider the wider system (and for example the real potential for greater recycling - and hence the reduction of this waste – if the correct system conditions existed) the viability of such a business becomes questionable.

Small quantities - at the other end of the spectrum many wastes are too small for most companies to consider an environmental problem, and/or cannot be collected for recycling economically. It is often cheaper and easier for a company to add such waste to the landfill disposal skip. In this situation if enough companies become aware of others in a similar

position, a communal collection and recycling would be viable. Hence this calls for the development of sub-networks, or recycling loops.

Purity - one of the current barriers that prevents companies from using a recycled chemical product is the problem of guaranteeing purity for their process. The question is: who should guarantee the quality and be responsible for the expense of the analysis? Currently the price paid for recycled material makes it uneconomical for the recycling processor to do this. On the other hand, the price of virgin materials is often the same as, if not cheaper than, recycled material, and the purchaser obviously prefers the guaranteed quality of the virgin material. One interviewee noted that there could be some kind of tax incentive or legislation to encourage companies to use a certain percentage of recycled material.

Backup heat systems – a major barrier to the reuse of heat is the need to provide back-up systems so that heat can still be provided when production is down (particularly with district heating projects). This can increase the capital cost of projects dramatically and act as a strong disincentive to investment.

Space problems – in particular for the utilisation of waste heat. Some companies are isolated and/or don't have spare land capacity for a potential joint venture. An obvious joint venture possibility that is underutilised in many cases is the use of waste heat in greenhouses.

Organisational

Core Business focus – a look at the waste streams and potential inputs shows that there are often at least some small potential projects. Generally companies concentrate on what they consider their core role of adding value to the product, and waste is often seen as a necessary component of production, outside the scope of normal practice.

Management time – related to core business focus, managers have limited time in which to pursue projects outside their normal tasks. An OECD report (OECD, 1985) mentions the risk of too many regulations diverting management time and effort into compliance rather than pursuing the business growth which they see as an important driver of innovation. One Forth Valley company in this research noted that regulations meant that more staff was needed to comply and complete the voluminous paperwork. For this company, the COSHH regulations

had previously required an extra staff member and it was anticipated that the IPPC regulations would also entail an additional staff member.

Nature of the business - chemical and most pharmaceutical companies are by their nature linear dissipative production systems. In the short term, one of the most appropriate solutions to improving the resource efficiency for many chemical companies is servicizing and working with customers. This type of behaviour is becoming more common as was seen with the Diosynth example, who now make savings of £600,000/annum by working with their customers and a waste management company to recycle solvents. Alternatively companies could concentrate on increasing yields, but this approach is usually an attempt to only make incremental improvements within a *system* that needs to fundamentally change (i.e. move away from maximising sales to provide a service).

Informational

Informational – some companies are still not aware of the wider benefits of resource efficiency. There has also been no easy way (until the latest internet sites) to locate markets for by-products, or locate potential partners.

Ease of disposal – the many competitive routes for disposal can make contacting a waste operator the easiest and therefore seemingly most attractive option. This has also helped to culturally embed the concept that waste is somebody else's problem. There needs to be more pressure on the waste management companies to provide a solution, act as intermediaries, or perhaps provide more of a service to companies (e.g. advice) rather than making more money from more waste?

Barriers Discussion

Almost without exception, interviewees were keen and forthcoming with ideas of innovative possibilities. Why haven't these ideas been converted into reality? Employees simply aren't encouraged to do so and of course have limited time in which to follow-up ideas.

Overall the most important barriers that emerged are:
- Legislative label of waste

- Core business focus

There are many minor barriers that could be overcome if there were extra incentives. There are also a number of other general barriers which were not highlighted in Table 4.3, as they didn't relate to specific examples, but none the less are important considerations.

Inter-sector barriers – inability of many companies to look beyond the company boundaries, let alone those of the sector.

Limitations of input-output matching - a look at company business and these data reveals limitations that simple input-output matching from software could provide. The literature highlights the success of bringing possible partners together, ideally in informal situations, to discuss possibilities.

Shifts in products – can mean a change in by-product which may not be suitable for the present outlet.

Past waste exchanges facilities – there are a number of past and existing internet based waste exchange facilities that a number of the companies had tried without success. Potentially, companies may be reluctant to spend time to enter data in another database.

Overall it appears that barriers are not usually very significant. Although legislation can be frustrating, the situation is beginning to improve now that regulators are increasing the dialogue with industry. Unfortunately, it is usually just one type of environmental legislation, designed to protect the environment, which is at odds with another type. For example the legal label of 'waste' was originally designed to protect the environment, but often does the opposite when considered from a wider system perspective.

Sector group meetings - such as the CIA, are a potential barrier to company involvement in industrial symbiosis network meetings. The CIA encourages meetings between members every three months for discussion and best practice dissemination (which is not a bad thing). Whilst not specifically a barrier in itself it could discourage company involvement in IS meetings. One interviewee could see the value in the CIA meetings but would be reluctant to take part in other meetings. The same interviewee stated that they would be looking for synergies with another company that they had recently purchased – something which

appeared to them to be more attractive than finding synergies with 'outside' companies. Although this may seem obvious, it is important that facilitators of IS networks consider this and seek ways to overcome this barrier.

Barriers to the Research

The type and quantity of data supplied by the companies ranged from extensive (and confidential) to very minimal e.g. naming two possible inputs. Hence for some companies opportunities were very limited and existing exchanges non-existent. Another problem was that contacting companies and arranging meetings was very time consuming. It was often necessary to phone several times, sometimes leaving messages but without getting a return call. It is envisaged that, although the company representative showed an interest in the concept upon actually meeting, the priority of 'student' research was seen as very low. Meetings were sometimes put off two or three times and often had to be arranged months in advance.

4.3.2 Drivers at the Company Level

As above, drivers can also be divided into the same categories and are discussed below.

Economics

Economics and business potential – a number of the companies already have utilisation routes for their by-product streams but show an interest in IS as they see it as potentially providing a higher profit route.

Rising water prices - recent improvements and investments by the water companies are now having the knock on affect of increasing water prices.

Landfill Tax - was a very significant driver causing companies to re-evaluate their 'waste' and was particularly topical for all the companies visited. This is due to it being a new form of legislation but also because it is increasing each year. The 2003 price was £14/tonne, rising at £1 per tonne/year, but will rise by £3 per year after 2005, up to £35 per tonne

(Figure 4.3.2). This affects not only solid waste, because many liquid wastes result in sludge with ultimate disposal being landfill. Alternatively liquid wastes may be mixed with solid wastes and land-filled.
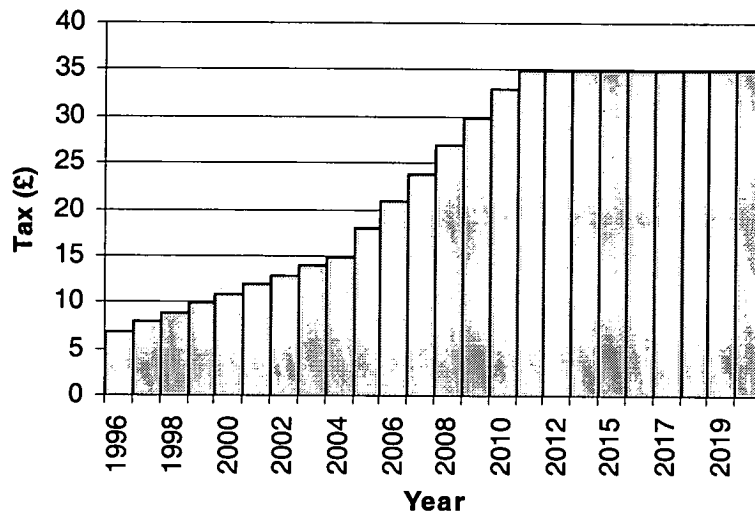
Figure 4.3.2: Landfill tax rising to £35 per tonne of waste.

Legislation and Regulation

Legislation – in particular the landfill tax is noted as a growing concern for many of the companies. Additionally, companies are aware of the growing importance of sustainability in policy making and are subsequently anticipating further legislation. The literature reports that many companies, in particular SMEs, are unsure of future legislation and generally have a 'wait and see' approach (which can often be more costly and uncompetitive). Interestingly, even one of the largest petrochemical companies interviewed was preparing to 'wait and see' what the regulator would be proposing for the industry waste strategy. This is the result of increasingly turbulent, and at present largely unpredictable, times in environmental legislation.

One interviewee noted the effect of climate change levy in the whisky sector and again illustrated a high degree of communication and co-operation amongst even competing companies:

'It [the CCL] *encourages technical dissemination in the whisky sector, things are quite open in the exchange of technical ideas – marketing's a different matter though'*

Technical

Large quantities of resource – can be a major driver, because not only can it be costly to dispose of, it can be very damaging for the image. For example, it is desirable for the petrochemical companies to keep their waste compositions and quantities as confidential as possible.

Large quantities of resources also have the potential to be commercially exploited where the material is suitable and the technology exists. For example, the case of the chicken dung plant that produces a significant quantity of electricity. The technology is now such that the chicken dung can be safely combusted and a valuable ash, rich is phosphate and potash is produced; which can be used safely and conveniently as a fertiliser.

Organisational

EMS – The need for continuous improvements under EMAS and ISO 14001 can act as a driver to find new routes for by-products and wastes.

Environmental managers – have an increasingly significant company role. They no longer merely make sure paper is recycled in the offices, but increasingly play a role in strategy and in product design.

Company image – is a growing driver for sustainability improvements in a world where image is increasingly important (though its importance depends largely on the size of the company). Image is especially important for the larger multinational companies, most of which also have social responsibility policies.

Informational

Past projects – there have been a number of regional and national resource efficiency projects in recent years. Knowledge of these or participation in them can act as a driver, by

showing that the belief that 'environmental' means loss in profits, is unfounded. Some companies have recently implemented their own waste minimisation projects or recycling processes that have produced significant savings. This again highlights the economic sense in resource efficiency.

Sustainability awareness – there are various channels of information (e.g. media, internet, trade associations, legislators and regulators) that emphasise the increasing importance of sustainability issues.

Drivers Discussion

IS Network – a network is potentially a significant driver, and could provide the added incentive that is needed in many potential cases. A network will potentially uncover many more exchanges (that would otherwise have arisen) by increasing information flow and receptivity amongst potential partners. This is especially the case for those projects that are less easily identified, because for example, companies are not in close proximity.

Past inter-company cooperation – companies that have entered these will recognise the benefits and will have developed the necessary collaboration skills. Additionally, the internal communication network necessary to support discussion of inter-company projects will have developed. The trend towards outsourcing and inter-company projects that was seen is supportive for the future of IS.

4.4 Regional Level Analysis

The aim of this section is to illustrate that at the local and regional level, and in relation to the development of a regional IS/IE network:

1. There are many practitioners and key players who could aid, and benefit from, an IS network.
2. There are many policies that are relevant and can effect the success of IS/IE
3. There are often many projects that are of importance and would benefit from central coordination to target resources more strategically.

4. An IS Network could potentially provide an 'umbrella' to these policies and projects and is of importance in many other policies such as social policy and job creation.

4.4.1 Key Players and Organisations

A potential key player at the regional level is the Regional Development Agency (RDA) in England and the Scottish equivalent Local Enterprise Companies (LECs). The RDAs were established under the Regional Development Agencies Act 1998 and launched in nine regions in England. Scotland is covered by 22 LECs.

RDAs are non-department public bodies (NDPBs) with a primary role as strategic drivers of regional economic development. RDAs aim to co-ordinate regional economic development and regeneration, enable the English regions to improve their relative competitiveness and reduce the imbalance that exists within and between regions' (DTI, 2003). Each RDA has 5 statutory purposes, which are:

- To further economic development and regeneration
- To promote business efficiency, investment and competitiveness
- To promote employment
- To enhance development and application of skill relevant to employment
- To contribute to sustainable development

RDAs' agendas include regional regeneration, taking forward regional competitiveness, taking the lead on regional inward investment, and working with regional partners, ensuring the development of a regional skills action plan to ensure that skills training match the needs of the labour market.

Clusters are receiving increasing attention from government in a number of recent publications (DTI, 2001; DTI, 2003; DTI, 2003c) and RDAs are increasingly at the centre of cluster initiatives.

'Clusters play a key role in driving economic growth and innovation in localities, cities and regions. They create an environment which encourages companies to adopt innovation-based corporate strategies and which facilitates knowledge sharing. The evidence suggests

that Governments cannot create clusters, but Government and RDAs can help remove the barriers to their success' (DTI, 2003c).

Hence it is not difficult to see that RDAs can play a central role in the success of IS networks and should have the facilities and capabilities to link the strategies on clusters, sustainable development and IS networks.

In Section 2.3, five overall approaches for the implementation of eco-industrial parks were identified from the literature. It was suggested that this could equally be applied to regional networks or 'virtual eco-industrial parks'. Both options, EIP or regional network, are potentially possible in the Forth Valley. But each would require different actors to become involved and play a central role. The local council planning department would play a strong role for an EIP, but would have very little significance if the focus was on a network.

In either method, the approach can centre on an 'anchor tenant' or concentrate on the 'business-stream model' (see Section 2.3) and the matching of material flows. Potential anchor tenants could be Scottish Power, BP or any large company or large producer of waste resources. Other key players include: local authorities, universities, trade associations, SEPA, Local Enterprise Companies (LECs), waste management companies, and the voluntary and not for profit sector.

4.4.2 Relevant Policies

There is already a huge amount of work being done in the area of sustainable development, by a wide variety of organisations. In this section we will concentrate primarily on the Falkirk Council area that contains Grangemouth, to illustrate the many differing projects, policies and strategies that have been implemented in UK regions. In Falkirk the Strategic Community Plan (SCP) 2000-2005 provides an umbrella strategy for all local agencies. The plan was drawn up after intensive partnership consultations and adopts sustainable development as an underpinning principle, but does not elaborate in detail how this will be delivered. Members of the Sustainable Falkirk Partnership are shown in Table 4.4.2.

Avecia Ltd	Falkirk Area Biodiversity Partnership	Keep Scotland Beautiful (EnCams Scotland)
British Waterways	Falkirk Council	Mid Scotland Environmental Education Forum (MSEEF)
BTCV Scotland	Falkirk Environment Trust (FET)	Scottish Environment Protection Agency (SEPA)
Central Scotland Countryside Trust(CSCT)	Forth Estuary Forum	Scottish Enterprise Forth Valley (SEFV)
CSV Central Action	Grangemouth Enterprise Ltd.	Scottish Natural Heritage (SNH)

Table 4.4.2: Members of the Sustainable Falkirk Partnership

To illustrate the range of different policies which could all be related to the regional application of industrial ecology, a list of the key policies/strategies driven by sustainable development follows (Falkirk Council, 2002):

• Local Transport Strategy (Falkirk Council)

• Home Energy Conservation Act (HECA) Strategy (Falkirk Council)

• Contaminated Land Inspection Strategy 2001 (Falkirk Council)

• Falkirk Council Structure Plan - Finalised Written Statement 2001

• Air Quality Strategy - 3rd Stage Review and Assessment (Falkirk Council)

• Central Scotland Forest Strategy 1995 (Central Scotland Countryside Trust)

• National Waste Strategy Scotland - Forth Valley Issues Paper: 'No Option But Change'; and Draft Area Waste Plan (Scottish Environment Protection Agency)

• Forth Estuary Forum Management Strategy (Forth Estuary Forum)

• Falkirk Council Countryside Access Strategy (Falkirk Council)

• Falkirk Area Local Biodiversity Action Plan (Falkirk Area Biodiversity Partnership)

Local Agenda 21 (LA21) strategies are also of strong relevance. LA21 is an international agreement signed by over 155 countries at the Earth Summit held in Rio in 1992. The objective of the agreement is for each country to take action to safeguard the natural resources of the planet. At the local level, Local Agenda 21 can be defined as "The process by which the Council works with its partners and communities to agree a strategy and action plan for the long term social, economic and environmental well-being of the area." (Falkirk Council, 2002).

4.4.3 Resource Efficiency Programmes and ICC

In the course of the field and desk-based research, many projects and forms of ICCs of relevance were uncovered (many of the ICCs were discussed in Section 4.3). The region has experienced increasing numbers of waste minimisation and resource efficiency projects, some of which have produced substantial savings. Over the years 1997-2000, thirty five companies were involved in the Resource Efficiency Action Programme (REAP), which provided waste minimisation training and on-site audits for companies. The project achieved over £3.8m of annual cost savings across a range of business sectors. The Business Environment Partnership has assisted over 440 businesses and had helped identify over £2.7m cost savings, mostly relating to waste minimisation, energy efficiency and improved water management. A recent mapping study of the area found over 40 'IS type' initiatives and over 20 organisations with a sustainability focus in the region but there appears to be no overall guiding policy for the area that could help to focus objectives and funds, and reduce the risk of overlap (Forward Scotland, 2003). These programmes have already built up their own individual networks that could be utilised and built upon. It is arguable that in many cases the companies that have saved money and resources with these programmes would be more receptive to IS and its benefits. Ackroyd (2003) noted that for many companies involvement in waste minimisation projects produced a cultural and attitudinal shift towards environmental improvement. Likewise companies that have undergone successful inter-company projects such as members of the Grangemouth Development Group or the Grangemouth Water Users Group, will have first hand experience of the benefits to ICC and will therefore also be more aware of the benefits and receptive to further ICC in the forms of IS.

The success of UK waste minimisation clubs is regarded as only the beginning of major savings that could be made with greater coordination. Practitioners have expressed the need 'for a range of new developments in waste minimisation clubs so as to build upon the best practice developed so far' (Gronow et al, 2000). This should include designing them to deliver sustainable waste management rather than merely changing the disposal route (Phillips et al, 1999) and designing them to work with best practice programmes to overcome market and information failure (Pratt and Phillips, 2000), as well as to facilitate staff development and training in resource efficiency (Cheeseman and Phillips, 2000). They must also encourage reduction of waste other than solid waste alone (Holt et al, 2000) and be

designed to correspond to the needs of a given UK area or region (Phillips et al, 1998; Phillips et 2000).

4.4.4 Regional IS Network as an 'umbrella' strategy

This section has endeavoured to illustrate that a somewhat indirect but none the less important driver for the development of regional IS networks is the potential for IS to appeal to a wide range of actors (and key players) and be central to their strategies. We are reminded of the anticipated benefits of IS, the potential to tackle economic, environmental and social goals simultaneously. It is this aspect of IS/IE that makes it suitable to be at the heart of regional economic plans. More importantly it should be at the heart of sustainable development because there can be no long term economic development without sustainability considerations, and now more than ever the sustainable future and growing markets are those within the environmental technology sector.

Hence the full realisation by the key players and actors of a region of the potential for IE to create the most efficient local system is potentially one of the biggest drivers for a successful IE system. It will require all actors to be aware of the potential and the goal, and it will require all actors to work together towards this most difficult objective. This is the reason why the importance of ICC cannot be over stated. Not only is current ICC shifting the culture and making key players aware of the benefits of working with others, it is also developing the valuable skills necessary for this cultural shift.

It should be apparent from the preceding sections that co-ordination is needed from a policy perspective, and is also needed so that the numerous projects don't overlap, wasting valuable resources and time. As well as providing an 'umbrella', IE can provide the vision for sustainable development. As was illustrated above, there are many actors with many differing strategies. Often sustainable development strategies will have 'priority areas' or 'objectives' but these strategies often fail to provide a vision as appealing, or as sound, as that provided by the eco-systems that surround us. They fail to appeal to the wide range of actors that is necessary to implement sustainability.

4.5 National Level Analysis

This section will first describe the current UK drive for sustainable development and aims to show:

1. The developing UK sustainability focus
2. The shift to economic instruments and resource productivity
3. The potentially central place for industrial ecology

4.5.1 UK Sustainability – policies and projects

In the UK the concept of sustainable development is receiving increasing attention, with an increasing focus from the UK government. Due to the UK's small size, and pressure from European directives, there is currently a particular focus on the waste issue and resource productivity at (UK Cabinet Office, 2001). In the UK's revised sustainable development strategy, the Department of the Environment, Transport and the Regions (DETR, 1999, para 1.1) define sustainable development as *'ensuring a better quality of life for everyone, now and for generations to come'* and base it on four objectives:

- social progress which recognises the needs of everyone;
- effective protection of the environment;
- prudent use of natural resources; and
- maintenance of high and stable levels of economic growth.

There has been recent government recognition of industrial symbiosis (DEFRA, 2003a). There is also government support for energy efficiency (Envirowise), a push towards supporting innovation, and an attempt to link good business sense with sustainability. Describing a competitive company, the government's Department of Environment Transport and Regions said:

'A sustainable business is on the leading edge of responding to forces for change, anticipates pressures on its supply chain, and on resource use, the needs and expectations of its customers, investors, employees and the community in which it operates. – The more efficient and competitive businesses will be those who have an eye on the 'triple bottom line',

focusing not only on the economic value that they add, but also on environmental and social value added or destroyed' (DETR, 1998).

The Government's Climate Change Programme (CCP) involves a range of measures including the Climate Change Levy. The CCL is a tax on energy used by businesses, with the aim of providing an incentive to improve energy efficiency. Other CCP measures include the Renewables Obligation, transport initiatives, improved building regulations, and company reporting, with DEFRA offering practical help on voluntary emissions reporting (POSTnote 213, January 2004). There are calls from some business leaders and NGOs that the CCP should go further and the focus be shifted. It is argued that current policy focuses almost exclusively on operational business emissions (POSTnote 213, January 2004). The focus should include the supply chain and product lifecycle where emissions also occur.

As noted in section 4.4, there is a focus on development of a regional approach to sustainable development through Local Agenda 21 and RDAs. In fact the regional focus is not limited to sustainability issues, but has become a political one with regional devolution a distinct possibility:

"The Government is committed to promoting the development of the English regions, and to devolving decision making down to regional level. It intends to move to directly elected regional government in England, where there is demand for it. Since May 1997, DETR has been responsible for taking forward this regional policy agenda and it is now a key part of the Department's objectives" (DETR, 1999).

In terms of laying the foundations for industrial symbiosis, there have been some noted successes with waste minimisation clubs: for example the 'Aire and Calder' project, and ETBPP (Philips PS et al, 2001). However, fewer than 0.1% of UK companies have undergone successful waste minimisation training through clubs (Ackroyd J, et al, 2003). In the last 10 years, the annual participation rates in waste minimisation projects ranged between a modest 10 to 60 companies. But a recent project in West Sussex achieved the participation of 308 companies (Ackroyd J, et al, 2003). This indicates that sustainability issues are becoming increasingly important for companies and that they are recognising its economic benefits.

A recently published strategy for innovation identified the opportunity for linking environmental policy and innovation (DTI, 2003c). The Landfill Tax and CCL are examples

of so called 'new environmental policy instruments' (NEPIs) that it is hoped will stimulate innovative ways of reducing environmental impacts (POSTnote 212, 2004).

These are all indications that finally the UK Government is recognising the seriousness of sustainability issues, and that sustainable development may actually be good for competitiveness where economic conditions are adjusted appropriately. With the 2003 Energy White Paper (DTI, 2003) the Government has committed the UK to achieving a long term reduction of CO_2 by 60% by 2050. However, to date a UK sustainable strategy is not yet in place.

4.5.2 UK Waste Strategies

The issue of recycling is primarily being dealt with by the implementation of National Waste Strategies that filter down to local level with the provision of area waste plans. The principal focus of these is on municipal solid waste (rather than industrial waste arisings) and sustainable waste management. The Scottish National Waste Strategy identifies three main drivers for change in the way waste is managed (SEPA, 1999): impact of EU polices; creating an efficient competitive Scottish economy; and the direct effect of individual legislation such as the EU Landfill Directive and other, UK, legislation. So far the focus of waste strategies has been limited to municipal solid waste. The limited available data on industrial waste arisings will hamper the next stage of waste strategies, which is to include the industrial sector.

Although the Scottish National Waste Plan relates primarily to domestic waste, it includes objectives to provide widespread waste minimisation advice to businesses; and to develop markets for recycled material to help recycling become viable and reduce costs (SEPA, 2003). In the Waste Strategy for England and Wales (DEFRA, 2000), sustainable development is placed at the centre of waste management policy. It states that:

"If we are to deliver sustainable development it is crucial that we begin to tackle our growing mountain of waste. This means designing products that use fewer materials and using processes that produce less waste. To engineer this step change in the way we think about waste we must work in partnership –with businesses, local authorities, community groups and the public. Persuading people to change their own approach to waste on a person by person, business by business basis is probably the biggest challenge that we face" (DEFRA, 2000).

On a national level the government has tackled the demand side for recycled materials with the formation of Waste Resources Action Programme (WRAP) and ReMade (Recycling and Market Development) that have the task to create markets for the following materials:

- glass
- paper/pulp
- organic waste
- wood waste
- plastics

There are also a growing number of advisory groups aimed at recycling in business such as:

- Business Environment Network
- Recycling Advisory Group Scotland (RAGS)
- Visions in Business for the Environment of Scotland – Awards Programme (VIBES)

Again the approach is somewhat sporadic and fragmented. It could benefit from an overall ethos or central vision because the waste issue is certainly not a separate issue, but links to numerous other policies and strategies at government, regional and company level.

4.5.3 IE as an umbrella for policies

The Waste Strategy quote in the previous section demonstrates two important components that are repeatedly mentioned in sustainable development and other strategies such as innovation – partnerships and behavioural/cultural change. These two qualities are central to the IE concept which additionally can provide a prevalent ethos to link related key areas:

- Sustainability /sustainable development – national and regional
- Waste policy strategy
- Regional development
- Innovation
- Economic policy
- Resource Productivity – Waste Not Want Not
- Clusters

- Partnerships for Prosperity

In essence all these policies and documents are drivers towards sustainability. They are all helping to evolve the culture, which is potentially the biggest overall barrier/driver. It is widely recognised that sustainable development is such an enormous and complex task that advancement will not be due to a single driver, but to a combination. Finding the right combination and the correct balance is the key to success. There is also a consensus that innovation should be central and a specific aim of legislation and policy (Wallace, 1995; Smith, 2003; Kass, 2000; Clayton et al, 1999; PIU, 2001). To foster this innovation it is essential to provide a stable policy environment in which manufacturers feel comfortable to innovate; where the risks involved with innovation are low. But what is equally important is a long term vision, with which society's designers and decision makers can associate. Thus at the regional level integrated IS networks provide local solutions, and at the national level industrial ecology provides the model and vision (through perhaps a focus on 'servicizing', recycling networks, LCA etc) of an integrated society. IE potentially represents the key to delivering the 'joined-up thinking' so demanded of government. Subsequent chapters will develop a framework which will aid understanding of how this complex task could be tackled.

4.6 The National Industrial Symbiosis Programme

This section introduces the National Industrial Symbiosis Programme (NISP) and the first three regional programmes that helped form it. It is developed from close dialogue, interviews, workshops and meetings with BCSD-UK and the NISP coordinators. It also draws on findings from a joint paper with Murat Mirata that was presented to the 2003 International Society for Industrial Ecology conference (Harris and Mirata, 2003). Each regional programme is displayed as a case study showing how different factors such as the regional composition of industries, industry type and also experience of facilitators, affect the implementation of regional networks.

4.6.1 History & Background

In 2002 the Business Council for Sustainable Development –United Kingdom (BCSD-UK) proposed to implement a National Industrial Symbiosis Programme (NISP) for the UK. This follows initial IS projects in Humberside, Merseyside and West Midlands. In 2002 BCSD-UK gained backing from the Department of Trade and Industry (DTI) and funding for NISP from the landfill credit scheme. The approach is to develop regional IS programmes that are locally run by a project champion or facilitator and a Project Action Group (PAG). The regional projects are overseen by BCSD-UK who disseminate best practice and manage data collection software, which is used to collect data on outputs and potential inputs and such other relevant parameters as spare human resource capacity.
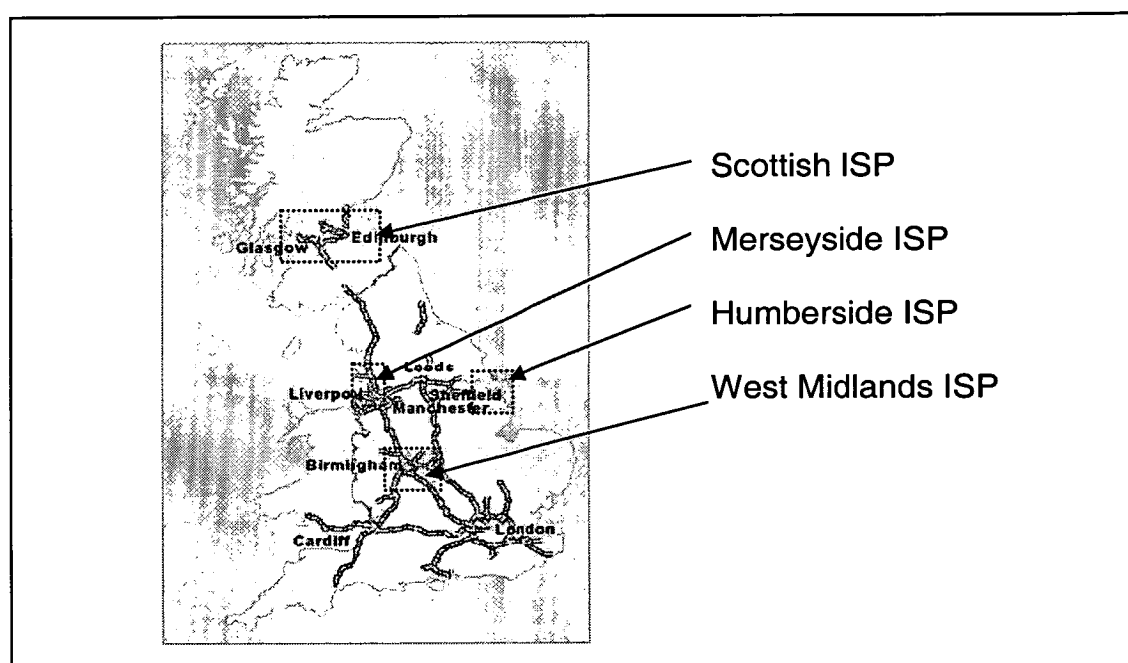
Figure 4.6.1: Map showing locations of NISP programmes

4.6.1.1 NISP - Humber

The Humber project was where initial efforts towards IS evolved. The primary industries in this region are the chemical, oil and gas industries, which developed along both sides of the Humber. Other industries include food processing, furniture, iron and steel and other metal processing. It is probably the region that has made the most mistakes upon implementation of IS and the only project with a long enough history to be re-launched.

The original project was developed by Conoco, the global oil and gas company, who have large operations in the area and who had taken part in the by-product synergy (BPS™) programme in Tampico, Mexico. They initially tried to fund the project with a method that has been used in the US whereby the companies involved would contribute a certain percentage of their profits. This however proved entirely unappealing to the UK based companies and was abandoned.

BCSD-UK eventually took over the coordination of the project and sought to develop awareness and interest with relevant parties including local authorities, companies and sector associations. The Humber area has faced continuing economic difficulties and as such is eligible for the European Regional Development Fund's Objective 2 programme. Keen to reverse the economic decline, the local councils and RDA saw the potential that IS could bring. The initial study coordinated by BCSD-UK, concentrated on two projects involving the chemical industry: a 650MW CHP plant and a chemical feedstock pipeline that would pass under the Humber River and connect the industries on the two sides ('The Humber Bundle'). Upon completion of the study, NISP-Humber was launched with a full day workshop. Over the following months a number of projects were identified and these are shown below in Figure 4.6.2.
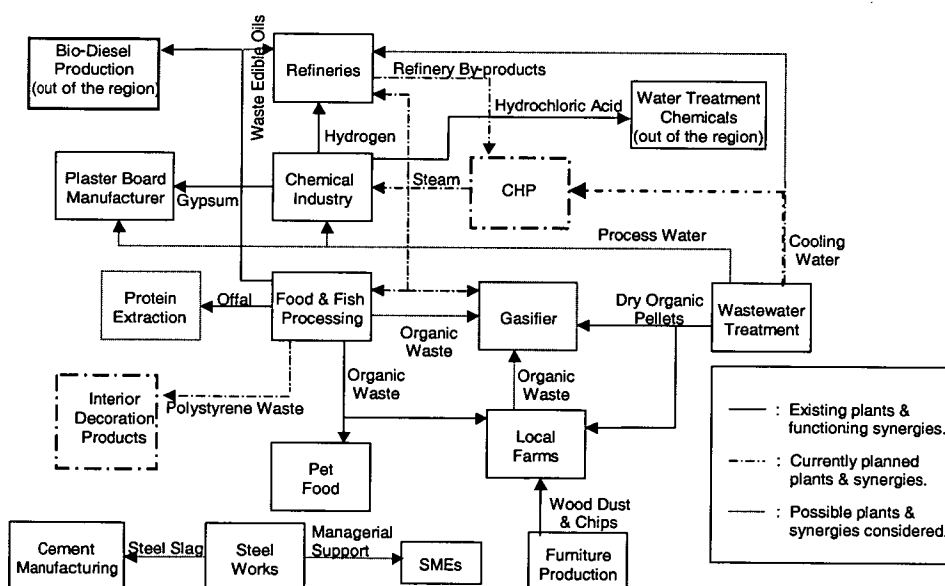
Figure 4.6.2: Existing, planned and potential exchanges in the Humber region. (source: Mirata, 2004)

107

Synergies were identified relating to the production of propylene and ethylene and their derivatives, acrylic acid and acrylic esters, sulphuric acid and hydrogen. Effluent and wastewater treatment, analytical services, logistical services and managerial support to SMEs were also identified as areas where inter-company cooperation can be beneficial.

The project has since secured additional funding from Yorkshire Forward (the RDA) and now employs a team of three. NISP-Humber was re-launched as part of NISP in June 2003 and has since been gaining impressive momentum.

4.6.1.2 NISP – West Midlands

The second project to develop under the auspices of BCSD-UK was in the West Midlands (NISP-WM). Industries present in this region include: automotive and aircraft manufacturing, metal production and fabrication, plastics and rubber, agriculture and food processing, ceramics and glass, logistics and service industries. Some of the existing and potential exchanges are illustrated in Figure 4.6.3.
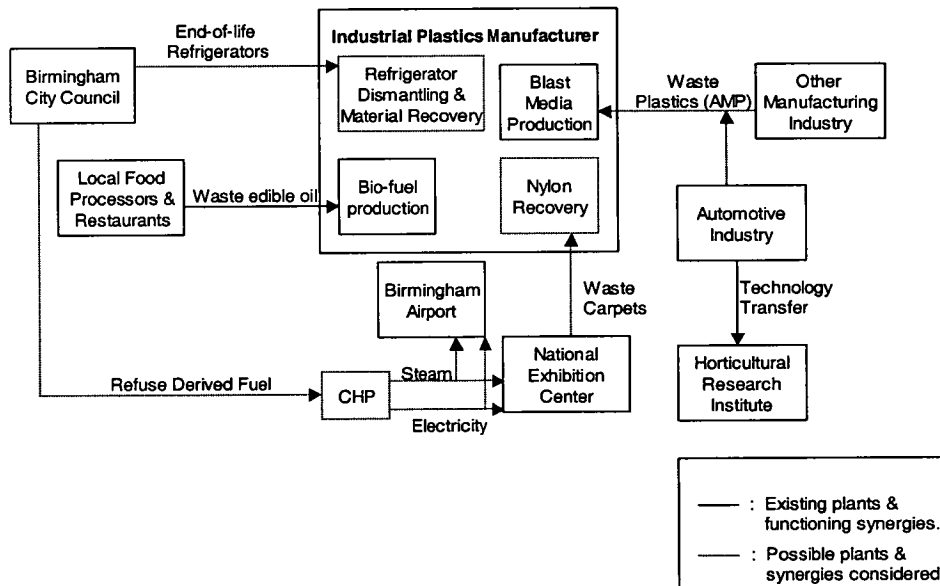
Figure 4.6.3: Existing, planned and potential exchanges in the West Midlands region. (source: Mirata, 2004)

The West Midlands is the home region of BCSD-UK, and as such has become central to the overall development of NISP. NISP-WM is believed to be the largest regional initiative of its type in the world (BCSD-UK, 2004) and recently received £660,000 of funding from Advantage West Midlands (the RDA). The regional programme was instrumental in developing a training course and guide, for the data collection software.

4.6.1.3 NISP-North West

The third project was implemented in the Mersey Banks region in northwest England. It is the UK's largest chemical producing region with 450 manufacturers, 110 sales offices, 220 service providers and 8 universities. The coordination role in this region is performed by the North West Chemical Initiative. This is a private organisation, well known and respected in the region, which proved helpful in gaining participation of local companies in NISP-NW. Again the programme was launched with a workshop which allowed participants a chance to discuss areas of cooperation. The project champion role was also filled by a managing director of a local refinery, and initially twenty two companies committed themselves. It was considered important by the project team for companies to make a financial contribution based on company size, to solidify commitment to the project and help it financially.

To date they have identified 100 opportunities and have conducted about 30 individual meetings regarding these. The meetings cover all considerations of inter-company cooperation from sharing resources (e.g. workshops) to by-product synergy.

4.6.1.4 The Scottish Industrial Symbiosis Programme

This section presents findings of action research from being involved with the implementation of the most recent addition to NISP: the Scottish Industrial Symbiosis Programme (SISP). SISP arrived at an appropriate time when the Scottish Executive was reinforcing its commitment to sustainable development. Recently the Scottish Environmental Protection Agency (SEPA) also released its Waste Strategy for domestic waste, which is to be followed shortly by a corresponding programme for the industrial sector.

BCSD-UK had refined the method of implementation from the previous projects and began with a meeting at Scottish Enterprise. It was a small meeting attended by representatives

from a number of companies and key organisations (potential facilitators and financers of SISP) including: the Scottish Executive, SEPA, BP, Scottish and Newcastle, Scottish Council Foundation, a number of consultants who were potential local facilitators of SISP, and the author. It was at this meeting that the Scottish Executive announced its support for the idea of SISP and later followed this with a grant of £200,000 to implement SISP over two years. It was agreed that the initial project would be primarily based in the Edinburgh and Forth Valley region but would expand to other areas of Scotland when additional funding sources come on stream.

The funding allows BCSD-UK to employ an Edinburgh based consultancy as a facilitator to run the initial stage of SISP. SISP was officially launched with a workshop event involving 85 Scottish companies in which the author was involved. At this workshop the author presented the initial findings of this research (Appendix 1). Shortly afterwards a Project Advisory Group was formed consisting of a number of major local companies, SEPA, The Forestry Commission, and the Scottish Energy Efficiency Office. As part of the implementation and to ensure no duplication, BCSD-UK commissioned a 'mapping study of existing resource efficiency and waste to product type programmes in Scotland' (BCSD-UK, 2003). This uncovered a number of projects and developments that could potentially support the implementation of SISP. It could also form the basis to develop an integrated regional approach that would involve a number of other organisations.

The initial targets for SISP agreed in the contract with the Scottish Executive were 50 companies signed onto the software, reduction of 100,000 tonnes going to landfill, reduction in CO_2 emissions, and job creation.

SISP Workshop Discussion

The SISP workshop started with a number of presentations that presented: a simplified concept of industrial symbiosis, the work of BCSD-UK, the software interface that is used in NISP, and the authors' findings. After this the participants were split into small groups to discuss the idea of SISP, how participants thought it could best be implemented and the drivers and barriers to SISP. Observations revealed that it was very fruitful to ask the following question to the participants: 'How do you think SISP can be taken forward and implemented?' This stimulated the participants enthusiasm by giving them ownership to the problem.

A second workshop for SISP was held on 3rd March 2004. The focus for the meeting was energy, and approximately 40 representatives from companies and other organisations were divided among six tables. Prior to the meeting, attendees had completed resource stream forms so that they could be placed on tables with others with whom they could potentially form synergies. Each representative on a table introduced themselves, the resource streams of their company and then opportunities for synergies. After a 45 minute session, participants were moved to different tables to facilitate discussions with other companies. Overall participants were moved to three different tables and conversations were lively and enthusiastic.

4.6.2 Discussion and Analysis of NISP and SISP

Several lessons emerged from the initial BCSD-UK projects. In the Humber project a limited enthusiasm from the initial launch event was adjudged to be due to an unintended emphasis on the Humber Bundle project and the chemical industry. This had the effect of isolating other sectors and made it difficult for the other companies to associate IS with their operations. To improve the diversity and numbers of companies involved, BCSD-UK visited 70 companies in the following months. However participation rates remained low, possibly because the managers did not get the opportunity to meet others that were enthusiastic about the program, which would have been obtained from additional workshops.

In the Humber IS programme the most significant barriers that were identified were (Harris and Mirata, 2003; Mirata, 2004):

- Poor integration of companies
- The culture of companies does not support inter-company co-operation (no significant history of cooperation)
- Lack of a company 'champion' that encourages others to participate
- Limited decision making powers of chemical, oil and gas companies; that belong to national and multi-national corporations. This presents a barrier to establishing a cooperative business environment.

The pace of the West Midlands project was much quicker than the Humber project, primarily because a local environmental business association, that already had a network of existing contacts, took over the coordination role. They were quickly able to arrange a meeting involving 10 representatives from key organisations in the area (private companies from a number of sectors, local administration and research institutes). The meeting, in contrast to the Humber meeting, was highly interactive, which can largely be attributed to the fact that participants were asked for help and asked how to *take the project forward* (hence this involved the participants and gave them a form of *ownership*). A project advisory group was also formed at this meeting and is chaired by a managing director of a company, who acts as a project champion encouraging the participation of others.

In contrast to the Humber project, the drivers that supported the faster paced development in the West Midlands project were identified as (Mirata, 2004):

Drivers
- A history of material reuse and recycling in many of the industries
- The headquarters of many companies are in the region, so that companies have good decision-making powers
- Financial backing had recently been gained from the regional development agency.

In the North West project region there is generally better integration of the companies than at Humber because existing facilities were previously under common ownership. Consequently the business culture is more familiar with inter-company cooperation. The overall lessons from the North West project are:

- Ultimately, there is a need to get industry buy-in at senior level
- Project management must have industry credibility
- Gaining company commitment is time consuming
- Project implementation is time consuming

The SISP workshop attendees uncovered several important points:

- There is a need to monitor and disseminate knowledge of technological and market developments

112

- IS can be driven through trade organisations, (this will be highlighted in Chapter 5 with the development of the 4A model)
- There should be more coordination between the various waste related programmes and projects around Scotland.
- It should be emphasised that SISP is more than a bit of software and that expert coordination will be required for ultimate success.
- SISP has to make IS look like an essential part of good business sense
- For businesses following Corporate Social Responsibility and EMS, SISP could offer a way to demonstrate commitment to continual improvement.
- SISP could make the case for taxes and tax breaks.
- SISP could play a role in overcoming barriers e.g. sharing of trial costs through partnerships (as in the case of cement feedstock),
- Question of legal liability from manufacturing with 'inferior' recycled feedstocks.
- It was generally agreed that the majority of barriers are 'perceived barriers' and can be easily resolved when properly looked at.
- Barriers are often by accident, one policy at odds with another (e.g. the label of 'waste' often conflicts with the desire to recycle)
- Label of waste – SEPA are considering labelling 'waste' from its creation, e.g. ash being used by ScotAsh would have the label of waste until its sold on. Therefore the appropriate legislation would need to be put in place and the necessary paperwork would increase costs and crucially reduce incentives.
- SEPA could forgive a small reduction in reporting to allow companies to free up staff to investigate IS opportunities.

At the second workshop, several participants highlighted the importance of social factors and organisational factors. For example, difficulties of absorption within the company, e.g. the participants were generally environmental managers or resource strategists, but expressed a frustration in trying to convince senior managers of the economic benefits of IS and sustainability.

Lack of onsite storage space was highlighted as a major barrier to the economic viability of recycling, which underlies the need for 'recycling rings'.

SISP – Drivers and Barriers

SISP is the youngest of the IS programmes within the UK and as such the following are preliminary findings and discussion. Potential barriers, especially with regard to moving beyond waste utilisation are as follows:

- **Over reliance on software** – particularly in the beginning of the programme there appeared to be an over-reliance on using the software to sell the project.

o Lack of wider IE explanation – there has been no real explanation of the IS concept at workshops let alone the wider IE concept. So how can IS play a role in introducing and embedding the concept of industrial ecology? This is partly due however to a strict business focus and it may be feared that a somewhat 'academic' explanation would diminish the business incentives. But there is also perhaps a lack of understanding amongst the facilitators of the potential of IS to promote the wider IE perspective; and a lack of appreciation of their potential role as educator in this situation.

- **Lack of momentum** – a follow-up workshop took 9 months to take place. This situation has since improved however as a result of securing additional funding from SEPA.

- **Targets** – the initial problems described above are partly attributable to the need to achieve targets and please the project financers (the Scottish Executive). The target of signing up fifty companies to the software encouraged the facilitators to concentrate only on the most enthusiastic companies, i.e. those that involved minimum effort. This may have caused important companies, such as those that could provide a path for a difficult waste or certain expertise to the network, to be overlooked. Additionally, from a systems perspective, those companies that are of most concern (i.e. are less sustainable or cause more environmental damage) were not in anyway targeted. However the targets have now been achieved so the emphasis can perhaps be shifted.

The drivers for the project have been identified as:

- **Fitting in with current strategies** – for example, the Waste strategy (SEPA) or Sustainability Policy (Scottish Executive).

o **Coordination between the relevant actors** – is developing now that both SEPA and the Scottish Executive are funding SISP. In addition SISP not only networks with companies but has a developing network of other important actors, such as other resource efficiency projects in the area. There is therefore a growing potential for IS to act as an umbrella and

provide cohesion to various projects. How the network can address the intangible benefits (e.g. innovation transfer/ inspiration) is an emerging challenge.

- **Software** - has also been observed to be a significant driver however. It is an easy way to get companies 'on-board' and signed up to such a programme. It gives the company representatives 'something in their hand' and along with the website gives them association to the project. The software is a potential way to communicate the concept of IS within a company and gives the members something to show other company representatives.

During the four projects that BCSD-UK have so far implemented, they have refined, the process of implementation. It is seen by them as a continual loop process (BCSD-UK, 2003b):

- Commitment and ownership
- Data collection
- Analysis and synergy identification
- Implementing commercially viable synergies
- Monitoring and maintaining.

Certainly some of the initial success of NISP has been the first aspect of this: gaining the commitment of several key players and companies by asking them how the programme can move forward; and making them part of the solution; hence giving them ownership.

A central body such as that provided by BCSD-UK and NISP offers strengths for:
- refining methodology
- data uniformity
- disseminating best practices and lessons learned
- feedback to regional and central government

The problems and solutions that BCSD-UK have met so far were presented at the IS workshop of the Business Strategy and Environment Conference (BCSD-UK, 2003b) and are shown in Table 4.8.

Issue / problem	Aid /solution
Top level commitment necessary but not enough	Find champion
Champion necessary but not enough	Provision of tools
Need expertise to have sensible discussion	££££/$$$$$
Businesses squeezed for resources/time Remote decision making	??????
Confidentiality	Limited Charter
Data handling	Net based DCS
Scale-ability	Environmental Technology SMEs
Synergy/ Symbiosis definition	Be holistic
Implementation	Be prepared to help
Enthusiasm	Keep the faith
Language of sustainability has little attraction	Don't use it

Table 4.8: Issues and problems, and the solutions used by BCSD-UK (source: BCSD-UK, 2003b)

BCSD-UKs plans are to develop regional programmes throughout the UK, ideally in as many regions as possible. Although projects are beginning to emerge in other regions, BCSD-UK has faced strong barriers in some areas. Their approach is to stimulate interest from key regional financers and groups. The main barrier, or perhaps hurdle, is stimulating this interest in certain RDAs which may have regional development strategies focused elsewhere. This has been a particular problem in the South West where perhaps lack of resources, but more probably lack of association to IS benefits by key individuals, is the problem.

4.6.3 Summary of Lessons from NISP

In summary, the success so far of NISP is due to a number of key factors. At the centre of these factors is the business focus that recognises the fundamental importance of getting industry involved. The key factors of each area of importance are highlighted below:

In securing funding this has been due to:

- Skills of the team

- Network of contacts

- Carefully chosen vocabulary that focuses on business issues - opportunities, new products, increased sales and cost reduction; instead of: waste minimisation, energy efficiency, environment and sustainability

- Giving ownership to key actors - and asking questions such as: how can we take this forward?
- Assimilating within the strategies of key actors, e.g. RDAs and Landfill Tax credit Scheme.

In securing business interest:
- Business focussed
- Carefully chosen vocabulary that focuses on business issues
- Paying for key individuals to represent the project
- Giving ownership to key companies in the area by forming Project Advisory Groups

In developing synergies:
- Workshops
- Professional internet based software with training course available
- Key actor involvement
- Building on existing regional strengths and projects

4.7 Chapter Summary

This Chapter has presented the initial analysis of the barriers and drivers identified from the scoping study. The study found that the strongest driver currently is the Landfill Tax. Regarding barriers, there exist some individual barriers for unique situations. It is therefore difficult to be general, but it does appear that the majority of the barriers could be overcome with a small incentive, perhaps one that is being provided in many cases by the rising landfill tax.

The interest and cooperation gained from the companies in the scoping study suggested that there is niche for an IS network. Subsequently the SISP has been extremely well received and at the time of writing (July, 2004) several exchanges are being implemented and more than 80 companies have signed on to the software and programme. There is strong evidence that the biggest driver to IS can be the creation of an IS network. Networks act as drivers in a number of ways:

- Informational – they provide a way to facilitate matches through software and meetings.

- Socially – they provide a socially constructed impetus and pressure, sometimes called the 'atmosphere.'

Analysis at the UK regional and national level showed that IE can fit within many strategies and policies. It is a driver in itself that IE can build on the trends of numerous policies and strategies, and potentially provide cohesion to many of these.

NISP has also shown that there is an important place for IS programmes and has facilitated many exchanges that without the programme would not have taken place. The IS concept is gaining acceptance in the business community, where many recognise it as an easy win – a way to turn waste disposal costs into by-product profit. Selling the more encompassing industrial ecology to industry (e.g. reverse logistics) has not yet been fully attempted. IS networks work because they foster information exchange between potential partners of economically viable exchanges. For IE to become a reality, for the system to be more cyclic and sustainable, the system must be economically attractive for business. Making the transition to such a system is the job of governments and their policies; and this is the reason why it is important to educate governments of the potential for IE to become central to many policies (whilst improving competitiveness).

The next Chapter develops a conceptual framework, based on a technology transfer model. This will provide a framework to help understand the complex series of interactions that are occurring.

Chapter 5 Conceptual Development

5.1 Developing a Conceptual Framework

A framework will now be developed to aid the analysis of the drivers and barriers and help understand the processes and decisions involved. From the research presented in Chapter 4 and from the literature, a number of important considerations in the development of a framework became apparent:

- Importance of association – companies must see the applicability and advantages of IS/IE for their company. This could come from a number of reasons. They: have large waste volumes and therefore they have an interest in 'disposing' or dealing with the 'waste' as economically as possible; have previously experienced networks or ICC and are aware of the advantages; see it as an image enhancer; can foresee the significance of a network; don't want to be seen as being non-cooperative.
- Innovation should be central.
- Evolutionary – business has evolved to its present state and will continue to evolve. Sustainable development is about learning at all system levels.
- IE should be an implicit aim – in the absence of wider system considerations, IS can develop and encourage non-environmental synergies.

These factors, in particular the importance of innovation for companies to survive and respond (to legislation or competition) in increasingly competitive times, led to the consideration of innovation and technology transfer models. One model that revealed itself as potentially pertinent to developing a framework for analysis was the technology transfer model developed by Seaton and Cordey-Hayes (1993). Subsequently, the model was developed by Trott (1995) to include four interacting processes: *awareness, association, assimilation and application.* It was evident that this could be of great value to the IE field and is developed below within the context of IE.

This chapter builds on the literature review and provides further findings from the literature to help develop the conceptual foundations. Much of the material in Chapters 5 and 6 has been published in the new IE journal *Progress in Industrial Ecology* (see Appendix II).

.

5.1.1 The Technology Transfer Model

Seaton and Cordey-Hayes (1993) view technology transfer as: *'the process of promoting technical innovation through the transfer of ideas, knowledge, devices and artefacts from leading edge companies, R&D organisations and academic research to more general and effective application in industry and commerce'*. They noted that mechanisms of technology transfer in the UK tended to have a preoccupation with: creating new technologies; making technology available; increasing information about what is available; and facilitating transactions between supplier and potential user. Hence technology transfer in the UK was seen to be dominated by the two preoccupations of:

- *Accessibility:* the level of technology knowledge and the availability of related information
- *Mobility:* the ease of obtaining this technology knowledge and the appropriate channels through which technologies are transferred (eg intermediaries, people movements, networks, partnering)

These are important considerations, but Seaton and Cordey-Hayes (1993) noted that there was less thought given to the difficulties of exploitation of new technologies within companies. For inward technology transfer to be successful: *'an organisation must have not only the ability to acquire but also the ability to assimilate and apply ideas, knowledge, devices and artefacts'*. The 'process' view of technology transfer is concerned with creating or raising the capability for innovation. Hence the organisation and the individuals within it must have the capability to:

- scan for and recognise the value of ideas, knowledge devices and artefacts which are new to the organisation;
- communicate these and assimilate them within the organisation;
- and apply them for effectiveness or for competitive advantage.

Within an organisation, Seaton and Cordey-Hayes (1993) noted that there is a need for:

- the technical functions (such as product development, R&D, manufacturing, engineering, training and management information systems (MIS)) both to support current business priorities and also to create new opportunities;

- such integrated functions to be part of well-designed external and internal networks;

- the development of employees so that they are capable of comprehending and functioning effectively within such activities; and

- the development of managers capable of shaping organisations to achieve these opportunities.

This lead to the creation of the next component of the model:

- *Receptivity:* an organisation's overall ability to be aware of, to identify with and to take effective advantage of technology. (Other authors have described this component as 'absorptive capacity' (Cohen and Levinthal, 1990)).

These three ideas: accessibility, mobility and receptivity, serve as a framework for a process view of technology transfer and a simple conceptual device that emphasises the company perspective. The concept of *receptivity* was later extended to consist of *awareness, association, assimilation and application* (Trott, 1993). The framework attempts to illustrate technology transfer more realistically as a series of interacting sub-processes, rather than a simple one-off transaction or decision process. The transfer process is broken down into a series of sub-processes as shown in Figure 5.1.1. Successful innovative companies must therefore function well in all four stages within the process of receptivity, which are described in Table 5.1.1.
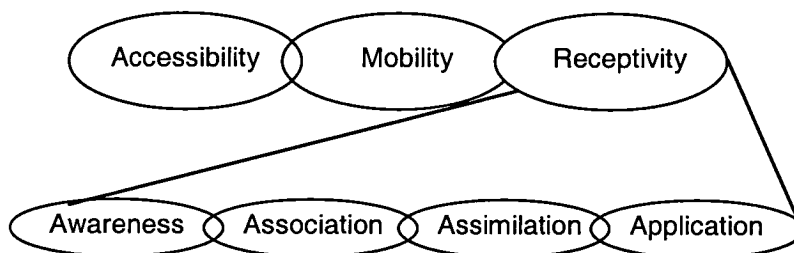
Figure 5.1.1: Conceptual framework of technology transfer and inward technology transfer (source: Trott, 1998)

Activity	Process
Awareness	The processes by which an organisation scans for and discovers what information on technology is available
Association	The processes by which an organisation recognises the value of this technology (ideas) for the organisation
Assimilation	The processes by which an organisation communicates these ideas within the organisation and creates genuine business opportunities
Application	The processes by which an organisation applies this technology for competitive advantage

Table 5.1.1: The "4A" conceptual framework of technology transfer (source: Trott, 1998).

5.1.2 Integrating IE with the Technology Transfer Model

From Chapter 4 we can see that there are several different groups of barriers and drivers. These may be classified in different ways, none of which is entirely satisfactory as there is always some overlap. In terms of the evolutionary concept, one useful way to classify them is as barriers and drivers to:

1. Waste utilisation
2. Inter-company co-operation
3. Industrial symbiosis
4. Industrial symbiosis networks
5. Industrial ecology

Section 2.1 discussed the various concepts and terms of IE, and gave definitions for the above terms. It was shown that Industrial Ecology can be viewed as a desired end state, but also provides the means by which to achieve this end state. What Welford (1997) asserts about sustainability is equally true of IE: *'There exists a strange and fruitless search for a single definition amongst people who do not fully understand that we are really talking here of a process rather than a tangible outcome'.* By viewing IE as a learning process within a company we can postulate three stages. In the list of barriers and drivers above 2, 3 and 4 can be grouped together under Industrial Symbiosis and the three stages of learning are proposed as:

Stage 1: Input-output (or waste utilisation)

Stage 2: Industrial Symbiosis

Stage 3: Industrial Ecology

This does not neglect the product-based approach because product-based improvements (PBI) will need to be implemented in order to move from Stage 2 to Stage 3. Table 5.1.2 provides definitions of these stages alongside definitions for the concepts and perceived characteristics of companies at each of these stages. The characteristics describe typical strategies and techniques that it is perceived would be used by companies at each stage. Unless otherwise quoted (hence where not found in the literature) these are proposed by the author to help provide clarity to the developed model.

STAGE	Definition	Stage Recognised by:	Company Characteristics
(1) Input-ouput	A previously unutilised emission (material, gas, liquid, heat or energy), is utilised in some way by another company.	Companies find a user for the emission rather than non-use or waste disposal.	Companies react to economically attractive emission exchange.
(2) Industrial symbiosis	*Industrial Symbiosis, as part of the emerging field of industrial ecology, demands resolute attention to the flow of materials and energy through local and regional economies. Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographical proximity'* (Chertow, 2000)	Industrial Symbiosis is the STAGE where companies aim to utilise 100% of resources and increase overall productivity of operations; by looking beyond company boundaries for environmental and economic improvements, and implementing resource exchanges and inter-company co-operations.	Actively seeking to utilise 100% of resources. Looking beyond company boundaries for environmental and economic improvements by the forming of IORs. Two main aspects: • Resource exchange • Inter-Company Co-operation.
(3) Industrial Ecology	*'Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to component, to product, and to ultimate disposal. Factors to be optimised include resources, energy and capital'* (Gradel and Allenby, 1995)	Industrial Ecology is the STAGE represented by companies aiming to use 100% of resources; and whose activities involve closed loops either directly or indirectly. The anthropogenic system exists harmoniously with its natural host system (life) by reducing its material flow to and from the natural world to a level that has no net effect on earth's carrying capacity.	As above and: looking beyond company boundaries to re-engineer/ structure business and close the loop. Considering the whole life cycle including post-consumer flow. Using both the **product based systems approach** as well as **regional ecosystem** and methods such as: • Life cycle analysis • Integrated chain management • Concurrent engineering • Reverse flow / logistics – reuse, remanu. & recycle • Servicizing • Sustainable consumption

Table 5.1.2: Definitions of Stages, and company characteristics at these Stages.

A concept of relevance here is that of single, double and triple loop learning (Argyris and Schon 1978). Snell and Chak (1998) provide concise definitions for this type of looped learning:

"It is single-loop when they [group members] make simple adaptive responses. It is double loop when members begin to see things in totally new ways, e.g. changing their views of their roles, of the business or the business environment. Triple loop individual learning entails members developing new processes or methodologies for arriving at such reframing."

Likewise the learning from Stage 1 through to Stage 3 can be viewed as:

1. Stage 1/I-O is when companies reactively find a company to utilise a material previously considered a waste;

2. Stage 2/IS learning occurs when companies seek productivity improvements through ICC and I-O exchanges, and begin to reassess products and processes;

3. Stage 3/IE learning involves companies maximising profit through re-engineering their entire business (products and processes, but most notably markets) so that its purpose is to function within a highly cyclical anthropogenic system.

Hence when IE is seen as a process, then IS can also be seen as a tool, and the means to help foster the behavioural shift needed towards IE. An industry's move to industrial symbiosis (Stage 2) is marked by increasing amounts of inter-company co-operation (ICC) and by looking beyond company boundaries for improvement opportunities and inspiration.

Stage 3 involves working with others to re-engineer or re-structure business, in an attempt to close the loop. The need for sustainable consumption becomes apparent, and most importantly the *co-operation* element is extended to consumers. Radical relationships will be needed between manufacturers and consumers to develop servicizing[1] and extensive return flows from consumers. For example, in the much quoted example of Xerox photocopiers (see e.g. Von Weizsacker et al, 1997), recycling of spare parts (and the whole machine) is made easier and more efficient because the customer does not own the photocopier, but pays for the service. Relationships between manufacturers would additionally need to be strong,

---

[1] Servicizing is also known as 'systemic dematerialisation' – the strategy of service economy, which promotes the selling of services instead of products (Stahel, 1981 and 1992). '*Systemic dematerialisation refers to the fact of increasing the resource productivity not only at the level of the product, but at the level of global infrastructures, in order to reduce not only the total material throughput, but also, most importantly, to decrease its speed within the industrial system, thus minimizing the problem of dissipative emissions during normal use*' (Erkman, 1997).

e.g. electronics companies cooperating to form a separate company that handles post-consumer products.

The overall framework produced by combining the technology transfer model with the concept of three stages of learning is shown in Figure 5.1.2 (herein known as the LIES model – Learning Industrial Ecology Strategy). Each stage is viewed as a process (although the learning cycle for a company or actor may not necessarily begin with Stage 1) moving from awareness to application. As with the original 4A model, the process should not be seen as linear but as a series of interacting sub-processes. The main application of the model is in helping to understand how actors can become *aware* of IS/IE possibilities, *associate* it with their objectives and/or operations, *assimilate* it and then proceed with the *application*.
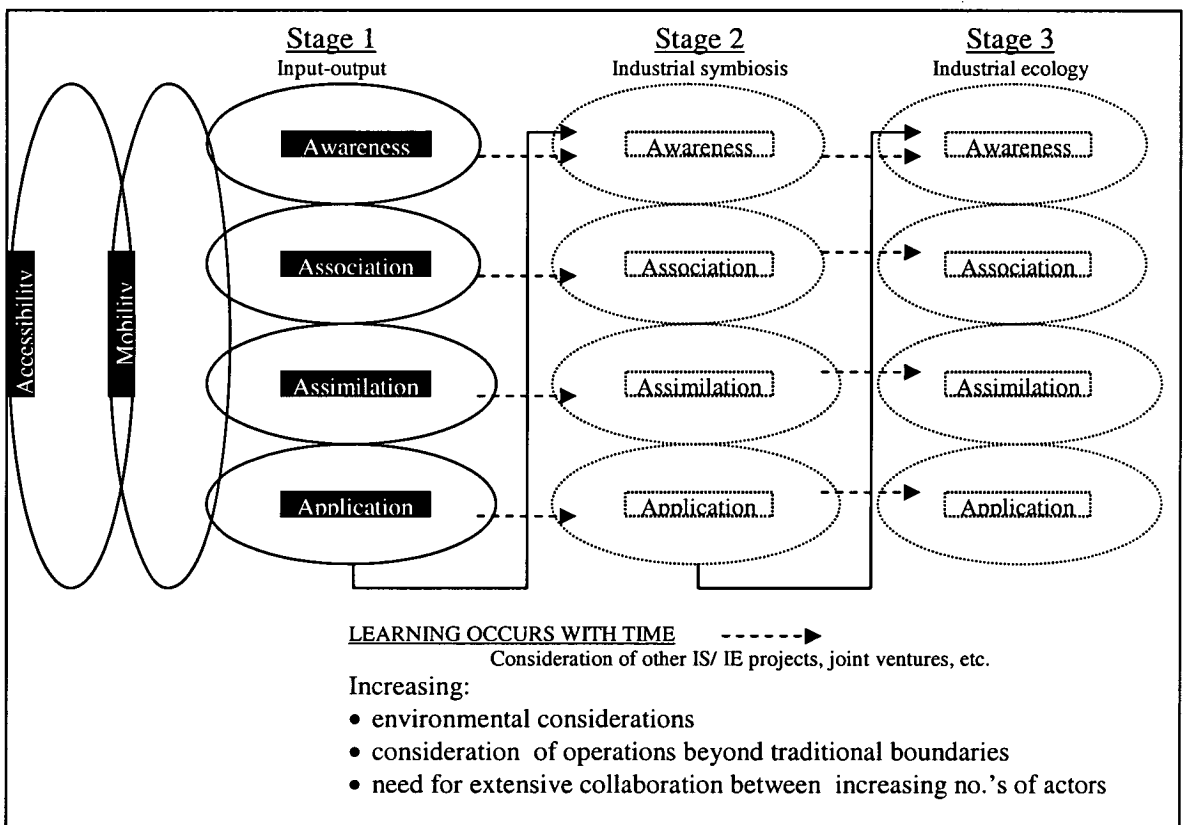
Figure 5.1.2: The learning process of industrial ecology. The Learning Industrial Ecology Strategy (LIES) model (developed by Steve Harris).

125

5.2 Applying the Framework for Industrial Ecology

For IE to be realised, many actors will have to learn new methods and tools, and undergo a cultural shift. Chief among those actors is industry. The role of industry in sustainable development is often ignored:

'On the contrary, the role of industry is central in how we address the environmental crisis. Industry is a much larger part of the problem than is normally recognised and can take much more a part of the solutions than it has been allotted. If what we are trying to do is manage the impact humankind has on the environment, then it is industry that we find fault and hope (Cohen Rosenthal E, 2003).

The next section discusses the 4As in the context of the company and IE.

5.2.1 Awareness

This can be described as the process by which an organisation discovers the concept of IS, an existing IS network or an application of IS for the company. As shown in Table 5.2.1 companies have a wide variety of sources that provide *accessibility and mobility* from which they gain knowledge and information.

Journals	Visits to other companies	Trade associations / competitors
Information scientists	Internal meetings	Competitor analysis
Internet and email lists	Internal business reports	Meetings with suppliers
Browsing in the library	Social friends	Consultants / consultants' reports
Conferences & exhibitions	Meetings/visits with/ to customers	Patent departments
Company accounts	Academic contacts	Government departments

Table 5.2.1 Examples of possible information sources of companies (adapted from Trott et al, 1995)

At this level, business support can be one of the prime movers. The business support community have an important intermediary role. Some support organisations operate on a regional basis: Local Learning and Skills Councils, Regional Development Agencies (RDAs) (in Scotland the role of both of these is performed by Local Enterprise Companies (LECs)), Chambers of Commerce and regional innovation and technology centres. Trade associations give support and representation to individual industries, whilst individuals' membership of professional institutions can bring information into companies. Business support is often

delivered on a commercial basis. Universities are developing increasing commercial focus and industrial contacts. Research and Technology Organisations (RTOs) concentrate on commercially applicable research, and are potentially even closer to industry. All of these organisations act as information providers to companies and provide companies with services and/or expertise (Trott et al, 1995). The awareness and attitude towards IS/IE of these intermediaries is therefore extremely important.

Awareness can change over time, not only because the information channels have become improved, but also because the ability to associate, and therefore become *aware* of the association will improve.

5.2.2 Association

Input-output synergy is the part of Industrial Ecology most touted in industrial ecology projects around the world. This is because it is the stage with the most obvious benefits and the stage most immediately attractive to business. It is therefore easiest for those companies that have larger waste volumes (or for those that want to accept waste or spare heat capacity). How do companies with lower waste volumes *associate* with IS? What does IS have to offer them? This is where the significance of *inter-company co-operation* emerges. There are a great number of potential projects and corresponding benefits that require a high degree of ICC (e.g. sharing of workshops or of human resources). Also, moving beyond Stage 1 to achieve greater overall efficiency levels will require greater ICC. Relating to Kalundborg, Cohen-Rosenthal (2000) expressed this compellingly:

"Most observers, while impressed with their [energy and by-product exchanges] effect, have difficulty in seeing how to replicate this icon [Kalundborg] of industrial ecology in their own situation. That is because the focus is on the wrong end: it is not just about waste heat and materials, it is about the co-operation among firms to support symbiosis and integration into their own business operations. It changes the way they do business"

In the UK, inter-organisational relationships (IORs) are becoming increasingly common and these prepare the ground for IS initiatives. According to Barringer and Harrison (2000) the six forms of 'inter-organisational relationships' (IORs) most commonly pursued are: *joint ventures, networks, consortia, alliances, trade associations, and inter-locking directorates.*

Barringer and Harrison also examined six widely used paradigms to explain IORs (*transaction costs economics, resource dependency, strategic choice, stakeholder theory, organisational learning and institutional theory*) and found that, whilst each was useful, each is also insufficient to capture the complexities involved in formation of relationships. Rather than just one reason for the formation of alliances, firms tend to have a portfolio of reasons such as cost minimisation, risk sharing and learning. As discussed in chapter 2, supply chain management and outsourcing are becoming increasingly common, arguably almost complete in some industries (Borch and Arthur 1995). The significance and advantages of clusters has also been widely reported (Porter, 2003).

Companies are waking up to sustainability and its benefits and increasingly want to make progress. A survey of Burnside Industrial Park in Nova Scotia, Canada, indicated a strong commitment to the environment and willingness to make changes (Cote, 1995). The survey revealed that 90.4% of the companies were willing to participate in cooperative waste reduction mechanisms; 95.4% would like to be informed of opportunities to improve efficiency and minimize waste; and 92.3% would support opportunities that make use of their waste for productive and environmentally acceptable activities.

5.2.3 Assimilation

> *'The real act of discovery consists not in finding new lands but in seeing with new eyes'* Marcel Proust

Assimilation can be described as the process by which an organisation communicates the concept of industrial ecology/symbiosis <u>within</u> the organisation and thereby creates business opportunities. IS/IE projects with obvious financial benefits will be more easily assimilated into the company. Moving to other ICCs will require companies to have a greater understanding of the IE concept and the necessary skills, particularly internal and external collaboration.

The implementation of IE will require increasing amounts of innovation. Similarly it has been shown that innovation is the key to a successful response to environmental legislation (Wallace, 1995); and that certain organisational characteristics facilitate innovation and are shared by technically progressive firms (Carter & Williams, 1959). These same factors would foster technology transfer and therefore IE and are listed in Table 5.2.3 (Godkin L, 1988).

Section 2.6 described the evolution that manufacturing and management techniques have undergone in the drive to increase productivity and improve competitiveness. Some of the characteristics of these philosophies are potentially conducive to innovation to IE: removal of hierarchical levels, employee ownership (that can refer to employee ownership of stock and shares, but also to increased decision making empowerment of employees), and increasing communication between departments. Further evolution of this trend is already apparent in some firms, where employees are encouraged to engage with the community beyond their firms (Wallace D, 1998). The importance of a well-trained workforce, inter-company co-operation, and sustainable business practices, for increasing competitiveness and innovation has also been recognised (Ackroyd et al, 2003; Porter,2003). Companies that have adopted these techniques are likely to be better prepared for integration of the IS concept into operations.

High quality of incoming communication	Use of management techniques
A readiness to look outside the firm	An awareness of costs and profits
A willingness to share knowledge	Identification of the outcomes of investment decisions
A willingness to take on new knowledge, to license and to enter joint ventures	Good-quality intermediate management
Effective internal communication and co-ordination mechanisms	High status of science and technology on the board of directors
A deliberate survey of potential ideas	High quality chief executives
A high rate of expansion	

Table 5.2.3: Characteristics of innovative companies that facilitate innovation (source: Godkin L, 1988).

5.2.4 Application

Application is the process by which an organisation applies the concept of IS/IE for competitive advantage. Application may evolve from executing input-output matches, through other ICCs, to basing the whole business strategy on the concept IE. This may require completing redesigning the business by, for example, making the business a service and/or employing reverse logistics (return flows from the consumer). Application will also involve performing feasibility studies and removing barriers.

5.3 Summary and Discussion

The framework presented suggests the importance of each level and that policies need to consider the 4 'A's. In addition the way each level can be influenced by a range of factors and how association is influenced by past experience. Therefore the significance of past experience through such things as waste minimisation and the foundations needed for change can be better understood.

In summary, the model is based on the following assumptions and suggests:

- IE is the ultimate potential state of sustainable development (represented by the cyclical patterns of nature)
- *Application* of IE is the ultimate state for a company to reach
- IS can be considered as a tool to invoke a cultural change towards IE, particularly in industry

Additionally the following points are worth noting:

- Companies may reach application of IS or IE without understanding, or knowledge of, the concept.
- It is difficult (probably impossible) for one company to reach IE on its own because of life cycle and supply chain considerations.
- Techniques recently developed (e.g. supply chain management, life cycle analysis) are necessary tools for the achievement of IE
- The triple loop model illustrates that organisations must possess different skills for each stage.
- Companies consist of individuals – there will always be limitations of the individual to *associate*, depending on available information and knowledge. For development from Stage 1 through to Stage 2, an individual internal champion must have an increasing understanding of the organisation's capabilities and future plans. Important for the field of IE, is how the champion communicates his *awareness* internally (part of *assimilation*) and then develops *association* to IE (beyond simple IS).

Chapter 6 Barriers and Drivers to learning at different levels

In Chapter 4 we considered the barriers and drivers to input-output, IS and IS Networks. The model developed in Chapter 5 provides a new way in which to look at the drivers and barriers. It recognises the importance of IE as a goal. The overall concern now becomes the drivers and barriers to the IE learning process.

For maximum success all levels (national, regional and company) of actors (NGOs, companies, regulators and even consumers) must learn together. After all, sustainability and IE cannot be achieved by one actor alone, nor be designed: society will evolve towards it – learn. It is possible that companies can begin to move towards IE alone (without learning of the regulator for example) but the evidence suggests this would be a much more difficult path (e.g. 'waste' label needs to be revised). Hence a major barrier occurs if one level does not learn (or evolve). Of particular importance is the global level - e.g. agreements such as Kyoto need to be ratified by more countries. The global level is largely outside the scope of this thesis and in this chapter we concentrate on the learning at the company, network, regional and government level.

Companies are the elements that most importantly must learn. Chapter 4 showed how IS/IE can fit within the policies and strategies of regions and nations. The model emphasises that to evolve onto the next *stage* the company, actor or government first needs to *associate* it with their strategy, pressures or desires. For example one of the reasons for the initial funding by the Scottish Executive of SISP (section 4.7) was because they could *associate* it with their sustainable development policy and waste strategy.

Finally, if we can better understand the drivers and barriers for this paralleled learning of the different levels of actors, then we can begin to suggest optimum conditions to foster this evolution.

6.1 Company Level

This section examines two case studies within the framework of the model, to show how it helps understand the processes that occur between companies or within region.

6.1.1 Grangemouth Case Study: GDG and GWUG

Awareness and Association at Grangemouth

Companies in this area were highly receptive to the research and to the concept of industrial symbiosis. This stems from the type of industry which is predominately the chemical industry. For the chemical industry *association* to Stage 1 is relatively easy because finding uses for by-products has for decades been part of good business. At Grangemouth, Stage 2 has also been evolving for at least the last ten years, through the activity of Grangemouth Development Group (GDG). GDG is an organisation formed in 1992 and consists of the major companies at Grangemouth, the Local Enterprise Council, Forth Ports, and Falkirk District Council. Meetings held every three to six months allow members to present and discuss ideas with the primary aim of improving the competitiveness of the local chemical industry and creating further jobs. Some of the existing and potential exchanges that were discovered were shown in Figure 4.2.1. The reasons for the high level of association and for the continuing work can be identified as:

- Large waste volumes
- All companies had an environmental manager whose role and importance within the companies has significantly increased in recent years
- Growing awareness of sustainability issues through trade associations (e.g. Chemical Industries Association), legislation, news, media.
- Public and community pressure – the companies have close proximity to local housing and need to maintain good relations
- Landfill tax increasing to £35 /tonne (see section 2.4.3)
- Increasing international competition.

GDG are attempting to attract more companies to the area by offering brownfield sites that are already covered by CIMAH (major accident hazard) approvals, and which have utilities such as steam, electricity, water and waste handling laid on. GDG's R&D and analytical labs would also be available on site, as would other central services, such as warehousing and emergency services, medical and canteen facilities. As was discussed earlier, training of employees will be an integral part of the move to sustainability and the fact that GDG is supporting a Technician Training Centre of Excellence is further evidence that the area is evolving favourably. Another example of growing ICC in the area is demonstrated by Polymeri Europa UK who have agreed a contract with an outside organisation to operate the utilities, and another to operate the packing area. They are also planning to work with a third party to treat and recycle water onsite.

A CHP plant has recently been built in the area with the intention of supplying the local companies with steam and power. Several companies are in the process of considering its viability but one company's intention of having this supply was met with stiff opposition. In this case there was a requirement to build a steam pipeline across a public highway, which attracted much public opposition due to a recent accident involving a member of the general public. This is an example of how public fear can jeopardise sound environmental improvements.

The process involved in decision making can be illustrated using the technology transfer model as shown in Figure 6.1. The figure illustrates how the:

- *Accessibility* is provided by the wide availability of knowledge on CHP and related information, helped by a strong UK government initiative.
- *Mobility*, in this case is chiefly provided by the CHP company and GDG.
- *Assimilation* success is dependant on many factors within the company that were discussed above and by consideration of external criteria, such as market conditions and legislation.
- Successful implementation will lead to consideration of other projects and potentially an increased pace of the learning process.
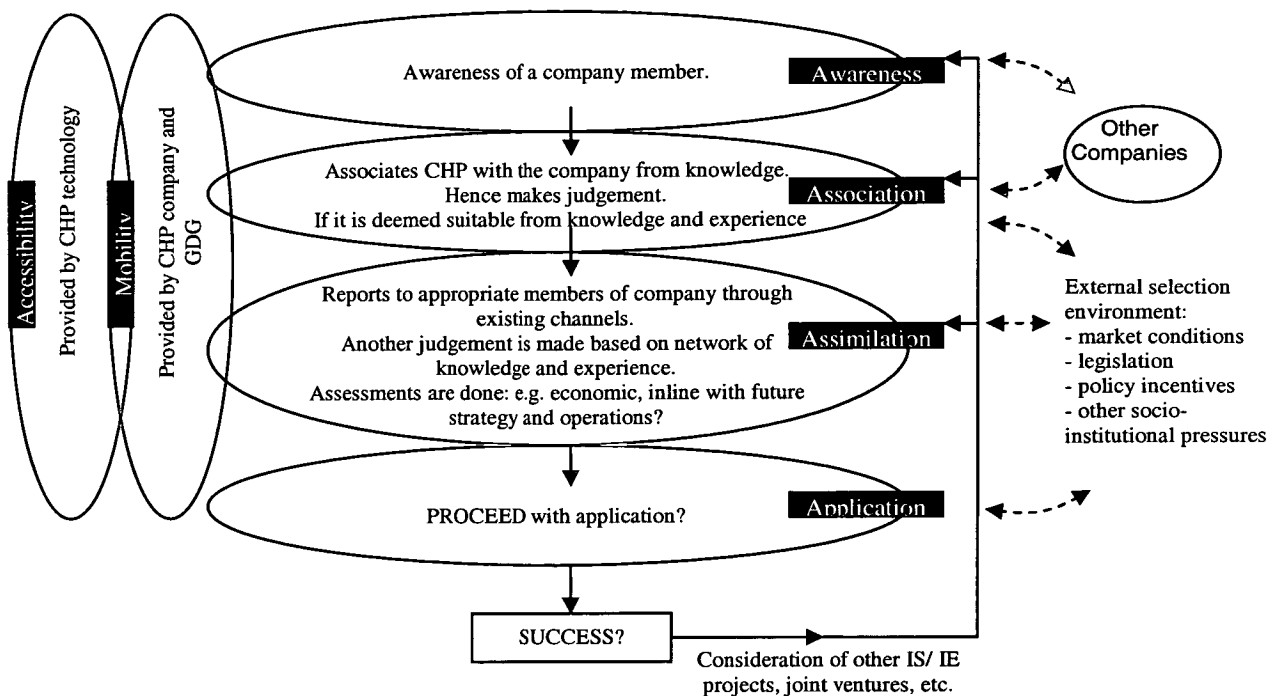
Figure 6.1: The process of CHP consideration and implementation

Another project to emerge from the GDG partnership is a proposal for district heating that involved a local petrochemical company and the local Council. The main driver for this project was the Council's desire to reduce fuel poverty and improve social conditions by providing cheaper heating. The biggest barriers to the project are:

- the capital cost of the distribution network

- plant changes leading to uncertainties about the amount of excess low pressure steam available.

A further example of inter-company co-operation in the area is the recently formed Grangemouth Water Users Group (GWUG). The group was formed in 1999 to explore opportunities for a more sustainable use of water in Grangemouth. The group's members were: BP, Avecia, Enichem, NEL, British Waterways, Scottish Environmental Protection Agency, Scottish Water, Ondeo Nalco and JWEC Ltd. The main aim was to reduce the 71 million litres of potable water used per day, which costs the companies £11.5 million per year. The benefits shown below were highlighted in a recent report (NEL, 2002) and are typical of inter-company projects:

⊚ A fresh look at company operations, identifying many cost-saving opportunities

- Security of partnership – and improved relations between companies and with SEPA
- Information exchange – examination of Best Available Techniques; open and honest dialogue leading to better understanding of the situation
- Technical Knowledge – useful information was gathered for continuing research and identification of cost saving opportunities
- Experimental results – of fouling studies for heat exchangers
- Savings arise not only from reduced supply costs but also from reduced treatment costs
- Reduction or elimination of the need for future infrastructure development by Scottish Water
- British Waterways will generate income and ensure the ongoing development of the canal system

Additionally there are likely to be some intangible benefits (such as technology transfer) and the building of better relations for future projects.

Overall, the projects discussed above reveal a definitive trend towards the formation of inter-company projects that allow companies to investigate problems more effectively together and reduce the costs and risks. The projects reveal a "snowball effect" that drives the company culture towards further co-operation and outsourcing, at a time of increasing competitiveness. This evolving culture is a driver and platform for IS/IE to build upon because companies can more easily *associate* with the benefits of co-operation and environmental projects.

6.1.2 The Forth Valley Area Case Study

Although this case study was discussed in Section 4.4.3 the model now provides a framework to base discussion and increase understanding.

Awareness and Association in the Forth Valley

Again, companies were highly receptive to the research and to the concept of IS. The reasons for this can be put down to a combination of factors that increase both the *awareness* and *association* of the companies: increasing legislation (and the perception of increasingly stringent legislation), growing sustainability awareness, and increasing use of EMSs. In

addition, as was discussed in Section 4.4.3, there have been increasing numbers of regional waste minimisation and resource efficiency projects. Because of the success of these projects and the savings that companies made, they will be more receptive and open to 'environmental' projects. Experience with these projects could also aid *assimilation* and *application* because the companies would have developed the necessary skills.

Assimilation and Application

The scoping study revealed several interesting and large commercial exchanges shown in Figure 4.2.2. Some involve joint ventures such as ScotAsh, set up between LaFarge and Scottish Power, to utilise the power station ash. LaFarge has set up further joint ventures, one to source raw materials (with an emphasis on sourcing waste materials) and another with Michelin to source waste tyres at a set rate. A large driver for this latter project is the growing mountain of waste tyres, which the process at LaFarge can incorporate whole (steel included). But it may be argued that this situation represents the failure of the tyre manufacturing system (and the government) to find more sustainable solutions, such as promoting markets for re-moulded tyres. Although it is difficult to assess the most sustainable option without a full life-cycle analysis, the materials for tyre manufacture (both steel and rubber) are effectively lost forever once incinerated or incorporated into cement. Seen in industrial symbiosis terms, the burning of tyres which replaces fossil fuels and improves the emissions of the cement works could be seen as a major success (for the cement company it is). But in terms of Stage 3 and considerations of the efficiency of the overall industrial ecosystem, this represents an easy but sub-optimal solution, because the maximum added value is not extracted from the materials. For example if tyres were remoulded, the core of the tyre would be used again. This would obtain more added value from the core which contains the majority of material in a tyre. Potentially, the best route for the core is then to be incorporated into cement, but only after it has been reused several times. The model highlights the fact that IE should be an implicit aim and this case is an example of what may happen if IS is implemented without LCA or consideration of IE and the overall system.

There are other examples in the Forth Valley that could be described as Stage 1 behaviour, and other co-operative examples. For instance, one major pharmaceutical company that works with its customers to recycle solvents makes savings of £600,000 per year. These type

of savings help to further embed a culture that sees co-operation and environmental projects as profitable.

6.2 Barriers and Drivers to Industry's Learning of Industrial Ecology - Stage 1 to 3

The framework can also be used to illustrate how the complex array of evolutionary trends and pressures can influence companies and individuals. In Chapter 2 the evolution of industry, manufacturing and management techniques was discussed. Chapter 4 highlighted local, regional and national policies. Figure 6.2 illustrates many of these evolving trends and policies with regard to the 4As.
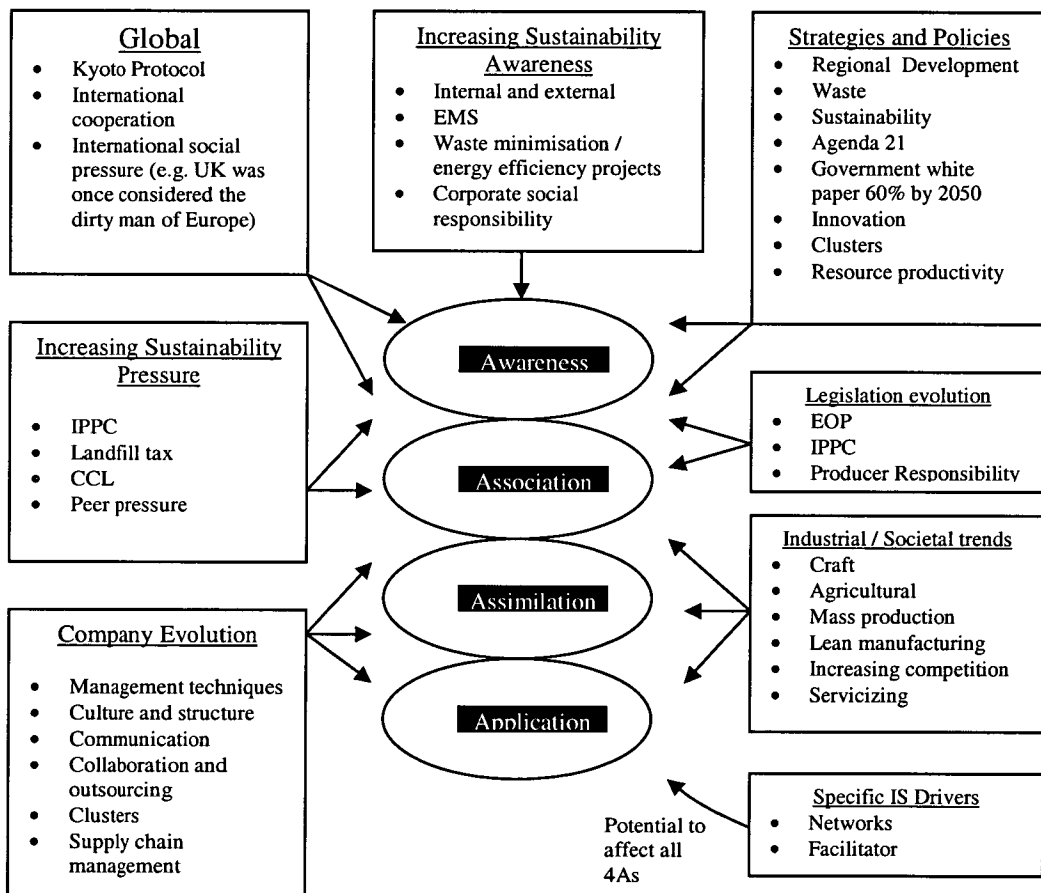
Figure 6.2: Influences, drivers and trends affecting the company for industrial ecology

Many of the trends not only point to the positive need for IE, they also suggest that evolution of industrial ecology is occurring, and its emergence is not only desirable but necessary for

continued evolution of the anthropogenic system. Trends and policies are pointing in the direction of IE, which is beginning to be matched by complimentary management techniques.

The research presented in Chapter 4 showed that there are many individual barriers for the case studies. Below we highlight and discuss the main barriers and drivers for each Stage and which of the 4As they affect predominately.

6.2.1 Stage 1: Input-output

At this stage barriers predominately exist at the level of *awareness* and *application*. Hence either companies are not aware of opportunities; or technical difficulties mean the opportunity cannot be realised.

Barriers	Related to
Lack of information	Awareness and Association
Regulation (waste label)	Application
Technical	Application
Low waste	Application
Drivers	**Related to**
High waste volumes	Awareness and Association
Economics – financial gain	Association
Landfill Tax	Association

Table 6.2.1: The main barriers and drivers to Stage 1 in relation to the 4As

Barriers

Lack of information flow

The main barrier for Stage 1 is that *awareness* and *association* of the necessary information and knowledge is not held concurrently by the appropriate individuals within companies or organisations. *Awareness* in terms of input-output is generally a simple case involving the dissemination of information. If one company has a resource available and they are able to get that information to a suitable recipient then the deal is done.

An internet-based waste-exchange could potentially increase *awareness*. In this case a barrier could simply be a poorly designed system that is not user friendly. In the UK there have been at least 12 such databases (ENDS, August 2000) but success has not been well documented. Also, these often operate on a commercial basis, which is generally not popular with industry. They are potentially direct competition for IS networks. Generally they are not user friendly and have no search facility, just a long list of 'wants' and 'for sales'. The main barrier appears to be getting companies to use such a facility regularly. This is the essential difference between a simple internet-based exchange and a proactive IS network that has workshops and other incentives to maintain momentum.

Internally, the organisation may have poor information flow, and communication structures that mean the right people don't communicate within the organisation, or recognise the full value of the resource or the fact that there is a use for it. In terms of the model, *awareness* does not link with *association*.

Regulation (waste label)

This was discussed in Section 4.3.2 and is a common barrier to the *application* of projects. Another example of a regulatory barrier that could perhaps be solved with more flexible regulation is the example of company 'H' (a petrochemical company). It would need an additional license if it were to process one of its by-products into a fuel (currently the by-product is reprocessed off-site by a third party). But an additional barrier is that this processing would mean that its own sulphur emissions would increase.

Technical

Technical barriers such as purity or reliability of material flow are major barriers at this stage.

Low waste volumes

Low waste volumes are a strong barrier to *association*. Without an IS sub-network, the costs involved and the time spent finding a suitable recipient make the prospect unattractive. It is generally much easier therefore to dispose of the material in the skip designated for landfill.

Drivers

Economics – financial gain

The main drivers are all linked to economics, which causes a high degree of *association.*

High waste volumes

Awareness and *association* are stimulated by high waste volumes. Any company that can turn a 'waste' into a sellable resource has potentially a new profitable product. Several of the case study companies were running projects that investigated the potential treatment and marketing of their by-products. The aluminium plant had for years attempted to find a market for its red mud, but only 46 tonnes (sold as paint pigment) of the 100,000 tonnes/year were actually sold. Another option being investigated was using the mud for heavy metal fixing in soils, but currently it is difficult to foresee any significant use for such a material.

Economic instruments - Landfill Tax

Data from Table 4.3 and evidence from the interviews strongly suggests that landfill tax is currently the main driver causing both *awareness* and (the link with) *association* to finding better routes for material outputs. Legislation has been a strong driver for environmental improvement to date, but hasn't caused companies to directly reconsider their waste in the same way that landfill tax is doing.

6.2.2. Stage 2: Industrial Symbiosis

For Stage 2 the main drivers and barriers are as for Stage 1, but there are additional drivers and barriers (particularly with regard to projects involving high levels of co-operation) as shown in Table 6.2.2.

Barriers	Related to
Core business focus	Association & Assimilation
Limited Awareness & Association of top managers	Assimilation
Turbulent legislative scene	Assimilation and Application
Capital expenditure	Application
Drivers	**Related to**
Anticipated Legislation	Association
Network	Awareness and Association
EMS	Assimilation and Application
Economic Instruments	Association and Assimilation

Table 6.2.2: The main barriers and drivers to Stage 2 learning (in addition to Stage 1 barriers and drivers)

Barriers

Core-business focus -Association & Assimilation

One of the main barriers for IS projects is 'core-business focus,' compounded by the fact that waste is often seen as a necessary component of production. Therefore managers do not generally *associate* it as a problem and it is not *assimilated* within the company as an opportunity or design consideration.

Even where potential projects are recognised, changes in economic conditions can lead to projects being cast aside, as in the district heating example in the Grangemouth case study. In this case, the focus of the oil company (one of the major champions of the projects) turned instead to cutting jobs and increasing competitiveness. The Local Council was left to drive the project, as there is no real incentive for the oil company, other than improving company image.

A further example is a petrochemical company that had the idea to make decorative wood chippings from waste wood. This however, is far removed from the core-business and so as an idea is easily sidelined. It also requires an internal champion to drive such an idea forward, which hence also requires employee time. For this company a driver is their EMS, which has the facility to maintain momentum with small improvements such as these. A network may also provide the necessary impetus here by finding a market. Companies need to free-up some of the time of employees to allow innovation to happen. This is not a new proposal, as it has been widely mentioned in the literature, but it is reinforced by this research.

141

Gaining management support is key to *assimilating* IS within the company especially for the more complex projects and for the wider benefits. But again, poor internal communication, personal barriers (e.g. lack of respect for the internal champion) can cause potential for IS to dissipate.

The process of *assimilation* can also be difficult and frustrating for company representatives who can see the value and potential of IS but who have difficulty convincing managers who have a traditional economic outlook. This was highlighted in Chapter 4 from one of the workshops of SISP.

Turbulent legislative scene

The fact that the legislative scene is so turbulent leaves companies unsure of what precisely to invest in, and whether the projects they are considering will payback before legislation is drafted in. Amongst the plethora of barriers this can often be the last straw that breaks the camels back.

Drivers

Anticipated Legislation

Legislation is generally regarded as the most significant driver causing companies to make environmental improvements. It can also act as an important driver for partnerships, e.g. WEEE and ELVs. There is generally a 'wait and see' approach however, even by the large companies. This is caused by an uncertainty of what legislation will emerge from Europe, and also from possible future global agreements.

Network - Awareness and Association

From the action research, study of NISP/SISP and the literature, one of the chief drivers for identifying IS projects appears to be co-operative networks (further research is needed as to how successful a driver IS networks are in the actual *implementation* of the opportunities).

Although software can help raise *awareness* of synergies (but only after the corresponding companies have already entered their information), many more synergies are found from meetings that bring potential partners together, such as the SISP meetings described in Chapter 4. The evidence from the literature also strongly indicates that meetings and workshops are far more successful than mere software matching. Workshops, especially if well run, can inspire participants to find synergies they hadn't previously imagined. In effect, participants work to find common ground, and develop *association* of a project concurrently.

In addition, an IS network could potentially aid *assimilation* by raising the profile of the benefits of IS and providing case studies. This would aid an internal champion in his/her communication to senior management. As with NISP, networks can provide training to company members. Currently, the NISP training is limited to using the database. However, in the future, by combining resources and expertise with key actors (e.g. the regulator (SEPA/EA), universities, key companies, business groups and associations) this could be extended to produce a much wider educational package. Ultimately this would promote aspects such as LCA and integrated chain management, and learning towards Stage 3.

EMS – Association, Assimilation and Application

Often the implementation of an EMS means that a dedicated employee is tasked with seeking environmental improvements such as those offered by IS opportunities. Many of the companies were seeking improvements in this way. The EMS could additionally act as a basis to communicate any IS opportunities within the company.

Economic Instruments

In addition to Landfill Tax discussed for Stage 1 above, the CCL can potentially lead to sharing of CHP plants (good quality CHP being exempt from the CCL) as is demonstrated in the Grangemouth case study.

6.2.3 Stage 3 Industrial Ecology

To consider the drivers and barriers for IE, we first need to consider what aspects of IE are important. Hence we need to consider barriers and drivers to:

- Product based systems approach &life cycle analysis

- Regional industrial symbiosis networks

- Integrated chain management

- Reverse flow / logistics – reuse, remanufacturing & recycle

- Servicizing

This research did not find any evidence of IE activity in the chemical industry of the Forth Valley. In other industries there were a handful of companies that showed limited signs of IE behaviour (i.e. have some form of closed loop, and or recycled input): for example the companies EPR (input of chicken litter; output: energy and agricultural fertiliser), Smith Anderson (paper recycling) and Scottish Water & Scottish Power (sewage pellets for energy, which hypothetically could be used for cooking food, which in turn leads to more sewage).

Since IS is a driver to IE, then subsequently the drivers and barriers to IS also become important for IE (as I-O drivers and barriers were for IS). In addition to the fore mentioned drivers and barriers for the first two Stages, the main drivers and barriers to IE are summarised in Table 6.2.3.

Barriers	Related to
Market infrastructure	Association, Assimilation & Application
Technology Lock-in	Association, Assimilation & Application
Drivers	**Related to**
Legislation – EPR e.g. WEEE, ELVs	4As
Economics	Association, Assimilation & Application

Table 6.2.3: Additional Barriers and drivers at Stage 3 learning

Barriers

Market infrastructure - Association, Assimilation & Application

Companies make profit by selling goods, hence the more they sell the more profit they currently make.

A famous example of 'technology lock-in' is that of cars. A century of development has put the petrol engine, and the infrastructure to maintain it and supply its fuel, in a virtually unassailable position. Technologies based on alternative fuels, batteries, or fuel cells will have to compete with petrol engine performance and cost efficiencies that continue to improve.

Drivers

Currently the drivers for IE are very limited. Although many companies would like to be considered sustainable, the drivers are currently too weak to overcome the enormous barriers of market infrastructure and technology lock-in.

Economics – Association, Assimilation & Application

Not surprisingly where companies can readily see the economic advantages of IE, or any of its aspects, then they are likely to implement it.

Legislation

EPR legislation soon to come into effect, such as WEEE or ELV, has the potential to act as a strong driver for IE. However, to date they are limited to the electrical, electronics and vehicle sectors (representing only 1% of total waste arisings) and their effect could be limited by the form of collection (see section 2.4.3)

6.2.4 Discussion: Company Barriers and Drivers to Stage 1-3 Learning

At Stage 1 the main barriers are technical (e.g. material composition), informational or due to regulation. But at Stage 2 organisational factors, such as management commitment/time and capital investment, become more important. At Stage 3 cultural and infrastructure barriers become more important, as does the actual nature of the business.

Financial benefits are of course the underlying reason/driver guiding companies at each of the three stages. At Stage 1 high waste volumes, and recently the Landfill Tax, are strong drivers (obviously the larger the waste quantities the greater the incentive). In the case of energy, the CCL provides an incentive to find symbiosis, e.g. in joint CHP ventures. Currently at Stage 2, networks (trade associations, and industry groups as well as IS networks) are the strongest drivers causing IS type initiatives. An EMS can also provide an incentive for improvement and hence symbiosis. For Stage 3 there are few incentives for companies.

One of the most important aspects that the triple loop model highlights is that, as we move from Stage 1 to Stage 3, internal factors *(assimilation)* become more important. In particular the need for top management or even top executive support for projects/ventures becomes increasingly important. IS projects may require capital investments and significant management time, whilst IE (Stage 3) often requires business reengineering and radical innovations in products and processes. Collaboration and cooperation also become more important with each stage of the model. IE is likely to require even more extensive collaboration than IS ventures because, for example, with techniques such as reverse logistics, there is a need for a wide range of actors to be involved.

Several of the companies noted that there was generally a lack of incentives for IS/IE improvements. IS networks can facilitate information exchange and (depending on the skills of the facilitators) have the potential to create a degree of social momentum. The importance of legislation is likely to continue, but will need shrewd use of economic instruments to overcome the barriers of the current market structure and technology lock-in.

The Chemical Industry Stage 1 to 3

Whilst the chemical industry may be beginning to function well within the context of Stage 1 and 2 it is more difficult to envisage how it will move towards Stage 3. The chemical industry is keen for others to take their by-products but they are less keen and currently less able, to accept inputs. This is mainly due to purity and liability considerations. As with most other industries, profits are based on maximising sales and there is therefore no incentive (in fact there are plenty of disincentives) to address the sustainable consumption factor.

EMSs have had some success in reducing pollution, but even if all companies adopted them the industry would still not be sustainable (Dunn, 2004). The levels of consumption continue to rise, thus cancelling out any improvements in environmental performance per unit. But the room for improvement is vast and EMSs are in fact a good starting point. Corporate social responsibility reporting is also growing and provides a way for companies to assess their social impacts. Ultimately though, (as oil and oil-based products become increasingly scarce) the sourcing of chemicals from petrochemical feedstock needs to be switched to waste and biomass materials. Following this route would in turn force sustainable consumption considerations because the 'ecological footprint' of the chemical industry would have to be tackled directly: – consumption would be limited by the amount of land devoted to appropriate bio-resource production, plus the amount of recycled material. Again, this will require cooperation between a range of stakeholders and would probably need government backing. This is not such a difficult scenario to imagine in a country such as the UK, where agriculture is at something of a crossroads (e.g. with declining profitability; the foot and mouth crisis; and the GM debate). Not only would it provide jobs and a possible renewable energy source, it could potentially secure relative independence from imports and thereby greatly strengthen the economy.

A medium term solution would be that of 'servicizing' based on a partnership approach between customer and supplier. The aim is to increase the efficiency of chemical use and where possible recover the chemical at the end of its lifecycle. BP Castrol, for instance, provides total fluid management services to UK Airbus' maintenance department (ENDS, June 2003b). The model of chemical management services developed steadily in North America in the 1990's, where an aerospace company saved over $1 million in the first year by consolidating chemical purchasing and management and reducing its spend on waste treatment (ENDS, November 2001). One example was found in the Forth Valley area of a chemical recycling company that is attempting to offer more of a service, but the uptake of the concept has been slow in the UK (ENDS, June 2003b; ENDS, June 2002).

Additional potential drivers caused by industrial symbiosis

IS Prompting System Analysis

IS can potentially change the way companies do business by prompting them to look at their businesses through different eyes. For instance, one company involved in the IS Programme

makes friction products such as brake pads for well known car manufacturers. The company representative interviewed was exasperated that no one was willing to take approximately 1500 tonnes of very useable material because the exact mix of materials could not be guaranteed. This is because it is impractical to separate the wastes from each process. But thinking outside the normal parameters, the question was asked that possibly the customers could agree to use a similar composition of ingredients and therefore the waste would be more uniform. If we are serious about sustainability, and on a systems basis, is it really necessary to have so many different products whose performance, overall, is not greatly different? The interviewee agreed that in the past his company had estimated that probably 12 different compositions could provide the necessary products, but that they made over 200 variations because of customer requests. It was felt by the interviewee that many of the designers, who routinely change the product composition, do so to keep themselves in a job and not for any remarkable increase in performance. The focus from a wider IE systems perspective would be to ask whether the customers could be convinced to use more homogenous compositions? Could there be a discount for the customers to do so, and how much would this need to be?

6.3 Regional and Network Level

Organisational networks may also be considered as 'learning organisations' (Cohen-Rosenthal, 2000). A potential learning path to IE for a regional industrial symbiosis programme or an eco-industrial park (such as that of Burnside Industrial Park, Nova Scotia, Canada, see: Cote and Smolenaars, 1997) using the developed model can be illustrated as in Figure 6.3. Here, *accessibility* is provided by academia, research and case studies; and *mobility* is provided by a range of intermediaries (see section 5.2). A network may develop due to economic reasons (increase/maintain the competitiveness of the area), social reasons (job creation or to improve conditions) or environmental reasons (reduction in pollution).

In this section an IS network is viewed as a path to regional learning and evolution to Stage 3. Ultimately other than the companies in a region other key players need to learn IE within the network such as planners, RDAs and local authorities. The barriers and drivers can be summarised as shown in Table 6.3.
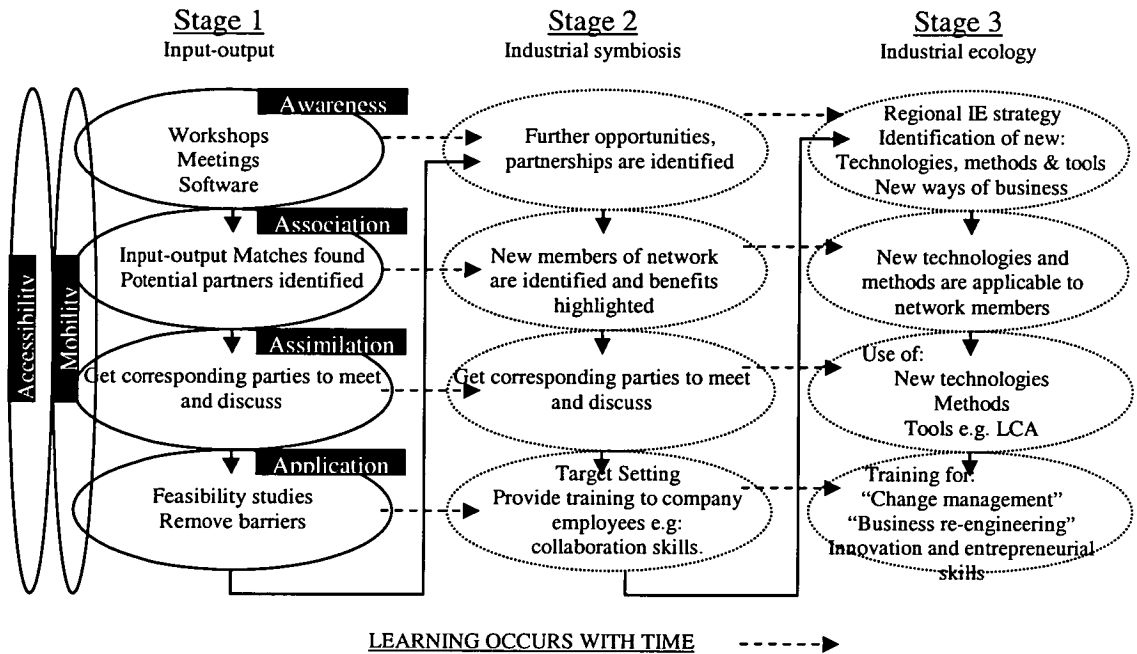
Figure 6.3: Industrial ecology learning process in a network (developed from Trott et al, 1995).

Barriers	Related to
Misplaced emphasis	Association
Maintaining momentum	Application
Confidentiality	Awareness
Limiting targets	
Drivers	**Related to**
Facilitator	Awareness & Association
Business focus	Association
Ownership	Association
Software	Awareness, Association and Assimilation
Diversity	Application
Combining resources and training	Assimilation and Application
Fitting in with strategies and policies	Association, Assimilation

Table 6.3: Barriers and drivers to regional learning

6.3.1 Barriers

Misplaced emphasis – Disassociation

One barrier that could emerge when developing a regional project is the danger of placing too much emphasis on the most readily assimilated Stage 1, and input-output matches. Esty

149

and Porter (1998) noted that '*Because IE focuses attention on materials and energy flows it may not optimise other variables that contribute to competitiveness within the corporate sector*'. Placing too much emphasis on input-output matches runs the risk of the network becoming a glorified waste exchange service (as well as missing opportunities that the network could be credited for). Ideally, a project needs to appeal to a wide audience and not just to companies with large volumes of waste. It is important to realise that *awareness* and *association* go hand-in-hand. The significance of their linkage can be more readily appreciated when we consider that the human mind is more aware of factors it considers important and blocks out non-important stimuli, e.g. background sounds that don't fluctuate. In the same way an individual ignores concepts and ideas that it does not recognise or are not deemed important. Thus the *awareness* raising of IS needs to be coupled with *association* and will be achieved best by targeted marketing. This point when illustrated appears obvious, but is additionally important because *disassociation* can easily occur (as happened in the NISP-Humber case study, section 4.6.1).

Heeres et al (2004) recommend starting with simple utilities sharing, and moving on to other projects (such as materials exchanges that require more effort and potentially more expenditure by the company) once companies have seen the benefits and have adjusted culturally. As the innovation web-site of the UK government states:

"*Any attempt to push forward to new ways before the people are ready to assimilate and believe in them could result in severe distortions to the organisation's culture*" (Innovation Unit, 2003).

Maintaining Momentum

One potential barrier to learning is the difficulty of maintaining funding and momentum. As Oerlemans and Assouline (2004) discussed with regard to networking amongst farmers:

"*Another barrier is the declining cohesion of the group over the years due to differences in expectations, commitment and expected benefits, especially between the ones who started the project and the ones who joined in later. As the first members set up the network to turn the tide and to prove that quality production did have a future, the later members mainly joined in because of economic motives. In this sense, the network has been attractive to new members, but this attractiveness might also endanger the initial values and reasons of the network for getting together. Also the lack of new challenges and innovations turns out to be a barrier in securing group cohesion. In the beginning of the project many questions had to be answered and this triggered enthusiasm and collective action. Collective action took place in several, still to be explored fields: marketing and distribution of products,*

environmentally friendly cultivation methods, selection of suitable wheat varieties and network building through the enrolment of actors needed to secure success and development prospects" (Oerlemans and Assouline, 2004).

Confidentiality

Sterr (2004) puts part of Kalundborg's success down to the openness and *transparency* of material flows and undesired outputs amongst the company. One potential barrier is that companies will want to maintain their confidentiality and therefore limit information sharing.

Limiting Targets

The facilitator also has an *awareness* and *association*, and will be more inclined to concentrate on those projects which are associated with network targets (e.g. the inclusion of a predefined number of companies into the network or reduction in a certain quantity of waste going to landfill). The setting of targets can be a motivating factor but also a limiting one.

Funding

Funding of some kind is crucial for the networks survival. The amount required is dependant on the approach used and the source of the funding. BCSD-UK have only implemented programmes in regions where funding has been provided by regional sources. Where they have been unable to appeal to the strategies and policies of regional key players the programmes have thus far been unable to progress.

6.3.2 Drivers

Facilitator

As a report from NISP- North West stated:

'An Industrial Symbiosis project is a discretionary activity and therefore companies may find genuine difficulty in devoting resources in the face of other pressures, e.g. regulatory compliance. Progress will therefore be slow and may not happen at all without continual Project Manager input' (Curry, 2002).

'In order to get businesses involved in the process, the industrial ecology approach therefore needs to be sold to them' Welford (2004).

The 4A model can be used to demonstrate how networks can sell the idea to industry. Figure 6.3.2 illustrates the range of services that a network could ultimately provide to help industry 'onboard.'
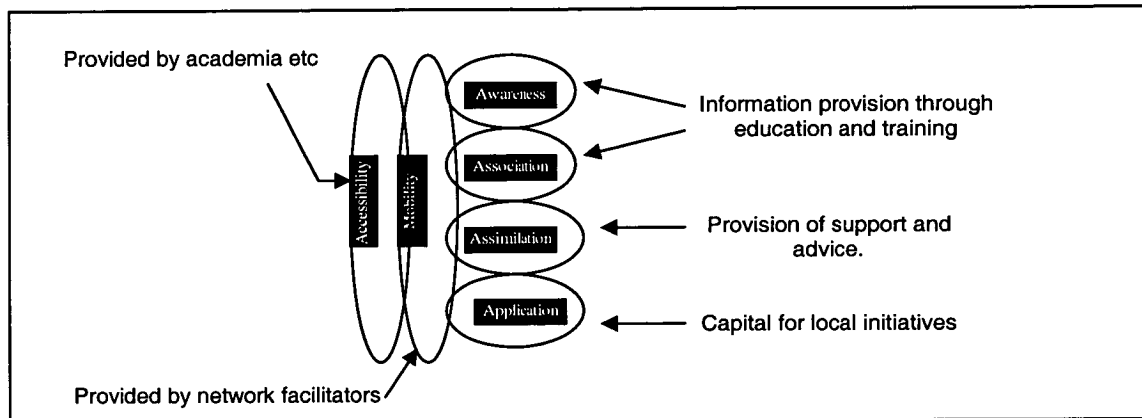
Figure 6.3.2: The range of services that the network can provide to the company.

The initial success of NISP & SISP (measured in terms of funding gained and number of companies involved and demonstrating a strong interest) is due to the business focus. SISPs 'Partnership Marketplaces' are showing that there is significant interest and that these events stimulate innovative and entrepreneurial behaviour (see section 4.6.2).

Software

The network and software provide a means not only of *awareness* and *association* but also of assimilation. This was witnessed while accompanying SISP facilitators on company visits that involved introducing the software. Because the software allows the company to enter a range of data, from inputs and waste through to spare human resources, it deepens the *association* process and provides a visual tool to aid communication (and hence *assimilation*) within the company.

Involving firms in the process of sustainable development is continually recognised as important in promoting action, particularly with environmental management (Revell and Rutherfoord, 2003). This type of social empowerment or 'ownership' induced by associated involvement is recognised as an important social driver in many situations including management (Capra, 2003). In the same way companies that use a wide range of positive human resources practices (e.g. empowerment, incentives and training) are more likely to innovate than firms using fewer or none of these practices (Therrien, 2003).

Diversity

Maximising the number of companies involved is important as a driver because as in natural systems stability and opportunities for symbiosis will be improved by diversity. Diversity (along with roundput, locality and gradual change) represents one of the four principles for industrial development proposed by Korhonen (2001). However in a more recent paper Korhonen states that IE practitioners shouldn't automatically assume that diversity in networks is a positive aspect (Korhonen, 2004). His argument in this paper mainly relates to having too many stakeholders (organisations other than companies) whose many differing opinions and desires could cause conflict.

To increase diversity regional IS projects need to increase the possibility of companies *associating* their operations with IS. This can be done through a business focus and also by providing a range of examples that highlight the similarities between existing *inter-company co-operation* (particularly those from the same region) and IS. Cohen-Rosenthal (2000) provides an extensive list of possible areas of 'eco-industrial networking' (Table 2.2.5). The best way could well be to target sectors or individual companies, as Cohen-Rosenthal writes:

'My rule is that, if industrial ecology is to be accepted by corporations, it must have a significant and measurable impact on the top three to five drivers for organizational success. If market image is the major concern, then the industrial ecology strategy must address that issue. The same holds true for cost leadership, product innovation, risk management, quality, market access, reliability of supply chain, customer core requirements and so on. Although a value-based commitment to environmental stewardship is welcome, even in those situations the particular industrial ecology strategies must demonstrate a difference in the success of the organization. If it doesn't, commitment will wither quickly and , more importantly, opportunities to make a real difference will be overlooked or dismissed' (Cohen-Rosenthal, 2000).

A regional IE network has the potential to provide an umbrella for a range of regional initiatives, from sustainability or resource efficiency through to innovation networks. In a country such as the UK, IS/IE networks can potentially see much closer integration between the facilitators, the RDA, and the Environment Agency/SEPA. This closer integration could help combine tasks and goals and free up further funding that would build on the success of the network and provide ongoing training to company employees. This would provide the skills necessary for companies to function successfully in the network. As the network strengthens, a wider variety of stakeholders (such as local environmental groups and community groups) may join and the network could begin functioning as a regional industrial eco-system.

6.3.3 Discussion: Network and Regional Level Barriers and Drivers to Stage 3 Learning

The prime objective of networks should be to foster the necessary learning that aids the move to Stage 3 of the model. This applies to both the companies and key actors within the region. For purposes of discussion here, we will discuss networks in the context that a facilitator exists and oversees the network.

Initial learning to Stage 2 is provided by the network facilitator through their attempts to increase integration of companies by searching for and facilitating IS opportunities. But momentum must be maintained, so facilitators need to think beyond the initial phase. The search for opportunities can continue (and probably will need to, due to companies coming and going in an area) but how does the network and region move towards Stage 3? Can the network be a major cause of this wider learning? Can IS networks influence companies to make product and process based improvements (PBI)? The answer is potentially yes, although other incentives will undoubtedly be needed. IS opportunities will potentially cause companies to consider PBIs, but IS networks could also be instrumental in facilitating reverse logistics. Additionally there are potentially a range of intangible benefits that could develop from IS networks such as innovation transfer and inspiration etc, that could aid learning to Stage 3.

As has been discussed, for Stage 3 to occur on a regional level it is important that key players such as local authorities become involved in an IS network and ultimately adopt the IE concept. The network facilitator can help facilitate this by illustrating the deeper role that IE can play in the region's strategy particularly with regard to planning and regional development. This is also likely to increase the prospects of network funding. Projects such as district heating, greenhouses that utilise spare heat capacity of industry, are just two examples of "easy gains" that create local jobs (a major goal of RDAs and LAs) and increase regional prosperity[1]. For network financers (current/potential) it may also be beneficial for facilitators to highlight the activity that is already going on that is similar to industrial symbiosis, and the corresponding benefits. These highlighted benefits and the *association* with IS will form as a major driver to fund the projects for the long term. This is most important, because the real benefits could take up to twenty years to emerge.

Inclusion of influential organisations (e.g. the regulator) in the network could help remove any barriers (such as legislative barriers, e.g. the liability involved in the 'waste' label). A current barrier for progress towards Stage 3 is that the regulatory and legislative conditions often do not consider things from a systems perspective. This is demonstrated by the case of one petrochemical company that has to pay a waste disposal company to collect water with very low zinc contamination. The waste disposal company simply tanks the water away and virtually disposes of it down the drain (although ~ 30 miles away) where the regulatory consent is higher.

An IS network has the potential to identify spin-off projects, innovations and joint ventures. Barriers such as small waste quantities could be solved by ICC and the building of sub-networks. e.g. reuse of wood waste. Successful exchanges would then be presented at network meetings, potentially encouraging more and building on the learning of the network. Building on the successes is where the network will start to learn and begin to function as a 'learning organisation'; developing a degree of self perpetuation.

"Learning and change is seen as more successful where commitment is built on the experience of early successes and where there are commonly appreciated problems.

---

[1] Projects such as greenhouses using excess heat will of course only succeed where there is a market for the produce. The products would have to compete with the efficiently produced crops from places such as the Netherlands. Again the advantages have to be calculated from a systems perspective. What are the social gains for the area from further jobs etc? Is it beneficial to subsidise such projects (if there is a need of subsidy)?

Moreover, learning through processes by which actors work together is viewed as more successful than learning arising through the attempts of one actor in the network to impart formal knowledge to others" Roome (2001).

Universities could help with the assimilation stage by using their research skills in their areas of expertise such as chemical engineering or management research. Strengthening the bonds between universities and industry could additionally improve innovation and knowledge transfer.

Central to the success of networks is the need for business focus; recipients may not be ready for the wider (and far more complex) concept of IE and may not be able to *associate* it with their business. Ehrenfeld and Chertow (2002) attested that: *"even explaining industrial symbiosis – the educational component – is arduous because industrial symbiosis is not 'business as usual', and requires significant change to traditional individualist mental models".*

The Regional Industrial Ecology Strategy (RIES)

The idea of RIES builds on the theory of regional environmental management systems. For a network to function as a learning network and move to Stage 3 there is a need for a strategy. A RIES can provide a common vision that can help to maintain momentum and act as a driver by setting targets and involving a wide range of actors and organisations. There has been little research on RIESs and there is little available in the literature. The concept of Regional Environmental Management Systems involve: Environmental risk analysis; policy, planning, implementation and operation, checking and corrective action and management review (Welford, 1993). RIES could act as a driver because it can help to:

- Embed IS in a region by promoting further ownership to the companies
- Encourage individual company members to associate their business with regional development
- Create a vision to work towards in collaboration with others
- Begin the cultural shift needed
- Encourage companies to adopt a product based approach and move towards Stage 3

Implementation of a RIES, combined with regular workshops and meetings to disseminate progress and results amongst network participants, would go a long way to establishing a community feeling and the associated pressure. This type of regional structure would provide a solid ground for combining the resources (as discussed above) of the regulator, network facilitators, LAs, and resource efficiency projects; thereby avoiding duplication and helping to disseminate best practice. This would also facilitate a knowledge pool of the area and help to target those companies or stakeholders, whom are lagging in resource productivity. A recent study found that there is a need for one port of call where manufacturers can go for information (Harris, 2000). This could potentially be provided by such a network's port of call (e.g. the IS network chief facilitator). These types of regional strategies would also help to provide the other aspects that are called for in the most recent literature and research: good dialogue, appropriate intermediaries and support, skills development and training. A RIES would also help to avoid one of the limitations of IS – concentration on material waste streams; and help the stakeholders to keep the wider vision of IE and goal in mind.

6.4 National Level

For IE to be successful it must be adopted not only as business strategy but also as government policy. Figure 3.3 uses the analogies developed earlier to illustrate how a national government may take onboard the concept of industrial ecology.

As discussed in Chapter 4, at the national level IE can act as an umbrella for many policies towards social, economic and environmental development: innovation, sustainability, waste, clusters, regional development, employment, social equality, national economy. It is here that *association* to IE can be achieved at the government level, especially if IEs' economic benefits are recognised. Industrial ecology may provide the framework to facilitate the 'joined-up thinking' that many request from government. Ultimately industrial ecology must enter the political sphere to really achieve all it sets out for.
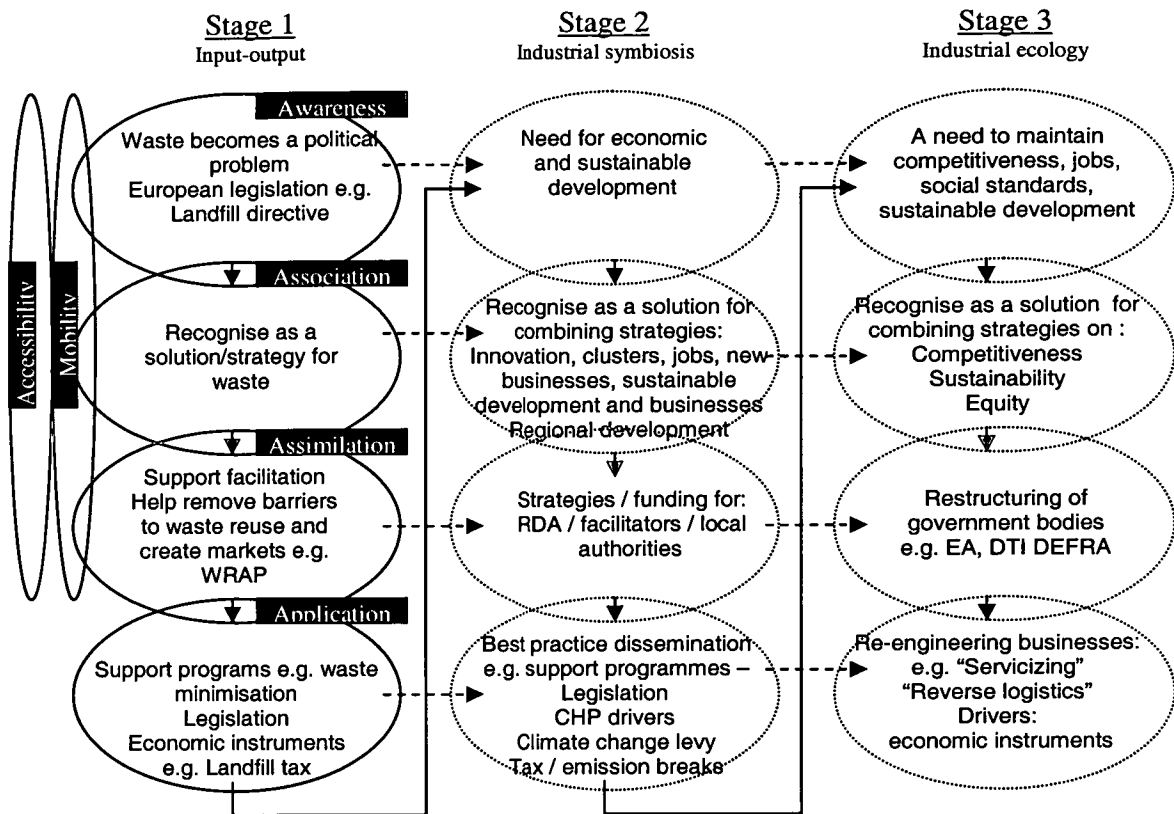
Figure 6.4.1: A possible learning process for national governments (developed from Trott et al, 1995).

Scotland's devolution could be considered a driver because it can help to produce the 'community feeling' (smaller areas can create this more readily through competitive desires) and a sense of nationalism. Additionally the devolution can act as a driver because smaller areas are easier to manage and envision. Table 6.4 summarises the drivers and barriers at this level.

Barriers	Related to
Risk	Assimilation and application
Short term political goals	Application
Drivers	**Related to**
EU legislation	Association , Assimilation and Application
Economic development	Association
Combining and achieving policy goals	Assimilation and Application
Sustainable Development	Association
Waste problem	Association
Kyoto commitments	Association

Table 6.4: Barriers and drivers to government learning

6.5 Creating Favourable IE Conditions

6.5.1 Considering the two paths to IE/ Stage 3

This thesis has focused predominately on the IS path towards IE, rather than the product based approach (e.g. rather than LCA). But for IE evolution, companies will need to make both product based improvements as well as utilising IS. Figure 6.5 builds on Figure 3.6.1 and illustrates how some of the major drivers affect the components of IE.
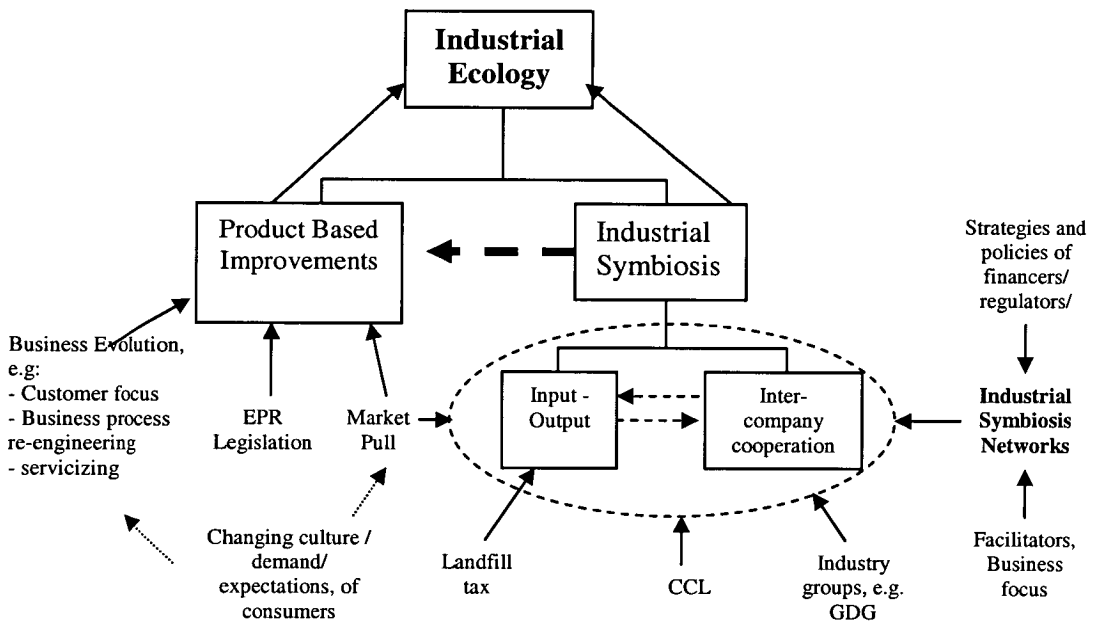
Figure 6.5: Illustration of the major drivers for the components of IE

The diagram illustrates that product-based-improvements (PBI) and IS are not only paths or components of IE, but can also be viewed as drivers for IE. The two sub-components of IS (I-O and ICC) are also seen as interacting drivers for IS. Either can lead to the other, e.g. companies exchanging materials develop trust and may move to other forms of ICC, or vice versa. IS networks are seen as the most important driver causing I-O and ICC, and therefore leading to IS. In fact, as with the 4A model, the bottom four components of Figure 6.5 can be viewed as interacting processes.

One of the aims of encouraging companies to seek IS opportunities should be to foster PBI. Likewise PBI may facilitate material flow considerations and therefore considerations of waste arisings and their potential pathways (i.e. IS).

6.5.2 What should policy foster?

It is important to distinguish exactly what policy is aiming for. *Association* to IE is potentially the next phase of industrial development. How can companies *associate* with industrial ecology? To be successful IE must cause *association* and comply with short and long term profitability. IS helps to achieve this because learning towards IE will require much collaboration to facilitate a change in infrastructure and business methods.

Different sectors will require different approaches. For example, the chemical industry could be encouraged to either: implement servicizing; recycle more (this is technically and practically difficult); or shift their feedstock source to a more renewable one, by forming partnerships with agricultural producers (although again not unproblematic, chiefly because of the enormous quantities involved – hence enormous amounts of land – and therefore consumption has to be addressed as well).

IE on a national scale implies that there would need to be fewer imports because materials are internally recycled more. Would this make the economy stronger? Would it jeopardise free trade movements? Surely major restructuring and recycling would create more jobs, fewer imports would be required and the economy would be stronger. However the focus of the economy is based very much on the strength on exports. Will the trend of globalisation be too strong, and thus will recycling also be needed on a global scale. Could recycling itself be major business?

Recent international agreements (such as the Kyoto Protocol) have underlined the fact that sustainability will only be approached with global cooperation, but that these agreements have their own fragility. The globalisation of the world seems to be an unstoppable machine that is reaching the farthest corners of this small planet. Globalisation and free trade, to some, represent the fastest way to overcome the severe poverty that is witnessed in many developing countries. Whether these countries actually wish to 'develop' in the direction of

globalisation (or even change) is often a forgotten issue. To others, globalisation and the continuing drive of capitalism is a frightening and ominous occurrence, epitomized by the enormous powers that corporations have developed.

Jürgensen (2000) applied the idea of a circular industrial metabolism to two modes of development: one based on sustainable development as defined in Agenda 21 and relying on globalised production; the second based on local self-sufficiency and small-scale production methods. What is likely to happen, and needed, is a combination of these two modes with an emphasis on local production. Although the Kyoto Protocol has faced several setbacks, the trend to international cooperation is likely to continue.

Currently business is unsure of the government's strategy on sustainability and generally has a 'wait and see' approach (hence is *reactive* to legislation). If the goal is represented by the industrial ecology vision, then the policy conditions should foster the learning and subsequent innovation needed to evolve towards that state. Conditions need to be aimed at continuing the evolution of learning (continuing on from the trends that have developed in this direction as discussed in Chapter 2, such as JIT, change management and lean manufacturing) to IE, by inducing a cultural change. As has been discussed in Chapter 4, if IE is made central to national policy then it can provide an umbrella strategy for many policies, particularly sustainable development, innovation, clusters and regional development.

The government must make bold decisions, because industry awaits and needs a vision to work towards. Evidence suggests that as has happened in the Netherlands (Wallace, 1995), companies can respond better to governments who make bold but clear policies. Likewise companies that commit more fully to sustainability are more likely to retain their competitiveness (Wallace, 1995; Gouldson & Murphy, 1998; Singh, 2000).

In terms of the LIES model the importance of *assimilation* increases for IS opportunities beyond simple I-O exchanges. Moving from Stage 1 to Stage 3, companies must develop collaborative skills and there is an increasing importance of:

- Top management support
- Management tools
- IE tools (there is a need for these to be developed, e.g. enhanced LCA)
- Innovation – in all aspect, products, process, relationships, culture and services

- Re-conceptualising / re-engineering business, and radical innovation
- Integrating business with sustainable consumption
- Employee ownership
- Open culture that tolerates innovation failures
- ICC – to cope with R&D, innovation; the creation of sub-networks to deal with legislation e.g. EPR take back.

Therefore, drivers that are particularly needed are those that can increase *assimilation* by prompting top management support. The model illustrates that organisations must possess different skills for each stage.

Many of the concepts and techniques discussed throughout this thesis can be integrated into an approach to foster both PBI and IS. The important sub-components of PBI and IS that policy and other drivers should encourage, and the reasons why are given in Table 6.5.2. Policy must initially foster *awareness* and *association* of these factors.

Factor to encourage	IE Component	Reason
Environmental Innovation	PBI/ IS	For sustainable products, processes, infrastructure and relationships
Input-output exchanges	IS	To utilise wastes and foster a change in culture
Co-operation and collaboration	IS	To facilitate integration towards IS and ICC
Industrial Symbiosis Networks	IS	To facilitate and encourage the above
RIES including all stakeholders	IS /PBI	To encourage and help facilitate movement development of Stage 3. Community aspirations, improved overall emissions, greater integration, information and knowledge transfer, sustainable innovation training. For VISION.
Integrated supply chain management	PBI	Efficiency of production chain and encouragement of return flows
Reverse logistics	PBI	For return flows of materials
Business reengineering	PBI	Companies must be encouraged to re-conceptualise their business e.g. by servicizing
Servicizing	PBI	For improved consumption patterns
Sustainable consumption / integrated product policy	PBI/ IS	To foster culture towards limited consumption desires and needs

Table 6.5.2: Factors to encourage for evolution to Stage 3

6.5.3 Developing Policy

Firstly, policy must act to remove barriers to IS and IE, but most importantly must provide the stimulus to implement IS and IE.

Secondly, the overarching aim of policy must be to induce a cultural and behavioural shift to IE activities. Considering Figure 6.2 (showing the influences, drivers and trends on the company, towards IE) and the arguments developed in this thesis, there are a number of trends which policy can build on: industry is already influenced from many angles. Policy must encourage/foster IE from both angles – PBI and IS; a two pronged approach.

Therefore, for IE to prosper, national policy should foster the evolution of (from table 6.5.2):

- Innovation of products, processes, relationships etc
- Industrial symbiosis, networks and RIES
- Encourage Business Re-engineering, Servicizing and Reverse Logistics.

This will be aided by:

- Providing a guiding vision and strategy
- Unifying several policies at regional and national level
- Building on existing projects (such as waste minimisation and energy efficiency) and regional strengths.

Innovation of products, processes, relationships etc

The evidence from this thesis and the literature suggests that there is a need for regulatory flexibility. The tools which provide greatest flexibility are economic and financial instruments (Smith and Skea, 2003). Regulators need to work with industry to provide a flexible implementation and collaboration between industry and government has many advantages. Past research has noted that the regulators role needs to shift from one of regulation to one of information provider and advisor (Wallace, 1995; Harris, 2000; Smith and Skea, 2003). Clayton (1999) and Wallace (1995) cite the example of Dutch approaches in which there is a sense of a 'shared mission' between regulators and regulated. This is again an example of 'ownership' that Capra (2002) refers to, a concept showing its

163

importance in many realms (particularly in stimulating co-operation). Again, there is a need to set goals and facilitate progress towards them rather than being prescriptive about the technologies themselves. Some literature emphasises the importance of creating a tailored regulatory framework (Clayton, 1999; OECD, 1985). Irwin and Hooper (1992) suggest that a combination of a firm disincentive to pollute, with support on technical and organisational issues, could promote the uptake of cleaner technology.

Others argue that focusing on markets is the answer to achieve sustainability (White, 2001; Desroches, 2003). Chief among the calls from these authors is the removal of perverse subsidies and monopolies. Ideally markets should provide price signals that guide choices in the direction of overall sustainability (Desroches, 2003). At least those products that are openly wasteful should receive a tax penalty. Market development for certain materials is currently the task of WRAP and ReMade (as discussed in section 4.5.2.). However, when conditions are made favourable by the correct market and fiscal conditions innovative companies will emerge to exploit these opportunities

Kass, (2000) suggests that radical innovation in environmental technologies is most likely to be stimulated using a portfolio of policy tools (see Table 2.11):

- Technology forcing standards
- Tradable permits
- R&D subsidies
- Networking and 'matchmaking'

Encourage Industrial Symbiosis, Networks and RIES

For IS to prosper regional and local conditions ultimately need to be constructed to:

- Combine strategies and policies – many actors want to foster innovation transfer, IS, sustainability, job creation
- Provide a guiding regional vision and strategy
- Build on regional strengths

The value of a regional approach comes from its manageability and its ability to produce a 'shared mission' or 'community feeling'. A regional IS network can be combined with regional development strategy and should focus on building on regional strengths and existing partnerships. There is scope for several actors to combine resources, thereby giving a more focused and efficient regulation and support to industry. This could include skills development and training, thereby strengthening the skills base of the area.

Successful networks will result from good management and regular meetings to continue momentum from early interest and advertising successes. In the UK the Landfill Tax and CCL are both encouraging moves to IS. It would make sense for eco-taxes such as the Landfill Tax to be recycled back (as Landfill Tax has been) to fostering and aiding industry towards IE by funding IS networks.

The more stakeholders and practitioners involved with IS and especially IE, the more successful they will be (although numbers have to be kept to manageable levels – see Korhonen, 2004). This is conceivably best achieved with the implementation of a Regional Industrial Ecosystem Strategy (RIES).

Combining a RIES with voluntary agreements and regulatory guidance would mean that companies and other stakeholders could work together towards a shared goal of reduced emissions and waste. This could even involve a shift in regulation so that emissions are measured and regulated on a regional basis. A supportive policy framework on integrated products and Producer Responsibility would additionally encourage progress to IE.

Encourage Business Re-engineering, Servicizing and Reverse Logistics

The distinction between radical and incremental innovation is somewhat hazy – especially in reference to organisational innovations such as servicizing. What is radical for one company could be incremental for another. Business re-engineering, servicizing and reverse logistics may well be radical for many companies but, as we have seen, many companies have already dealt with aspects of these concepts.

Smith (2004) argues that the available evidence shows great potential for incremental innovation and suggests that *'continuing with gradualist approaches remains an appropriate course of action'*. Therefore Smith (2004) advocates the government's existing initiatives

such as waste minimisation. It has been argued in this thesis that these initiatives provide platforms to build on towards Stage 3 and they help to prepare companies culturally. Again vision, knowledge transfer and training could help induce these concepts and could be encouraged through an IS network/ RIES, facilitated by the combined actions of the key actors discussed above.

6.6 Chapter Summary

This chapter has utilised the developed LIES model to examine the drivers and barriers to the evolution and learning of IE in the UK. It has examined the company, regional/network and national level to show how this learning can occur concurrently. Indeed, examination of the drivers and barriers suggest that learning must occur concurrently. The chapter ended by making some policy suggestions in order to create favourable conditions for IE to emerge.

The final chapter of this thesis will summarise the lessons of the research.

Chapter 7 Conclusions

7.1 Summary of Conclusions

1. Concentrate on Drivers

- Although there are some specific barriers that are a cause for concern, often it is not one major barrier but a unique combination of smaller barriers that hinder projects. The overarching barrier is culture; and lock-in of technology and infrastructure.

- There appear to be numerous possibilities for synergies that current market conditions do not adequately encourage (from the action research, literature and NISP/ SISP).

- Even where close co-operation has occurred, there are not always adequate drivers to see projects through to completion.

- It is therefore suggested that it is more important to concentrate on drivers to IS and IE.

- In the same respect, tipping the balance in favour of IS/IE will come from a combination of drivers that foster the 4As. The focus should be on providing the correct mix of incentives tailored to industry sectors.

2. Policy needs to be experimental, flexible and adaptive; aimed towards an overall vision of IE.

One of the most important aspects involved in encouraging innovation and sustainable development is the setting of goals. This thesis has argued that the goal should be industrial ecology, and suggested that there is a strong case for the development of RIESs. Policy should also focus on harnessing social momentum by inducing a cultural change of industry and consumers.

3. Foster both IS and PBI as drivers for IE

Figure 6.6 illustrated that there are two interacting paths to IE: the product based approach and industrial symbiosis. Of the two paths to IE it is difficult to say which one is currently

dominant. Both paths, perhaps more appropriately termed *methods,* will need to be implemented by companies for IE to be realised.

There are real limits as to what IS can achieve in terms of progress towards sustainability, especially without product based improvements. IS should only be applied within the overall aim of Stage 3, because without this guidance IS can lead to distortions and produce a negative impact on the overall system. There is therefore a need for research on metrics for the application of IS and LCA tools.

The latest EPR legislation such as WEEE and End-of-Life, have the potential to be the strongest drivers that have so far emerged for PBI. But if manufacturers are allowed to collaborate and collect end-of-life goods as a sector, rather than individually, there may be less incentive to make significant DFE improvements.

		IS Drivers	PBA Drivers
Regulation and legislation have a key role	Awareness	IS Network	Legislation –EPR
	Association	Landfill tax- Economic benefits	Legislation – EPR
Market development is key	Assimilation	Market creation	Market creation
	Application	Market creation	Market creation

Table 7.1: Main drivers in relation to 4As on the company, for the two paths to IE

4. IS Networks are the most significant driver for IS

The main driver for IS (at least potentially) is the implementation of IS Networks, which can uncover synergies which would not have otherwise emerged. There are two interacting paths to Industrial Symbiosis: I-O and ICC.

5. *Association* of key actors is the main driver for IS networks

The main driver for IS Network implementation is *association* of key actors – companies, regional actors (or building on strengths of cooperation and networks; diversity). This is aided by a range of contributory factors that prompt *association.* For example:

    a. Companies – *associate* with: business focus, ownership of problem. *Association* prompted primarily by cost, e.g. through landfill tax.

    b. Regional actors – e.g. network financers - *associate* with: strategies and policies

6. IE can build on many Evolutionary Trends

There are several trends that have been evolving in a supportive direction for IE and which IE can therefore build on: the evolution of industry; management and manufacturing techniques (including outsourcing, ICC etc); organisational structure and culture; and legislation and regulation.

7. IE can build on and potentially unify national policies and strategies from several areas.

Developed appropriately, IE can also provide the vision for sustainability. The particular areas of policy it can bring together are:

- Sustainable Development
- Economic and Regional Development
- Innovation
- Waste, and Resource Productivity
- Clusters, and partnerships

8. IS Networks can build on and unify several local and regional policies and projects.

The policy focus on regional development, waste, networks and partnerships, for economic prosperity was discussed, and parallels drawn with IE and sustainability. Building on this is itself a driver. Waste minimisation and energy efficiency projects can help to lay the cultural foundations for IS/IE. A Regional Industrial Ecology Strategy (symbiosis between EA, RDA, LAs and facilitators) can combine resources (thereby saving resources and company time) and help to increase dialogue to remove barriers; and give feedback to policy makers.

9. There are drivers for IS (Stage 2) but much fewer for IE (Stage 3).

For Stage 2, drivers must be aimed at stimulating top management *association/* commitment and therefore *assimilation* within the business. Whereas for Stage 3, drivers must be aimed at business strategy, and the *association* of top executives' (hence business process re-engineering etc).

10. Simultaneous learning needs to occur at all levels – company, network, region and national – so that barriers are removed and that appropriate drivers are put in place.

For this to occur, policy should foster the evolution of:

- Innovation of products, processes, relationships etc
- Industrial symbiosis, networks and RIES
- Business Re-engineering, Servicizing and Reverse Logistics.

This would be aided by:

- Providing a guiding vision and strategy
- Unifying several policies at regional and national level
- Building on existing projects (such as waste minimisation and energy efficiency) and regional strengths.

7.2 Further Work and Challenges
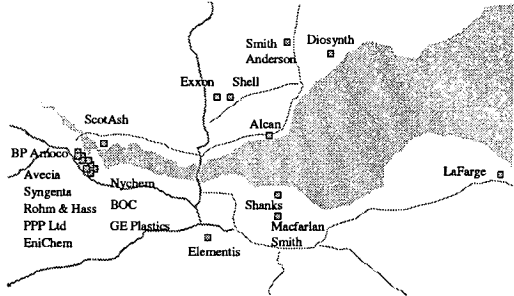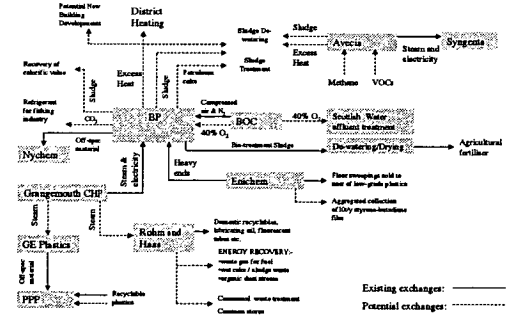
1. **Industrial Ecology / Symbiosis and SMEs** – a large fraction of the sustainability challenge lies in the hands of SMEs. The majority of the IE research (and the examples of its application) has involved larger companies. The role of IS and IE for SMEs and how they *associate* with them, needs much greater exploration

2. **RIES** – there is need for further research (and experimentation) on the potential of regional industrial ecology strategies to help facilitate the next level beyond IS.

3. **Cross sector research** – there is vast potential for IS/IE to achieve sustainable improvements by facilitating cross-sector projects. A simple example is again greenhouses, perhaps run by the agricultural sector utilising heat from chemical companies or power stations.

4. **Innovation in IS Networks** - the link between IS/IE and innovation – what is IS/IE's potential to stimulate sustainable innovation?

5. **Coalesce lessons from related fields** – bringing together lessons from other fields should be a primary task of the field, to avoid reinventing the wheel.

6. **Metrics** – IS needs to be applied within a framework that has the specific aim of IE. Consequently there is a need for easy to use applied LCA techniques and metrics that can guide companies and IS facilitators as to which opportunities are favourable.

Appendix

Presentation for the Scottish Industrial Symbiosis Programme Launch:

18th March 2003

Industrial Symbiosis Network in the Forth Valley

Industrial Symbiosis (IS) Research Programme (2000-3)

- Research Programme Overall Aim
  - Explore barriers and drivers to IS in the UK, analyse how conditions can be improved to foster IS

- Scoping Study Aims:
  1. Identify existing and potential IS examples,
  2. Identify major players and facilitators
  3. Demonstrate potential for IS network

- Develop Case Studies

Zero Emissions Scoping Study

- Identified Companies from IPC List

- Simple Method- explain ZE philosophy
  - discuss by-products, wastes, other outputs and potential inputs
  - discuss other potential projects, i.e. other forms of collaboration

---

Forth Valley Area of Research

Grangemouth: Existing and Potential IS Examples

Grangemouth

- Chemical Companies- material flow experts
- BP
  - Propylene
  - Waste polymer - landfill disposal to product
  - Sulphur
  - Benzene
  - Xylenes
- Grangemouth Development Group
  - major companies, Falkirk Council, Scottish Enterprise, Forth Ports and SEPA

Grangemouth Water Users Group (GWUG)

- BP, Avecia, Enichem, NEL, British Waterways, SEPA, Scottish Water, Ondeo Nalco, JWEC Ltd, and 2 PhD students
- 70 Ml/day costing £11.5m /year
- Grangemouth Water Users Group
  - "1999 was a good time for a group like GWUG to come into existence in the area and recent legislative developments have reinforced the value of the GWUG initiative since its inception"

Project Benefits of GWUG

- Fresh Look at Operations

- Partnership

- Information Exchange

- Technical Knowledge

Forth Valley: Existing and Potential IS Examples

Existing exchanges: ————
Potential exchanges: ------------
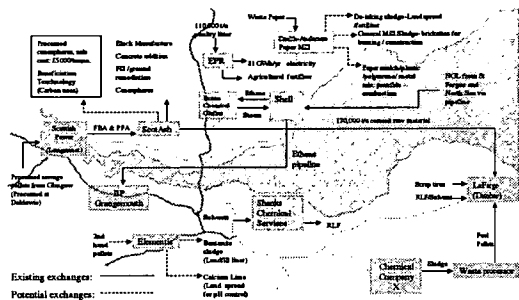
Conclusions

- Potential and Existing Exchanges
- Transfer of Information, Innovation and Best Practice
- Benefits of Inter company Co operation
- Working With Others

- The limits are......
  ...... the imagination

Next Steps

- Develop Case Studies (Mar 03 - Aug 03)
  - work closely with companies and Thirdwave to find potential symbiosis projects
  - explore the IS opportunities
  - examine how adopting the IS approach could benefit the company

- Publish Report- website

The real act of discovery consists not in finding new lands...

... but in seeing with new eyes

Appendix II

Industrial ecology as a learning process in business strategy

Steve Harris * and Colin Pritchard **

Abstract

Creating the ideal conditions to foster industrial ecology will require an understanding of the interactions at many system levels (e.g. company, region, country). It will also require the removal of barriers, and the development of a holistic systems outlook and approach, among many actors/practitioners in industrial society. At the company level, those that survive the increasing pressure from markets and legislation will be those that are flexible and adaptive – in a word – innovative.

This paper adapts the technology transfer model developed by Seaton and Cordey-Hayes (1993) and combines it with the idea of industrial ecology as a learning process. The resulting model is applied at the company, network and government level to help understand how IE can be viewed as a learning process.

The paper draws on research into regional industrial symbiosis in Scotland to illustrate how the approach can be used to understand the dynamics of the learning process. It also uses examples from the recently formed (UK) National Industrial Symbiosis Programme and the Scottish Industrial Symbiosis Programme. The importance of fostering inter-company co-operation within a region, building on previous partnerships, and involving a range of actors, is highlighted.

1. Introduction

How does industrial society implement the compelling concept of industrial ecology? This question is central to this paper. As with sustainability, industrial ecology (IE) has struggled to find an exact definition, but what Welford [1] asserts about sustainability is equally true of IE: '*There exists a strange and fruitless search for a single definition amongst people who do not fully understand that we are really talking here of a process rather than a tangible outcome*'. In this paper we view IE as an evolutionary and a learning process with the aim of equilibrium between the industrial and natural systems, achieved by the design of smarter sub-processes within the anthropogenic system that imitate (and integrate with) the cyclical eco-systems in nature.

Assimilating IE (beyond input-output matches) into business operations will require a high degree of innovation and hence knowledge and technology transfer. We adapt and explore the usefulness of a technology transfer model, for the development of IE, developed by Seaton and Cordey-Hayes [2] (and later Trott et al [3]). The models' main components of interest are: *awareness, association, assimilation and application* of technology transfer. At the company level, the adapted framework offers a way to help understand the complex nature of inward technology transfer

and knowledge accumulation, and thus processes needed for IE development. It is also a helpful way to understand the many relationships, markets, processes and interactions that occur in a regional industrial ecosystem.

According to Graedel and Allenby the goal of industrial ecology is for the anthropogenic system to mimic the 'Type III system' (an effectively closed system but for the input of solar energy, with virtually 100% recycling) seen in nature [4]. In nature '*biological ecosystems have evolved over the long term to be almost completely cyclical, with "resources" and "waste" being undefined, because [what is] waste to one component of the system represents resources to another*' [4]. By viewing industrial ecology as a process with the ultimate aim represented by the Type III model, we can postulate certain stages in its evolution. A concept of relevance here is that of single, double and triple loop learning [5]. Snell and Chak [6] provide concise definitions for this type of looped learning: "*It is single-loop when they [group members] make simple adaptive responses. It is double loop when members begin to see things in totally new ways, e.g. changing their views of their roles, of the business or the business environment. Triple loop individual learning entails members developing new processes or methodologies for arriving at such reframing.*"

For IE to be realised, many entities will have to learn new methods and tools, and undergo a cultural shift. Chief among those actors is industry. The role of industry in sustainable development is often ignored: '*On the contrary, the role of industry is central in how we address the environmental crisis. Industry is a much larger part of the problem than is normally recognised and can take much more a part of the solutions than it has been allotted. If what we are trying to do is manage the impact humankind has on the environment, then it is industry that we find fault and hope* [7]*'.*

In industry we perceive three stages of movement to IE:
                Stage 1: Input-output (or waste utilisation)
                Stage 2: Industrial Symbiosis
                Stage 3: Industrial Ecology

This is not a flawless (or perhaps entirely original) proposal and there is some overlap between the stages – but as we will show it presents a useful framework particularly when used alongside the technology transfer model. In some industries Stage 1 has been implemented for decades. It is however, still the part of Industrial Ecology most touted in industrial ecology projects around the world. This is because it is the stage with the most obvious benefits, and the stage most immediately attractive to business.

The term industrial symbiosis (IS) was originally coined by Valdemar Christensen, a manager at Kalundborg; Denmark and according to him is: '*a cooperation between different industries by which the presence of each… increases the viability of the other(s), and by which the demands [of] society for resource savings and environmental protection are considered*' [8].

The biological definition of 'symbiosis' is '*The living together in more or less imitative association or even close union of two dissimilar organisms*' [9]. But it is sometimes used as an umbrella term to cover three distinct types of inter-species relationship: *parasitism*, where one organism benefits from the relationship to the detriment of the other organism(s) involved; *commensalism*, where one organism benefits with no significant detriment or benefit to the other organism(s); and *mutualism*, where both

(all) species benefit from the relationship [10]. This seems to cover most business relationships! Interestingly, symbiosis has been developed as a third avenue of evolution, in the theory of 'symbiogenesis'. This theory sees the creation of new forms of life through permanent symbiotic arrangements as the principal avenue of evolution for all higher organisms. This echoes a possibly fundamental lesson for businesses who wish to survive: they must develop co-operative relationships.

Industrial symbiosis is commonly viewed as the inter-company sub-level of more the encompassing industrial ecology as shown in Figure 1 [11]. It 'involves the physical exchange of materials, energy, water and by-products among several organisations' [12].
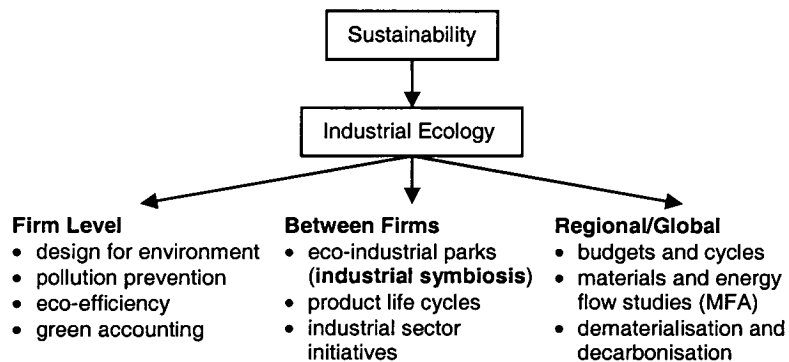
Figure 1: The elements of industrial ecology seen as operating at different levels.

An industry's move to industrial symbiosis (Stage 2) is therefore marked by increasing amounts of inter-company co-operation (ICC) and looking beyond company boundaries for improvement opportunities and inspiration.

Stage 3 is the most difficult and contentious to try to define. Achieving the step from Stage 2 to 3 is likely to consist of increasingly integrated *industrial ecosystems* According to Frosch and Gallopoulus: '*The industrial ecosystem would function as an analogue of biological ecosystems (plants synthesize nutrients that feed herbivores, which in turn feed a chain of carnivores whose wastes and bodies eventually feed further generations of plants.*'[13]) This move would be evidenced by increasing resource productivity, servicizing,[1] and extensive return flows from consumers.

The forming of eco-industrial parks, regional industrial ecosystems or industrial symbiosis networks has largely been seen as the path to industrial ecology [14,15,16] (This path should be complimented by product-based systems analysis, involving concepts such as life-cycle analysis [17]). There have been many projects worldwide that have attempted to achieve some of the exchanges and savings that have been achieved in Kalundborg. The projects can be viewed as the first attempts of achieving Stage 2 by implementing Stage 1. For various reasons, (perhaps including the brief history) only limited results have been achieved and to the authors' knowledge no project has yet touched on the wider IE model. For some this is perhaps a sign that other models should be sought [18]. However this ignores the

---

[1] Servicizing is also known as 'systemic dematerialisation' – the strategy of service economy, which promotes the selling of services instead of products.

enormous complexities involved, and more importantly the time needed in such a learning process. Ehrenfeld and Chertow [12] attested that "even explaining industrial symbiosis – the educational component – is arduous because industrial symbiosis is not 'business as usual', and requires significant change to traditional individualist mental models". The step to industrial ecology is even tougher, requiring a combination of measures aimed at both the internal company system (for example organisational learning structures, concurrent engineering and environmental management systems) and the external system (regulations and taxes).

2. The Technology Transfer Model

Seaton and Cordey-Hayes [2] view technology transfer as: *'the process of promoting technical innovation through the transfer of ideas, knowledge, devices and artefacts from leading edge companies, R&D organisations and academic research to more general and effective application in industry and commerce'*. They noted that in the UK there was a preoccupation with: creating new technologies; making technology available; increasing information about what is available; and facilitating transactions between supplier and potential user. Hence technology transfer in the UK was seen to be dominated by the two preoccupations of:

- *Accessibility:* the level of technology knowledge and the availability of related information
- *Mobility:* the ease of obtaining this technology knowledge and the appropriate channels through which technologies are transferred (eg intermediaries, people movements, networks, partnering)

These are important considerations, but Seaton and Cordey-Hayes noted that there was less thought on the difficulties of exploitation of new technologies within companies. For inward technology transfer to be successful: *'an organisation must have not only the ability to acquire but also the ability to assimilate and apply ideas, knowledge, devices and artefacts'* [2]. The 'process' view of technology transfer is concerned with creating or raising the capability for innovation. Hence the organisation and the individuals within it must have the capability to: scan for and recognise the value of ideas, knowledge devices and artefacts which are new to the organisation; communicate these; assimilate them within the organisation; and apply them for effectiveness or for competitive advantage.

Within an organisation, Seaton and Cordey-Hayes noted that there is a need for:

- the technical functions (such as product development, R&D, manufacturing, engineering, training and management information systems (MIS)) both to support current business priorities and also to create new opportunities;
- such integrated functions to be part of well-designed external and internal networks;
- the development of employees so that they are capable of comprehending and functioning effectively within such activities; and
- the development of managers capable of shaping organisations to achieve these opportunities.

This lead to the creation of the next component of the model:

- *Receptivity:* an organisation's overall ability to be aware of, to identify with and to take effective advantage of technology. Other authors have described this component as 'absorptive capacity' [19].

These three ideas: accessibility, mobility and receptivity, serve as a framework for a process view of technology transfer and a simple conceptual device that emphasises the company perspective. The concept of *receptivity* was later extended to consist of *awareness, association, assimilation and application* [3]. The framework attempts to illustrate technology transfer more realistically as a series of interacting sub-processes, rather than a simple one-off transaction or decision process. The transfer process is broken down into a series of sub-processes as shown in Figure 2. Successful innovative companies must therefore function well in all four stages within the process of receptivity, which are described in Table 2.1.
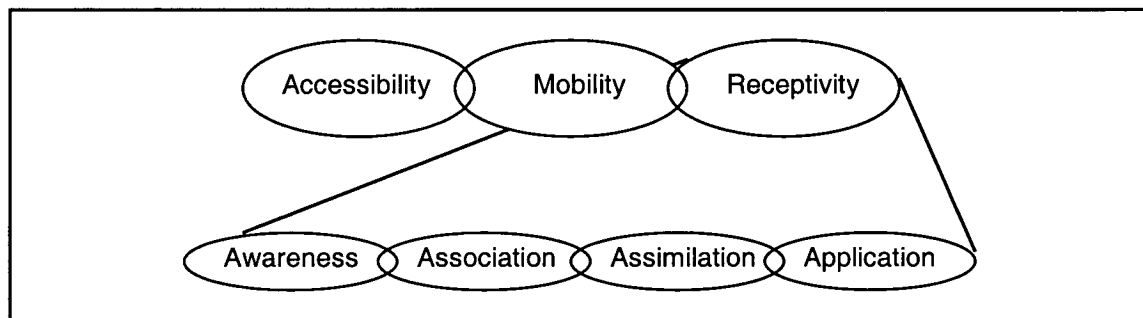
Figure 2.1: Conceptual framework of technology transfer and inward technology transfer (source [3]).

Activity	Process
Awareness	The processes by which an organisation scans for and discovers what information on technology is available
Association	The processes by which an organisation recognises the value of this technology (ideas) for the organisation
Assimilation	The processes by which an organisation communicates these ideas within the organisation and creates genuine business opportunities
Application	The processes by which an organisation applies this technology for competitive advantage

Table 2.1: The "4A" conceptual framework of technology transfer (source [3]).

3. Combining the Technology Transfer Model with the Context of the Learning Process

The overall framework produced by combining the technology transfer model with the concept of three stages of learning is shown in Figure 3.1.

Stage 1
Input-output

Stage 2
Industrial symbiosis

Stage 3
Industrial ecology

Accessibility

Mobility

Awareness — Awareness — Awareness

Association — Association — Association

Assimilation — Assimilation — Assimilation

Application — Application — Application

LEARNING OCCURS WITH TIME ------▶
Consideration of other IS/ IE projects, joint ventures, etc.
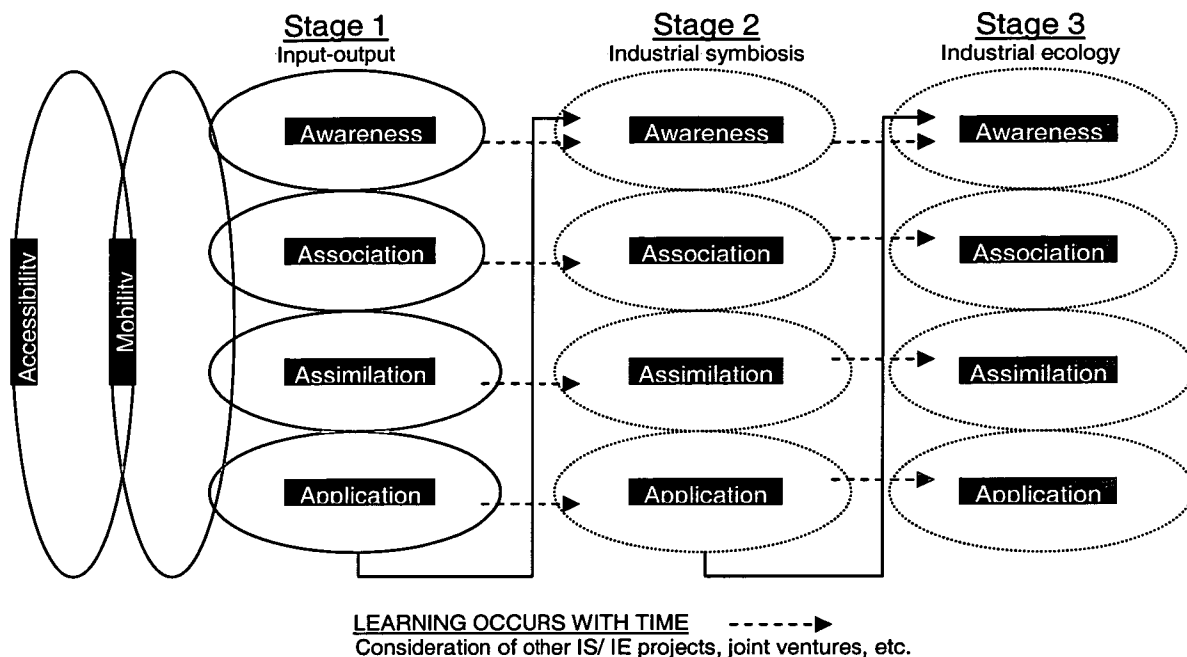
Figure 3.1: The learning process of industrial ecology (developed from [3]).

Each stage is viewed as a process (although the learning cycle for a company or actor may not necessarily begin with Stage 1) moving from awareness to application. As with the original 4A model, the process should not be seen as linear but as a series of interacting sub-processes. Moving from Stage 1 through to Stage 3 will require increasing amounts of innovation (of products, processes and company culture) and increasing amounts of ICC. This section examines the processes involved at three levels: the company, network and finally government. The main application of the model is in helping to understand how actors can become *aware* of IS/IE possibilities, *associate* it with their objectives and/or operations, *assimilate* it and then proceed with the *application*.

3.1 Company Level

3.1.1 Awareness

This can be described as the process by which an organisation discovers the concept of IS, an existing IS network or an application of IS for the company. As shown in Table 3.1.1 companies have a wide variety of sources that provide *accessibility and mobility* from which they gain knowledge and information. At this level, business support can be one of the prime movers.

Journals	Visits to other companies	Trade associations / competitors
Information scientists	Internal meetings	Competitor analysis
Internet and email lists	Internal business reports	Meetings with suppliers
Browsing in the library	Social friends	Consultants / consultants' reports
Conferences & exhibitions	Meetings/visits with/ to customers	Patent departments
Company accounts	Academic contacts	Government departments

Table 3.1.1 Examples of possible information sources of companies (adapted from[3])

180

The business support community have an important intermediary role. Some support organisations operate on a regional basis: Local Learning and Skills Councils, Regional Development Agencies (RDAs) (in Scotland the role of both of these is performed by Local Enterprise Companies (LECs)), Chambers of Commerce and regional innovation and technology centres. Trade associations give support and representation to individual industries whilst individuals' membership of professional institutions can bring information into companies. Business support is often on a commercial basis. Universities are developing increasing commercial focus and industrial contacts. Research and Technology Organisations (RTOs) concentrate on commercially applicable research, and are potentially even closer to industry. All of these organisations act as information providers to companies and provide companies with services and/or expertise [3]. The awareness and attitude towards IS/IE of these intermediaries is therefore extremely important.

Awareness can change over time, not only because the information channels have become improved, but also because the ability to associate, and therefore become *aware* of the association will improve.

3.1.2 Association

"Association" implies that *inter-company co-operation* is significant, therefore it is easiest for those companies that have larger waste volumes (or for those that want to accept waste or spare heat capacity). To move beyond this stage requires a high degree of inter-company co-operation. Cohen-Rosenthal [20] expressed this compellingly relating to Kalundborg:

"Most observers, while impressed with their [energy and by-product exchanges] effect, have difficulty in seeing how to replicate this icon [Kalundborg] of industrial ecology in their own situation. That is because the focus is on the wrong end: it is not just about waste heat and materials, it is about the co-operation among firms to support symbiosis and integration into their own business operations. It changes the way they do business"

In the UK inter-organisational relationships (IORs) are becoming increasingly common and these prepare the ground for IS initiatives. According to Barringer and Harrison [21] the six forms of 'inter-organisational relationships' (IORs) most commonly pursued are: *joint ventures, networks, consortia, alliances, trade associations, and inter-locking directorates.* Barringer and Harrison also examined six widely used paradigms to explain IORs (*transaction costs economics, resource dependency, strategic choice, stakeholder theory, organisational learning and institutional theory)* and found that, whilst each was useful, each is also insufficient to capture the complexities involved in relationship formation. Rather than just one reason for the formation of alliances, firms tend to have a portfolio of reasons such as cost minimisation, risk sharing and learning. Supply chain management and outsourcing are becoming increasingly common [22] (arguably almost complete in some industries). The significance and advantages of clusters [2] has also been widely reported [22].

---

[2] Clusters are geographically proximate groups of interconnected companies, suppliers, service providers and associated institutions in a particular field, linked by commonalities and complementarities [23].

3.1.3 Assimilation

'The real act of discovery consists not in finding new lands but in seeing with new eyes' Marcel Proust

Assimilation can be described as the process by which an organisation communicates the concept of industrial ecology/symbiosis <u>within</u> the organisation and thereby creates business opportunities. IS/IE projects with obvious financial benefits will be more easily assimilated into the company. Moving to other ICCs will require companies to have a greater understanding of the IE concept and the necessary skills, particularly internal and external collaboration.

The implementation of IE will require increasing amounts of innovation. Similarly it has been shown that innovation is the key to a successful response to environmental legislation [23]; and that certain organisational characteristics facilitate innovation and are shared by technically progressive firms [24]. These same factors would foster technology transfer and therefore IE and are listed in Table 3.1.3 [25].

High quality of incoming communication	Use of management techniques
A readiness to look outside the firm	An awareness of costs and profits
A willingness to share knowledge	Identification of the outcomes of investment decisions
A willingness to take on new knowledge, to license and to enter joint ventures	Good-quality intermediate management
Effective internal communication and co-ordination mechanisms	High status of science and technology on the board of directors
A deliberate survey of potential ideas	High quality chief executives
A high rate of expansion	

Table 3.1.3: Characteristics of innovative companies that facilitate innovation (source [25]).

Manufacturing and management techniques have undergone an evolution in the drive to increase productivity and improve competitiveness[3]. Some of the characteristics of these philosophies are potentially conducive for innovation to IE: removal of hierarchical levels, employee ownership (that can refer to employee ownership of stock and shares, but also to increased decision making empowerment of employees), and increasing communication between departments. Further evolution of this trend is already apparent in some firms, where employees are encouraged to engage with the community beyond their firms [26]. The importance of a well-trained workforce, inter-company co-operation, and sustainable business practices, for increasing competitiveness and innovation has also been recognised [27,28]. Companies that have adopted these techniques are likely to be better prepared for integration of the IS concept into operations.

---

[3] For example: Just-In-Time (JIT) or "lean manufacturing" (which emphases the elimination of waste by cutting inventory and removing delays in operations [3]); Total Quality Management (TQM) (with an emphasis on zero defects and the philosophy of continuous improvements, based on the belief that virtually any aspect of an operation can be improved and that the people most closely associated with an operation are in the best position to identify the changes that should be made.) and concurrent engineering based on increasing communication between departments and including all departments in the design processes

3.1.4 Application

Application is the process by which an organisation applies the concept of IS/IE for competitive advantage. Application may evolve from executing input-output matches, through other ICCs, to basing the whole business strategy on the concept IE. This may require completing redesigning the business by, for example, making the business a service and/or employing reverse logistics (return flows from the consumer). Application will also involve performing feasibility studies and removing barriers.

3.2 Using the Model to Illustrate Eco-Industrial Networks as Learning Networks

Organisational networks may also be considered as 'learning organisations' [20]. Whether the network is a regional industrial symbiosis programme or an eco-industrial park (such as that of Burnside Industrial Park in Canada [29]), the process of learning and moving to industrial ecology can be illustrated as in Figure 3.2.

Stage 1	Stage 2	Stage 3
Input-output	Industrial symbiosis	Industrial ecology

Awareness — Workshops, Meetings, Software → Further opportunities, partnerships are identified → Regional IE strategy, Identification of new: Technologies, methods & tools, New ways of business

Association — Input-output Matches found, Potential partners identified → New members of network are identified and benefits highlighted → New technologies and methods are applicable to network members

Assimilation — Get corresponding parties to meet and discuss → Get corresponding parties to meet and discuss → Use of: • New technologies • Methods • Tools e.g. LCA

Application — Feasibility studies, Remove barriers → Target Setting, Provide training to company employees e.g: collaboration skills → Training for: "Change management" "Business re-engineering" Innovation and entrepreneurial skills

(Accessibility / Mobility)

LEARNING OCCURS WITH TIME ----▶

Figure 3.2: Industrial ecology learning process in a network (developed from [3]).

Accessibility can be provided by academia, research and case studies; and *mobility* is provided by a range of intermediaries. The network facilitator (such as a regional development body, a purposely appointed organisation, or local champion) can raise awareness through workshops and other marketing and find matches using software and personal knowledge of companies. The facilitator also has an awareness and association, and will perhaps be more inclined to concentrate on those projects which are associated with network targets (e.g. the inclusion of a predefined number of companies into the network or reduction in a certain quantity of waste). The setting of targets can be a motivating factor but also a limiting one (see section 4.2). Universities could help with the assimilation stage by using their research skills in

their areas of expertise such as chemical engineering or management research. Facilitators can help with highlighting benefits of the exchange. Application would largely be left to the companies, but networks that may include influential organisations, could help remove any barriers (such as legislative barriers, e.g. the liability involved in the 'waste' label). Successful exchanges would then be presented at network meetings potentially encouraging more and building on the learning of the network. Building on the successes is where the network will start to learn and begin to function as a 'learning organisation'.

The prime objective of networks should be to foster the necessary learning that aids the move to Stage 3 of the model. When developing a regional project there is a danger of placing too much emphasis on the most readily assimilated Stage 1, and input-output matches. Esty and Porter [30] noted that *'Because IE focuses attention on materials and energy flows it may not optimise other variables that contribute to competitiveness within the corporate sector'*. Placing too much emphasis on input-output matches can isolate some companies (*disassociate* them from the network) and runs the risk of the network becoming a glorified waste exchange service. Ideally, a project needs to appeal to a wide audience and not just to companies with large volumes of waste. As in natural systems stability and opportunities for symbiosis will be improved by diversity. Diversity (along with roundput, locality and gradual change) represents one of the four principles for industrial development proposed by Korhonen [31]. Regional IS projects therefore need to increase the possibility of companies associating their operations with IS. This can be done by providing a range of examples that highlight the similarities between existing *inter-company co-operation* (particularly those from the same region) and IS. Cohen-Rosenthal [20] provides an extensive list of possible areas of 'eco-industrial networking'. Perhaps the best way is to target sectors or individual companies, as Cohen-Rosenthal writes:

'My rule is that, if industrial ecology is to be accepted by corporations, it must have a significant and measurable impact on the top three to five drivers for organizational success. If market image is the major concern, then the industrial ecology strategy must address that issue. The same holds true for cost leadership, product innovation, risk management, quality, market access, reliability of supply chain, customer core requirements and so on. Although a value-based commitment to environmental stewardship is welcome, even in those situations the particular industrial ecology strategies must demonstrate a difference in the success of the organization. If it doesn't, commitment will wither quickly and , more importantly, opportunities to make a real difference will be overlooked or dismissed' [20].

Practitioners can view those companies who reject IE as not yet ready for the concept (not having the ability to associate and assimilate) or as companies who will cease to exist under future competitive and legislative conditions. For many companies (particularly SMEs, who generally have fewer resources to cope) there is a need for more awareness-raising and there is an advantage of running waste minimisation or energy efficiency projects before the attempted introduction of IS. As the innovation web-site of the UK government states:

"Any attempt to push forward to new ways before the people are ready to assimilate and believe in them could result in severe distortions to the organisation's culture" [32].

A regional IE network has the potential to provide an umbrella for any sustainability or resource efficiency initiatives in the area. In a country such as the UK IS/IE networks can potentially see much closer integration between the facilitators, the RDA, and the Environment Agency. This closer integration could help combine tasks and goals and free up further funding that would build on the success of the network and provide ongoing training to company employees. This would provide the skills necessary for companies to function successfully in the network. As the network strengthens, a wider variety of stakeholders (such as local environmental groups, community groups) may join and the network could begin functioning as a regional industrial eco-system.

3.3 Industrial Ecology as a Learning Process at the Government Level

For IE to be successful as a concept it must be adopted not only as business strategy but also as government policy. Figure 3.3 uses the analogies developed earlier to illustrate how a national government may take onboard the concept of industrial ecology. It demonstrates how industrial ecology could provide an umbrella for the many pressures on and policies of governments. Industrial ecology may provide the framework to facilitate the 'joined-up thinking' that many request from government.
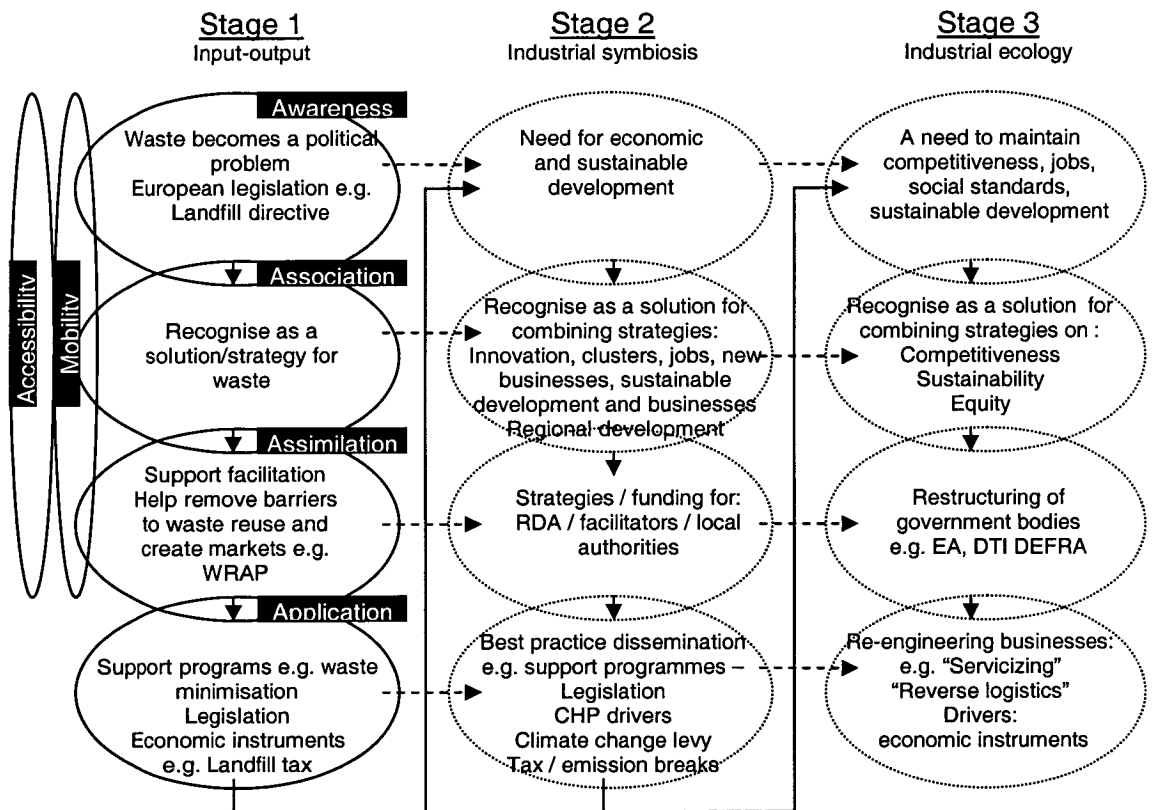

Figure 3.3: A possible learning process for national governments (developed from [3]).

4. Evolution and Learning in the UK

In the UK the concept of sustainable development is receiving increasing attention, with an increasing focus from the UK government. Due to the UK's small size, and pressure from European directives, there is a particular focus on the waste issue and resource productivity at present [33]. In addition there has been recent government recognition of industrial symbiosis [34]. There is also government support for energy efficiency (e.g. Envirowise [35]), a push towards supporting innovation, and an attempt to link good business sense with sustainability. Describing a competitive company, the government's Department of Environment Transport and Regions said:

'A sustainable business is on the leading edge of responding to forces for change, anticipates pressures on its supply chain, and on resource use, the needs and expectations of its customers, investors, employees and the community in which it operates. – The more efficient and competitive businesses will be those who have an eye on the 'triple bottom line', focusing not only on the economic value that they add, but also on environmental and social value added or destroyed' [36].

In terms of laying the foundations for industrial symbiosis (i.e. aiding association) there have been some noted successes with waste minimisation clubs [27,35,37] but fewer than 0.1% of UK companies have undergone successful waste minimisation training through clubs [27]. In the last 10 years, the annual participation rates of waste minimisation projects ranged between a modest 10 to 60 companies. But a recent project in West Sussex, achieved the participation of 308 companies [26], indicating that either marketing has improved, changing conditions are leading companies to take more notice of the waste issue, and/or facilitators are more knowledgeable and efficient. It was noted that, for some companies, involvement in the project seemed to produce a cultural and attitudinal shift towards environmental improvement. This is also likely to be the case for IS. As illustrated above, certain companies are better prepared for IS. However, from the other angle, IS can help develop a cultural change in the company that would be complimentary to competitiveness.

The next two sections will examine two cases from the UK and frame them within the context of the model. The cases were chosen from ongoing PhD research to help illustrate the usefulness of the framework. In addition, they demonstrate some of the exchanges commonly found in the UK, and the IORs that are increasingly common. Firstly we will discuss results of a study conducted in the Forth Valley region of Scotland which examined existing and potential exchanges, before moving on to discuss the recently formed National Industrial Symbiosis Programme instigated by BCSD-UK.

4.1 Forth Valley Research

As part of the PhD research we conducted a study of existing and potential IS exchanges in the Forth Valley, an area incorporating Edinburgh and Grangemouth. Grangemouth is the largest industrial complex in the region and consists predominately of petrochemical and chemical companies. In addition the Forth

Valley includes four large power generation sites, including the second largest coal fired power station in the UK and the only cement works in Scotland.

4.1.1 Grangemouth

Awareness and Association at Grangemouth

Companies in this area were highly receptive to the research and to the concept of industrial symbiosis. For the chemical industry, *association* to Stage 1 is relatively easy because finding uses for by-products has for decades been part of good business. At Grangemouth, Stage 2 has also been evolving for at least the last ten years, through the activity of Grangemouth Development Group (GDG). GDG is an organisation formed in 1992 and consists of the major companies at Grangemouth, the Local Enterprise Council, Forth Ports, and Falkirk District Council. Meetings held every three to six months allow members to present and discuss ideas with the primary aim of improving the competitiveness of the local chemical industry and creating further jobs. Some of the existing and potential exchanges that were discovered are shown in Figure 4.1.1. The reasons for the high level of association and for the continuing work can be identified as:

- Large waste volumes
- All companies had an environmental manager whose role and importance within the companies has significantly increased in recent years
- Growing awareness of sustainability issues through trade associations (e.g. Chemical Industries Association), legislation, news, media.
- Public and community pressure – the companies have close proximity to local housing and need to maintain good relations
- Landfill tax increasing to £35 /tonne
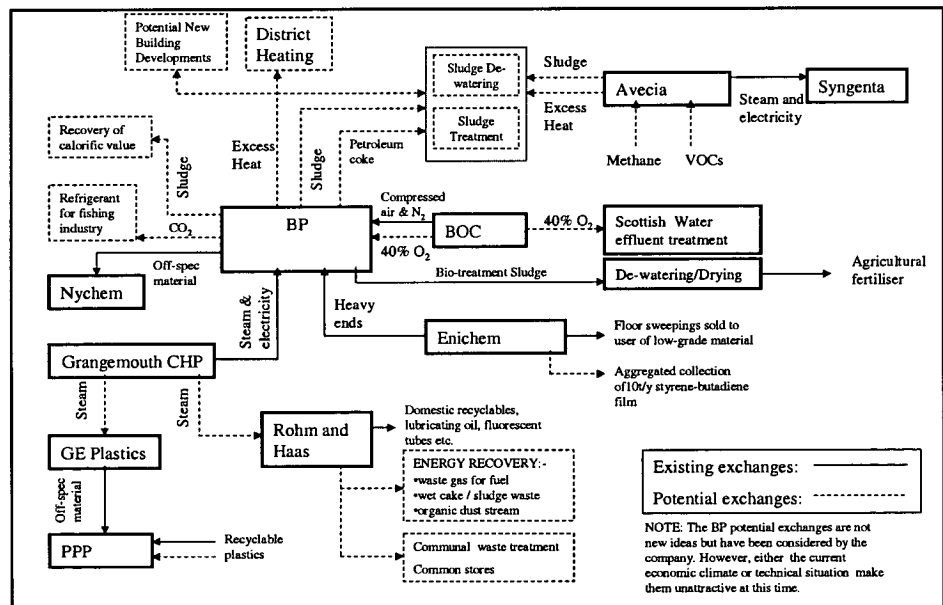- Increasing international competition.

Figure 4.1.1: Examples of Existing and Potential Exchanges in Grangemouth

GDG are attempting to attract more companies to the area by offering brownfield sites that are already covered by CIMAH (major accident hazard) approvals, and which have utilities such as steam, electricity, water and waste handling laid on. GDG's R&D and analytical labs would also be available on site, as would other central services, such as warehousing and emergency services, medical and canteen facilities. As was discussed earlier, training of employees will be an integral part of the move to sustainability and the fact that GDG is supporting a Technician Training Centre of Excellence is further evidence that the area is evolving favourably. Another example of growing ICC in the area is demonstrated by Polymeri Europa UK who have agreed a contract with an outside organisation to operate the utilities, and another to operate the packing area. They are also planning to work with a third party to treat and recycle water onsite.

A CHP plant has recently been built in the area with the intention of supplying the local companies with steam and power. Several are in the process of considering its viability but one company's intention of having this supply was met with stiff opposition. In this case there was a requirement to build a steam pipeline across a public highway, which saw much public opposition due to a recent accident involving a member of the general public. This is an example of how public fear can jeopardise sound environmental improvements.

The process involved in decision making can be illustrated using the technology transfer model as shown in Figure 4.1.2. The figure illustrates how the:
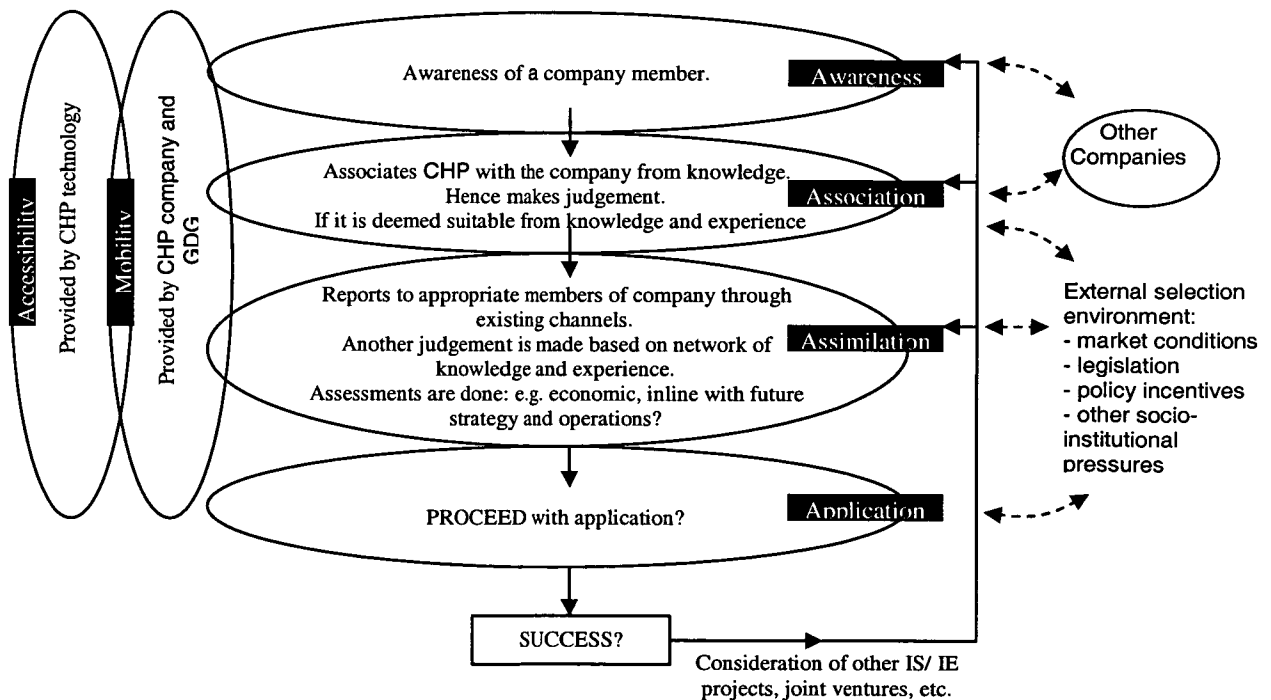

Figure 4.1.2: The process of CHP consideration and implementation

- *Accessibility* is provided by the wide availability of knowledge on CHP and related information, helped by a strong UK government initiative.
- *Mobility*, in this case is chiefly provided by the CHP company and GDG.
- *Assimilation* success is dependant on many factors within the company that were discussed above and by consideration of external criteria, such as market conditions and legislation.
- Successful implementation will lead to consideration of other projects and potentially an increased pace of the learning process.

Another project to emerge from the GDG partnership is research into district heating that involved a local petrochemical company and the local Council. The main driver for this project was the Council's desire to reduce fuel poverty and improve social conditions by providing cheaper heating. The biggest barriers to the project are:
- the capital cost of the distribution network
- plant changes leading to uncertainties about the amount of excess low pressure steam available.

A further example of inter-company co-operation in the area is the recently formed Grangemouth Water Users Group (GWUG). The group was formed in 1999 to explore opportunities for a more sustainable use of water in Grangemouth. The groups main members were: BP, Avecia, Enichem, NEL, British Waterways, Scottish Environmental Protection Agency, Scottish Water, Ondeo Nalco and JWEC Ltd. The main aim was to reduce the 71 million litres of potable water used per day, which cost £11.5 million per year. The benefits shown below were highlighted in a recent report [38] and are typical of inter-company projects:

- A fresh look at company operations, identifying many cost-saving opportunities
- Security of partnership – and improved relations between companies and with SEPA
- Information exchange – examination of Best Available Techniques; open and honest dialogue leading to better understanding of the situation
- Technical Knowledge – useful information was gathered for continuing research and identification of cost saving opportunities
- Experimental results – of fouling studies for heat exchangers
- Savings arise not only from reduced supply costs but also from reduced treatment costs
- Reduction or elimination of the need for future infrastructure development by Scottish Water
- British Waterways will generate income and ensure the ongoing development of the canal system

Overall, the projects discussed above reveal a definitive trend in the formation of inter-company projects that allow companies to investigate problems more effectively together and reduce the costs and risks. The projects reveal a "snowball effect" that drives the company culture towards further co-operation and outsourcing, at a time of increasing competitiveness. Whilst the chemical industry may be beginning to function well within the context of Stage 1 and 2 it is more difficult to envisage how it will move towards Stage 3. Whilst the chemical industry is keen for others to take their by-products, they are less keen, and currently less able, to accept inputs. This is mainly due to purity and liability considerations.

189

As with most other industries profits are based on maximising sales and there is therefore no incentive to address the sustainable consumption factor. A medium term solution would be that of 'servicizing' based on a partnership approach between customer and supplier. The aim is to increase the efficiency of chemical use and where possible recover the chemical at the end of its lifecycle. BP Castrol, for instance, provides total fluid management services to UK Airbus' maintenance department [39]. The model of chemical management services developed steadily in North America in the 1990's, where an aerospace company saved over $1 million in the first year by consolidating chemical purchasing and management and reducing its spend on waste treatment [40]. One example was found in the Forth Valley area of a chemical recycling company that is attempting to offer more of a service but the uptake of the concept has been slow in the UK [39,41].

4.1.2 The Forth Valley Area

Awareness and Association in the Forth Valley

Again, companies were highly receptive to the research and to the concept of IS. The reasons for this are similar to those discussed above they include: increasing legislation (and the perception of increasingly stringent legislation), growing sustainability awareness, and increasing use of EMSs. The region has experienced increasing numbers of waste minimisation and resource efficiency projects, which can aid the ability of companies to associate with emerging concepts such as IS. Some of these projects have produced substantial savings. Thirty five participants in the Resource Efficiency Action Programme (REAP), which provided waste minimisation training and on-site audits for companies, achieved over £3.8m of annual cost savings across a range of business sectors. The Business Environment Partnership has assisted over 440 businesses and had helped identify over £2.7m cost savings, mostly relating to waste minimisation, energy efficiency and improved water management. There is potential for a concept such as IS, to provide an 'umbrella' for these projects and thereby provide a degree of central coordination. These programmes have already built up their own individual networks that could be developed, and in many cases the companies that have saved money and resources with these programmes would be more receptive to IS and its benefits.

Assimilation and Application

The scoping study revealed several interesting and large commercial exchanges shown in Figure 4.1.3. Some involve joint ventures such as ScotAsh, set up between LaFarge and Scottish Power, to utilise the power station ash. LaFarge has set up further joint ventures, one to source raw materials (with an emphasis on sourcing waste materials) and another with Michelin to source waste tyres at a set rate. A large driver for this project is the growing mountain of waste tyres, which the process at LaFarge can incorporate whole (steel included). But this situation represents the failure of the tyre manufacturing system (and perhaps the government) to promote markets for re-moulded tyres. Once incinerated or incorporated into cement, the materials for tyre manufacture are effectively lost forever. Seen in industrial symbiosis terms the burning of tyres that replace fossil fuels and improves the emissions of the cement works could be seen as a major success (for the cement company it is). But in terms of Stage 3 and considerations of the efficiency of the overall industrial ecosystem this represents an easy but sub-

optimal solution, because the maximum added value is not extracted from the materials.
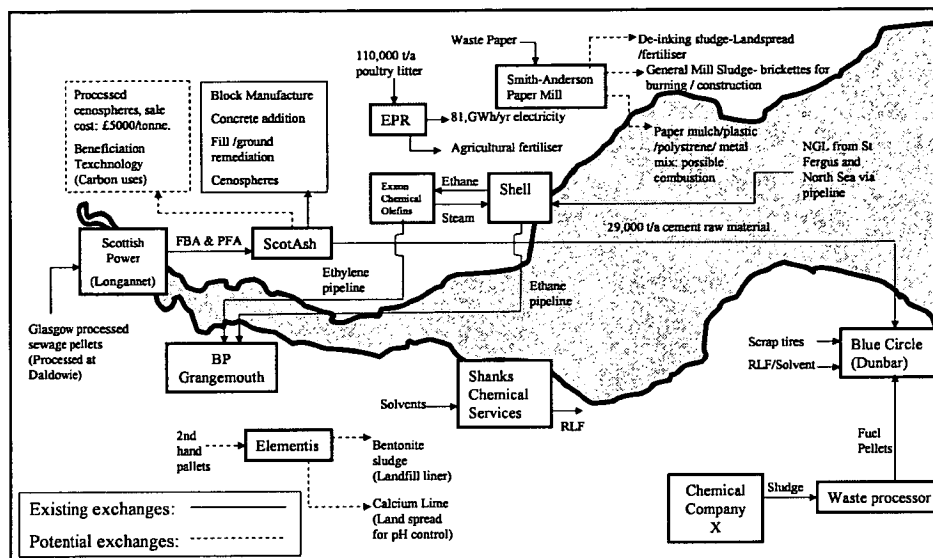

Figure 4.1.3: Existing and Potential Exchange in the Forth Valley

There are other examples in the Forth Valley that could be described as Stage 1 behaviour and other co-operative examples. For instance, one major pharmaceutical company that works with its customers to recycle solvents makes savings of £600,000 per year. A recent mapping study of the area found over 40 'IS type' initiatives and over 20 organisations with a sustainability focus in the region but there appears to be no overall guiding policy for the area that could help to focus objectives and funds, and reduce the risk of overlap [42]. The recently formed Scottish Industrial Symbiosis Programme which has its initial focus in the Forth Valley has the potential to improve the situation however and is discussed in the next section.

4.2 The National Industrial Symbiosis Programme

In 2002 the Business Council for Sustainable Development –United Kingdom (BCSD-UK) proposed to implement a National Industrial Symbiosis Programme (NISP) for the UK. This follows initial IS projects in Humberside, Merseyside and West Midlands. In 2002 BCSD-UK gained backing from the Department of Trade and Industry (DTI) and funding for NISP from the landfill credit scheme.

Awareness and Association

The approach is to develop regional IS programmes that are locally run by a project champion or facilitator and a Project Action Group (PAG). The regional projects are then overseen by BCSD-UK who disseminate best practice and manage data collection software. The method of implementation derives from the method used by BCSD in its original project in the Gulf of Mexico: Awareness, Data Collection, Analysis, Implementation and Evaluation. However, the method was significantly altered for UK use by members of BCSD-UK working with the International Institute

for Industrial Environmental Economics, Lund, Sweden. Of paramount importance for the implementation of the regional projects is the securing of funding (which has so far been relatively successful) from top stakeholders such as the RDAs. Awareness is then raised by phone calls, visits and workshops that feature relevant case studies to induce association. However, the Humberside launch workshop placed too much emphasis on a potential CHP plant and chemical exchange pipeline that lead to *disassociation* of other industries and an initial failure to interest significant companies.

The most recent addition to NISP is the Scottish programme (SISP). It arrived at an appropriate time when the Scottish Executive was reinforcing its commitment to sustainable development. Recently the Scottish Environmental Protection Agency (SEPA) also released its Waste Strategy for domestic waste, which is to be followed shortly by a corresponding programme for the industrial sector. The Scottish Executive was therefore supportive of SISP and agreed to fund its implementation for an initial two years.

The funding allows BCSD-UK to employ an Edinburgh based consultancy as a facilitator to run the initial stage of SISP. SISP was launched with a workshop event involving 85 Scottish companies. The PAG was also formed consisting of 13 local companies, the Scottish Environmental Protection Agency (SEPA), The Forestry Commission, and the Scottish Energy Efficiency Office. The PAGs help to give ownership and therefore increase association to the programme.

Assimilation and Application

The initial project is primarily based in the Edinburgh and Forth Valley region but will expand to other areas of Scotland when additional funding sources come on stream. The initial targets for SISP (set by the funding body, Scottish Executive) are 50 companies signed onto the software, reduction of 100,000 tonnes going to landfill, reduction in CO_2 emissions, and job creation. However, there is a danger that concentrating on short term targets can lead to the missing of opportunities to embed the wider IE concept. The initial goal of SISP appears to be the signing of 50 companies onto the software. This is to be achieved by the facilitator visiting companies to explain how the software functions, but there is no explanation, at present, of the wider context of industrial ecology. In general there appears to be an over reliance on the software perhaps demonstrated by the fact that the first follow-up workshop will take place 10 months after the launch event.

BCSD-UK have however been very successful at obtaining funding and hence the interest of regional development groups, and the interest and active participation of some of the largest companies in the UK. This is largely attributed to the skills of the team, their awareness of business needs and a carefully chosen vocabulary [43]: opportunities, new products, increased sales and cost reduction; instead of: waste minimisation, energy efficiency, environment and sustainability. It is easy to be cynical and suggest that there is a strong possibility of 'environmental hijacking' (as claimed by Welford in relation to the eco-efficiency drive by WBCSD [44]) but there currently exists no other national programme with such backing or potential. Moving towards Stage 3 however, will require involvement of a wider range of stakeholders and perhaps the need for BCSD-UK to offer training to companies and other organisations. This however, is dependant on the future financial support of NISP.

5. Discussion and Conclusion

This paper introduced a framework and has shown how it can be used to help understand the complex series of interactions at the company, network and government level. As the process moves from Stage 1 to Stage 3 we can identify certain factors that are increasingly necessary: inter-company cooperation, top management support, industrial ecology tools (e.g. LCA, EMS), management tools, radical innovation, re-conceptualising and reengineering business; and attempting to integrate business with sustainable consumption. Additionally the framework can be used to help understand how various influences act as drivers and barriers at each stage (Figure 5.1).

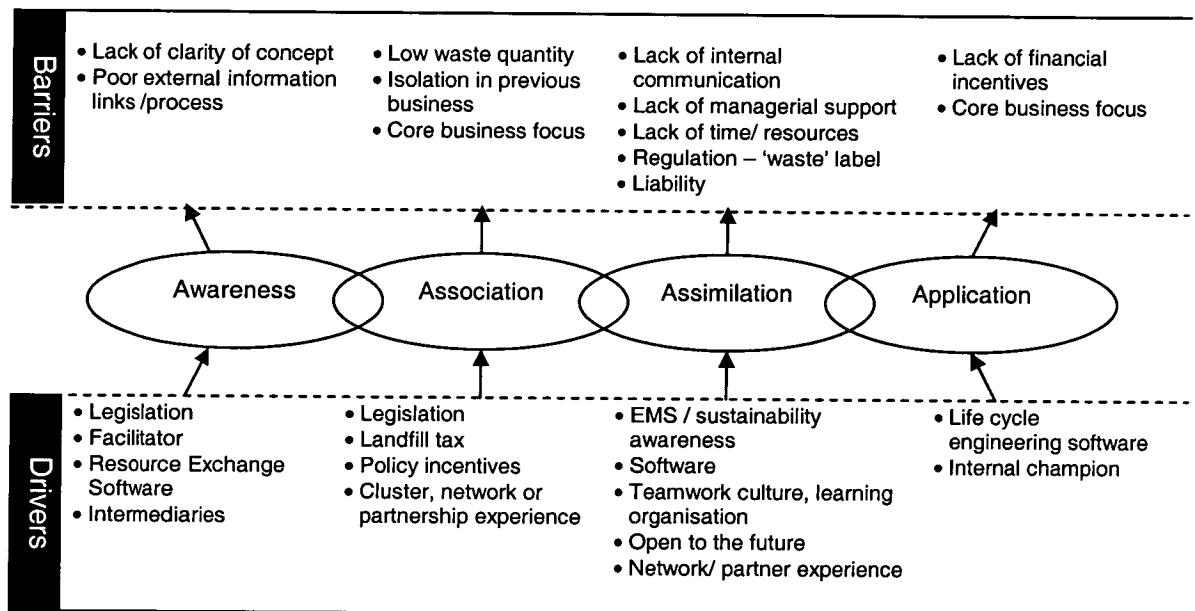| **Barriers**	• Lack of clarity of concept • Poor external information links /process	• Low waste quantity • Isolation in previous business • Core business focus	• Lack of internal communication • Lack of managerial support • Lack of time/ resources • Regulation – 'waste' label • Liability	• Lack of financial incentives • Core business focus
	Awareness	Association	Assimilation	Application
Drivers	• Legislation • Facilitator • Resource Exchange Software • Intermediaries	• Legislation • Landfill tax • Policy incentives • Cluster, network or partnership experience	• EMS / sustainability awareness • Software • Teamwork culture, learning organisation • Open to the future • Network/ partner experience	• Life cycle engineering software • Internal champion

Figure 5.1: Using the 4A model to help understand the barriers and drivers influencing IS development within a company, using the 4A model

In most industrialised countries, legislation has been the biggest driver causing environmental improvement [23]. There has been much criticism of past legislation that encouraged end-of-pipe techniques and was not only costly for industry but also shifted the problem from one medium to another (e.g. from air to water). The primary role of legislation in driving sustainable development is likely to continue for the foreseeable future. Research has shown that there are certain conditions that are more suitable to foster innovation [45]:

- Manufacturers are more comfortable innovating when the risks are reduced
- Risks are lower when environmental policy is stable and credible over the long term
- Regulatory processes should be based on open, informed dialogue and executed by competent knowledgeable regulators

It is important that governments are sensitive to industries' requirements and how best industry can be fostered towards sustainability. If industrial ecology is accepted as the goal, then the learning process framework can aid in understanding how this fostering may be encouraged. It shows that there must be a learning process based

on one of the natural world's most compelling features – balance and harmony. Pressure from legislation and from other drivers, must be matched by companies that are aware of the goal, and have the skills, and the ability to innovate. This can only be achieved by governments that produce bold and clear policies for sustainable development, and complement this with the necessary educational programmes.

Suggestions for further research

There is scope for several extensions to the research reported in this paper:
- A review from the technology and business literature of similar models that may be useful in the application of industrial ecology to business. This could evaluate the models' usefulness alongside the framework developed in this paper using the three levels of industrial ecology.
- Expansion of this work to other concepts of inter-organisational management such as clusters, supply chain management and life cycle management.
- Use of our model to analyse other case studies, including those reported in the literature.
- A comparison of the significance of the drivers and barriers at each level of the model (the 4A's) between countries, investigating how national policies are influencing companies.

References

[1] Welford R, 1997. Hijacking environmentalism: corporate responses to sustainable development

[2] Seaton RAF, and Cordey-Hayes, M, 1993. The Development and Application of Interactive Models of Industrial Technology Transfer. Technovation, 13(1), pp 45-53.

[3] Trott P, Cordey-Hayes M and Seaton RAF, 1995. *Inward technology transfer as an interactive process.* Technovation, 15(1), pp 25 -43.

[4] Graedel TE and Allenby BR, 1995. *Industrial Ecology.* Prentice Hall, New Jersey, USA.

[5] Argyris C and Schon D, 1978. *Organisational Learning: A Theory-in-Action Perspective.* Addison-Wesley, Reading, Massachusetts.

[6] Snell R and Chak M, 1998. *The Learning Organisation: Learning and Empowerment for Whom?* Management Learning, 25(3), pp 337-64.

[7] Cohen Rosenthal E, 2003. '*What is eco-industrial development?*' In: *Eco-industrial Strategies – unleashing synergy between economic development and the environment.* Greenleaf Publishing, Sheffield UK.

[8] Quoted in Holger Engberg, "*Industrial Symbiosis in Denmark*" Stern School of Business, New York University, 1993.

[9] Webster's Revised Unabridged Dictionary, 1996, 1998 MICRA, Inc

[10] Taylor TJ 1999. "*From Artificial Evolution to Artificial Life*". PhD thesis, Division of Informatics, University of Edinburgh. Available online at: http://www.dai.ed.ac.uk/ homes/ timt/papers/thesis/

[11] Lifset R and Gradel T, 2002. *Industrial ecology: goals and definitions.* In: *A Handbook of Industrial Ecology.* Edited by Ayres RU and Ayres LW, 2002. Edward Elgar Publishing Ltd, Glos, UK.

[12] Enrenfeld JR and Chertow MR, 2002. *Industrial Symbiosis: the legacy of Kalundborg.* In: *A Handbook of Industrial Ecology.* Edited by Ayres RU and Ayres LW, 2002. Edward Elgar Publishing Ltd, Glos, UK.

[13] Frosh RA and Gallopulos N, 1989. *Strategies for manufacturing.* Sci. Am. 261(3): pp 144-52.

[14] Cote R and Hall J, 1995. *Industrial parks as ecosystems.* Journal of Cleaner Production, 3(1-2), pp 41-46.

[15] Lowe E and Evans LK, 1995. *Industrial ecology and industrial ecosystems.* Journal of Cleaner Production, 3(1-2), pp 47-53.

[16] Schwarz EJ and Steininger KW, 1997. *Implementing nature's lesson: the industrial recycling network enhancing regional development.* Journal of Cleaner Production, 5(1-2), pp 47-56.

[17] Korhonen J, 2002. Two Paths to Industrial Ecology: Applying the Product-based and Geographical Approaches. Journal of Environmental Planning and Management, 45 (1), pp 39-57.

[18] Welford, Richard, 2003. *Comment at the Industrial Symbiosis workshop during the Industrial Ecology Symposium, Business Strategy and Environment Conference, Leicester, UK.*

[19] Cohen WM and Levinthal, 1990. *Absorptive capacity: a new perspective on learning and innovation.* Administrative Science Quarterly, 35, pp 128-152.

[20] Cohen-Rosenthal, E., *A walk on the human side of industrial ecology.* American Behavioral Scientist, 2000. 44(2) pp 245-264

[21] Barringer BR and Harrison JS, 2000. *Walking a Tightrope: Creating Value Through Interorganizational Relationships.* Journal of Management , 26(3), pp 367–403

[22] Porter M, 2003. *UK Competitiveness: moving to the next stage.* DTI Economic Paper, May 2003.

[23] Wallace D, 1995, *Environmental Policy and Industrial Innovation.* Royal Institute of International Affairs and Earthscan Publications.

[24] Carter CF & Williams BR, 1959. *The characteristics of technically progressive firms,* Journal of Industrial Economics, March, 87-104.

[25] Godkin L, 1988. *Problems and practicalities of technology transfer: a survey of the literature.* International Journal of Technology Management, 3 (5), 597-603.

[26] Wallace D, 1998. *Sustainable Production – paradigms for Greenfield economics.* In: Sustainability Strategies for Industry, Island Press, USA.

[27] Ackroyd J, Coulter B, Phillips PS, Read AD 2003. Business excellence through resource efficiency (betre): An evaluation of the UKs highest recruiting facilitated self-help waste minimization project. Resources, Conservation and Recycling 38 (2003) 271-299

[28] Porter ME, 2003. UK Competitiveness: moving to the next stage. DTI Economics Paper No. 3

[29] Cote RP and Smolenaars T, 1997. *Supporting Pillars for Industrial Ecosystems.* Journal of Cleaner Production, 5(1-2), pp 67-74.

[30] Esty D and Porter M, 1998. *Industrial Ecology and Competitiveness: Strategic Implications for the Firm.* Journal of Industrial Ecology 2(1), pp35-44

[31] Korhonen J, 2001. *Four Ecosystem Principles for an Industrial Ecosystem.* Journal of Cleaner Production, 9(3), 253-259.

[32] Innovation Unit. Website (last visited 15/12/04) http://www.innovation.gov.uk/ projects/partnerships_with_people/ paths_to_ success/ paths_to_ success.htm)

[33] UK Cabinet Office, 2001. *Resource Productivity.* Cabinet Office, Performance and Innovation Unit, London, UK.

[34] DEFRA, 2003. *Government Response to Strategy Unit report 'Waste Not, Want Not'.* DEFRA, http://www.defra.gov.uk.

[35] Envirowise. See website (last visited 15/12/04) at: http://www.envirowise.gov.uk/

[36] DETR, *Sustainable Development: opportunities for change – sustainable business, London, UK.*

[37] Philips PS, Pratt RM and Pike KP, 2001. *An analysis of UK waste minimization clubs: key requirements for future cost effective developments.* Waste Management 21 (2001) 389-404.

[38] National Engineering Laboratory (NEL), 2002. *A Sustainable Solution for Grangemouth Industry.* Report for GWUG.

[39] Environmental Data Services Report, June 2003. *First UK pilots for new chemical services await funding.* Issue No. 341

[40] Environmental Data Services Report, November 2001. *DTI declines to promote chemicals "servicizing" model.* Issue No. 332.

[41] Environmental Data Services Report, June 2002, *CIA lukewarm over chemicals service innovation.* Issue No. 330

[42] Forward Scotland, 2003. *A Mapping Study of existing Resource Efficiency and 'Waste to Product' type programmes in Scotland.* Available online (Last visited 15/12/03): www.vistest.co.uk

[43] Presentation at the Industrial Symbiosis Workshop, Business Strategy and Environment Conference, 15th September 2003. Available online: http://firstsupply.co.uk/nisp/uploads/ Leciester_conference_Sep.pdf

[44] Welford R,1997. *Environmental Hijacking – corporate responses to sustainable development.* Earthscan Publications, London.

[45] Harris S, 2000. *The Influence of Legislation and Enforcement on Environmental Innovation in Manufacturing.* MRes Thesis, Cranfield University.

Glossary

Cleaner Production (CP) - The continuous application of an integrated preventive environmental strategy applied to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment. For production processes cleaner production includes conserving raw materials and energy, eliminating toxic raw materials, and reducing the quantity and toxicity of all emissions and wastes. For products it involves reducing the negative impacts along the life cycle of a product, from raw materials extraction to its ultimate disposal. For services the strategy focuses on incorporating environmental concerns into designing and delivering services (United Nations Environment Programme).

Concurrent engineering – in the process called concurrent engineering, design engineers, manufacturing specialists, marketers, buyers, and quality specialists work jointly to design a product or service and select the production process (Krajewski and Ritzman, 1999).

Design for Environment (DfE) - The Design for Environment approach is grounded in comparing performance, costs, and the risks associated with alternatives. It uses cleaner technologies substitutes assessments (CTSAs) and life cycle tools to evaluate the performance, costs, and environmental and human health impacts of competing technologies. A goal of DfE is to encourage pollution prevention, front-end, innovations through redesign rather than relying on end-of-pipe controls to reducing potential risks to human health and the environment (U.S. Environmental Protection Agency).

Eco-Efficiency - Involves the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity (World Business Council for Sustainable Development).

Extended Product Responsibility (EPR) – addresses what many regard as the weakest link in the product responsibility chain - the final disposal of products after their sale and use by consumers. Under EPR, the responsibility for post-consumer products is extended to the producer of the product - a responsibility that has been traditionally held by municipalities and taxpayers. EPR embodies the principle that manufacturers of products should bare a significant degree of responsibility for the environmental impact of their products throughout the product's life cycle - including upstream impacts inherent in the selection of materials for the products, impacts from the manufacturers' production itself and downstream impacts from the use and disposal of the products. EPR is the basis for a new generation of pollution prevention policies that focus on the product instead of the production facility (Organisation for Economic Co-operation and Development).

Industrial Ecology - '*Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to component, to product, and to ultimate disposal. Factors to be optimised include resources, energy and capital*' (Gradel and Allenby, 1995)

Industrial Symbiosis - *Industrial Symbiosis, as part of the emerging field of industrial ecology, demands resolute attention to the flow of materials and energy through local and*

197

regional economies. Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographical proximity' (Chertow quoted in NISP 2004)

Life cycle analysis – see Life Cycle Assessment

Life-cycle assessment (LCA) - is a process of evaluating the effects that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities. It can be used to study the environmental impact of either a product or the function the product is designed to perform. LCA is commonly referred to as a "cradle-to-grave" analysis. LCA's key elements are: (1) identify and quantify the environmental loads involved; e.g. the energy and raw materials consumed, the emissions and wastes generated; (2) evaluate the potential environmental impacts of these loads; and (3) assess the options available for reducing these environmental impacts. (http://www.uneptie.org/pc/pc/tools/lca.htm)

Reverse logistics - The supply chain that flows opposite to the traditional process of order acceptance and fulfillment. For example, reverse logistics includes the handling of customer returns, the disposal of excess inventory and the return journey of empty trucks and freight cars (www.isourceonline.com/ research/ glossary/index.asp)

Servicizing - also known as 'systemic dematerialisation' – the strategy of service economy, which promotes the selling of services instead of products (Stahel, 1981 and 1992). *'Systemic dematerialisation refers to the fact of increasing the resource productivity not only at the level of the product, but at the level of global infrastructures, in order to reduce not only the total material throughput, but also, most importantly, to decrease its speed within the industrial system, thus minimizing the problem of dissipative emissions during normal use'* (Erkman, 1997).

Sustainable consumption - the use of services and related products which respond to basic need and bring a better quality of life, while minimizing the use of natural resources and toxic materials so as not to jeopardize the needs of future generations (Norwegian Ministry of Environment, 1994).

Sustainable Development (SD) – "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development - the Brundtland Commission).

References

Ackroyd J, Coulter B, Phillips PS, Read AD 2003. *Business excellence through resource efficiency (betre): An evaluation of the UKs highest recruiting facilitated self-help waste minimization project.* Resources, Conservation and Recycling 38 (2003) 271-299

AEA Technology (1999). *Developing Markets for Recycled Materials.* http://www.aeat-env.com/rau/home.html

Allenby BR, 1992. *Achieving sustainable development through industrial ecology.* International Environmental Affairs. 4(1), 56-68.

Allenby BR, 1999. *Industrial Ecology: Policy Framework and Implementation.* Prentice-Hall, Eaglewood Cliffs, NJ.

Argyris C and Schon D, 1978. *Organisational Learning: A Theory-in-Action Perspective.* Addison-Wesley, Reading, Massachusetts.

Ashkenas R, Ulrich, Jick T and Kerr S, 1995. *The Boundaryless Organisation.* San Francisco, CA: Jossey-Bass.

Ayres, RU, 1989. *Industrial Metabolism in Technology and Environment.* National Academy Press, Washington, 1989, pp23-49.

Ayres RU, 1995. *Life cycle analysis: a critique.* Resource Conservation and Recycling, 1995;14:199–223.

Ayres RU, Ferrer G & Van Leynseele T, 1995. *Eco-Efficiency, Asset Recovery and Remanufacturing.* The Zero Emissions Strategy Conference. Website: http://www.ecoplan.org/zero-ems/z-intro.htm.

Ayres RU, 1997. *Toward Zero Emissions: Is There a Feasible Path? Introduction to ZERI, Phase II.* The Zero Emissions Strategy Conference. Website: http://www.ecoplan.org/zero-ems/z-intro.htm.

Ayres RU, Ayres L, 1998. *Accounting for resources.* London: I & II, Edward Elgar.

Baccini P, Brunner P, 1991. *Metabolism of the anthroposphere.* Springer Verlag: Berlin, Heidelberg; 1991.

Barringer BR and Harrison JS, 2000. *Walking a Tightrope: Creating Value Through Interorganizational Relationships.* Journal of Management 2000, Vol. 26, No. 3, 367–403

Baas LW, 1999. *Reflections on Industrial Ecology: are the various concepts in symbiosis or parasitism with Sustainable Development?* In: Proceedings of the 6th European Roundtable on Cleaner Production. Budapest, 29 September – 1 October 1999: pp.12.

Bass LW and Boons FA, 2004. *An industrial ecology project in practice: exploring the boundaries of decision-making levels in regional industrial systems.* Journal of Cleaner Production 12 (2004) pp 1073–1085.

BBC News, 2001. *Iceland seeks waste-disposal crocs.* BBC News. Wednesday, 5 September, 2001. Website: http://news.bbc.co.uk/ 1/hi/world/europe/ 1526838.stm

BCSD-GM, 1997. *By-product Synergy: A Strategy for Sustainable Development. A Primer.* The Business Council for Sustainable Development. Downloaded from (Nov,2002): http://www.wbcsd.ch/printpdf/byprod.PDF

BCSD-UK, 2002. Peter Laybourn, Deputy Chief Executive. Communication at Scottish Enterprise meetings 5th July 2002.

BCSD-UK, 2003. *BCSD-UK newsletter - January 2003.* http://www.bcsd-nsr.co.uk/ news_jan2003.doc

BCSD-UK, 2003b. *Industrial Symbiosis Workshop.* Business Strategy and Environment Conference 2003, Leicester, England.

BCSD-UK, 2004. *National Industrial Symbiosis Programme - A Year of Achievement.* http://www.nisp.org.uk

Billen G, Toussaint F, Peeters P, Sapir M, Steenhout A and Vanderborght JP, 1983. *L'Ecosysteme Belgique. Essai d'Ecologie Industrielle.* Centre de Recherche et d'Information Socio-politique – CRISP, Buxelles.

Bohm, D, 1996. *On dialogue.* edited by Lee Nichol. London. Routledge. 1996

Bontoux L and Leone F, 1997. *The legal definition of waste and its impact on waste management in Europe.* A report prepared by IPTS for the Committee for Environment, Public Health and Consumer Protection of the European Parliament. European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTC), Isla de la Cartuja, Sevilla, Spain, 1997.

Boons and Bass (1997). *Types of Industrial Ecology: the problem of coordination.* Journal of Cleaner Production 1997; 5 (1-2): 79-86.

Borch, OJ and Arthur MB, 1995. Strategic networks among small firms: Implications for strategy research methodology. Journal of Management Studies, 32: 419-441.

BP, 2001. Conversation with BP Grangemouth employees.

Breakthrough Technologies, 2000. Web-site (last visited, 30/8/2001): http://www.breakthrough.co.uk.

Burns T and Stalker G 1961. *The Management of Innovation.* Tavistock.

Burton I, 2003. *Making Institutions Sustainable: What are the drivers?* Lecture given at St. Andrews, available at (last visited 06/2004): http://www.st-andrews.ac.uk/estates/ makinginstsust1.pdf

Capra F, 2002. *The Hidden Connections: A Science for Sustainable Living.* Harper-Collins, London, UK.

Carstensen, Iris (1999): "*Industrie- und Gewerbegebiete gemäß dem Ansatz der Industrial Ecology*" – unpublished report - prepared for GTZ-Section 44.

Carter CF & Williams BR, 1959. *The characteristics of technically progressive firms,* Journal of Industrial Economics, March, 87-104.

Cheeseman K and Phillips PS, 2000. *The Northamptonshire Resource Efficiency Project: a critical analysis of the opinions of project champions.* Environmental and Waste Management 3(4): 175-189.

Chertow M, 1998. *Eco-industrial park model reconsidered.* Industrial Ecology, 2(3), pp. 8-10.

Chiu ASF, 2001. *Ecological Industrial Networking Strategy in Asian Industrial Development.* Presented to the 7th European Roundtable on Cleaner Production, 5th March 2004.

Chiu SF and Yong G, 2004. *On the industrial ecology potential in Asian Developing Countries.* Journal of Cleaner Production. To be published in 2004.

Clayton A, Spinardi G, and Williams R, 1999. *Policies for Cleaner Technology – A New Agenda for Government and Industry.* Earthscan Publications, London.

Cohen WM and Levinthal, 1990. *Absorptive capacity: a new perspective on learning and innovation.* Administrative Science Quarterly, 35, pp 128-152.

Cohen-Rosenthal E, 2000, *A walk on the human side of industrial ecology.* American Behavioral Scientist, 2000. 44(2): p. 245-264.

Cohen Rosenthal E, 2003. '*What is eco-industrial development?*' In: *Eco-industrial Strategies – unleashing synergy between economic development and the environment.* Greenleaf Publishing, Sheffield UK.

Cote R and Hall J, 1995. *Industrial parks as ecosystems.* J. of Cleaner Production, Vol.3 No. 1-2, pp 41-46.

Cote RP and Smolenaars T, 1997. *Supporting Pillars for Industrial Ecosystems.* Journal of Cleaner Production, 5(1-2), pp 67-74

Côté RP & Cohen-Rosenthal E (1998): "*Designing eco-industrial parks: a synthesis of some experience.*" Journal of Cleaner Production 6:3-4, pp. 181-188.

Cousins PD, 2002. *A conceptual model for managing long-term inter-organisational relationships.* European J. of Purchasing and Supply Management. Vol. 8, pp 71-82.

Curry, 2002. *Mersey Banks Industrial Symbiosis – A Study into Opportunities for Sustainable Development through Inter-company Collaboration.* North West Chemical Initiative Report.

Daly HE, 1991. *Steady-State Economics: Second Edition with New Essays.* Island Press, Washington, DC.

da Vinci L, 1500. Manuscript RL 19115v; K/P 114r located in the Royal Library, Windsor Castle, Windsor Castle, Windsor, England, ca. 1500.

Davenport T, 1993. *Process Innovation: Reengineering Work through Information Technology.* Boston, MA: Harvard Business School Press.

Denaro (1999):"*Bioenergie- und Rohstoffzentrum Dorma-Tec*" - unpublished report – prepared for the City of Dormagen, Germany.

Department of the Environment Transport and Regions (DETR), 1998. *Sustainable Development: opportunities for change – sustainable business.* London, UK. DETR

Department of the Environment Transport and Regions (DETR), 1999. *DETR Annual Report 1999 The Government's Expenditure Plans 1999-2000 to 2001-02.* http://www.dtlr.gov.uk/annual99/17.htm

Department for Environment Food and Rural Affairs (DEFRA), 2000. *Waste Strategy 2000 for England and Wales.* http://www.defra.gov.uk/environment/waste/strategy/cm4693/

Department of Trade and Industry (DTI), 2001. *Business Clusters In The UK - A First Assessment.* http://www.consumer.gov.uk/clusters/map

Department for Environment Food and Rural Affairs (DEFRA), 2003a. *Government response to Strategy Units report 'Waste Not, Want Not'.* Defra Publications, http://www.defra.gov.uk.

Department for Environment Food and Rural Affairs (DEFRA), 2003b. *Beckett to take forward strategy units waste report.* News Release, 6th May 2003. Website last visited 06/2003: http://www.defra.gov.uk/news/2003/030506b.htm.

Department for Environment Food and Rural Affairs (DEFRA), 2003c. *Our energy future - creating a low carbon economy.* Available online (last visited 06/2004): http://www.dti.gov.uk/energy/whitepaper/index.shtml

Department of Trade and Industry (DTI), 2003a. *Regional Development Agencies.* Website last visited April 2004: http://www.consumer.gov.uk/rda/info/

Department of Trade and Industry (DTI), 2003b. *A Practical Guide to Cluster Development.* http://www.dti.gov.uk/clusters/ecotec-report/index.html, DTI.

Department of Trade and Industry (DTI), 2003c. *Competing in the Global Economy: the Innovation Challenge.* DTI, December 2003.

Department of Trade and Industry (DTI), 2003d. *Our energy future - creating a low carbon economy.* DTI, http://www.dti.gov.uk/energy/whitepaper/index.shtml

Department of Trade and Industry (DTI), 2004. *The UK and climate change.* Climate Change Projects Office. Website (last visited: 06/2004): http://www.dti.gov.uk/ccpo/uk.htm

DiMaggio PJ and Powell WW, 1993. *The iron cage revisited: institutional isomorphism and collective rationality in organisational fields.* American Sociological Review, 1993;48: 147-60.

Dunkerley D, 2001. *Work Organisations, managerial strategies and control.* In: Understanding Business: Organisations. Edited by Salaman G, The Open University, Routledge.

Dunn V, 2004. *Can we attain sustainability?* Chemistry and Industry, SCI, 2nd February 2004, pg 16-17.

Ecologist, The, 2000. *Global Warming.* July/August 2000.Vol. 30, 5, pp32.

Ehrenfeld JR, 1993. In: *The Greening of Industrial Ecosystems.* Eds. BR Allenby and DJ Richards. National Academy Press Washington, pp228-241.

Ehrenfeld, JR and Chertow M, 2002. *Industrial Symbiosis : the legacy of Kalundborg.* In: *A Handbook of Industrial Ecology.* Ayres, R.U.; Ayres, L.W., Editors. Edward Elgar, Cheltenham, UK, (2002)

ENN, May 14th 2004. *Sooty air pollution is linked to inherited genetic mutations, Canadian research finds.* Environmental News Network. Website visited 14/05/2004 http://www.enn.com/news/2004-05-14/s_23897.asp

Environmental Data Services Report (ENDS) August 2000. *Internet fuels growth in waste exchange services.* Report 307, pp 17-18.

Environmental Data Services Report (ENDS), November 2001. *DTI declines to promote chemicals "servicizing" model.* Issue No. 332.

Environmental Data Services Report (ENDS), June 2002, *CIA lukewarm over chemicals service innovation.* Issue No. 330.

Environmental Data Services Report (ENDS), June 2003. *Commission moves towards waste prevention targets.* Issue 341, pp 53-54.

Environmental Data Services Report (ENDS), June 2003b. *First UK pilots for new chemical services await funding.* Issue No. 341

Environmental Data Services Report (ENDS), 2004. *UKAS moves to strengthen EMS accreditation.* Issue 353, June 2004, p 5.

Engberg H, 1993. *"Industrial Symbiosis in Denmark"* Stern School of Business, New York University.

Envirowise. See website (last visited 15/12/04) at: http://www.envirowise.gov.uk/

Erkman S, 1997. *Industrial Ecology: an historical view.* Journal of Cleaner Production, Vol. 5, No. 1-2, pp. 1-10.

Erkman S, 2003. *'Perspectives on industrial ecology.' In: Perspectives on industrial ecology.* pp 338-342 Edited by Bourg D and Erkman S, 2003. Greenleaf Publishing, Sheffield UK.

Esty D and Porter M, 1998. *Industrial Ecology and Competitiveness: Strategic Implications for the Firm.* Journal of Industrial Ecology Vol. 2, Issue 1, pp35-44

EU Commission 2003. Towards a thematic strategy on the prevention and recycling of waste. http://europa.eu.int/eur-lex/en/com/cnc/2003/com2003_0301en01.pdf

European Council. Council Directive 75/442/EEC modified by Directive 91/156/EEC on waste, 1991.

European Council. Council Regulation (EEC) No 259/93 of 1 February 1993 on the supervision and control of shipments of waste within, into and out of the European Community, 1993.

Evening News, Jan 2004. *OAPs warned as big freeze looms.* Evening News, 24th Jan, 2004. Available online (last visited 28/6/04): http://news.scotsman.com/index.cfm?id=81472004

Fabtech, 2002. http://www.semiconductorfabtech.com/industry.news/0005/30.02.shtml

Falkirk Council, 2002. *Sustainable Falkirk. A strategy contributing to Local Agenda 21 in the Falkirk Council area.* Falkirk Council, April 2002.

Fiksel J, 1996. *Design for Environment.* McGraw Hill.

Financial Times, 1990. The Financial Times (London), Nov 14th 1990, Section 1, p.15

Fleig AK, 2000. *Eco-Industrial Parks: A Strategy towards Industrial Ecology in Developing and Newly Industrialised Countries.* Working Paper for GTZ, Germany.

Foresight Natural Resources and Environment Panel, 1999. *Environmental Futures.* Office of Science and Technology, March.

Foresight Programme, 2000. *Cluster Development Positioning Paper, Scottish Chemicals Industry.* Web-site (last visited 31/01/01): www.foresight.gov.uk/serevlet/DocViewer/ docoreddiredt=2272/

Forward Scotland, 2003. *A Mapping Study of existing Resource Efficiency and 'Waste to Product' type programmes in Scotland.* Available online (Last visited 15/12/03): www.vistest.co.uk

Frosch RA and Gallopoulous, NE, 1989. *Strategies for manufacturing in managing Planet Earth,* In: 'Readings from Scientific American', WH Freeman and Company, New York.

Gray B, 1989. *Collaborating – Finding Common Ground for Multiparty Problems.* Jossey-Bass Publishers, San Francisco.

Großmann et al. (1999): "*Mit vereinten Kräften*", Müllmagazin 1/1999, Feasibility study by Oekopol, Hamburg, Germany.

Godkin L, 1988. *Problems and practicalities of technology transfer: a survey of the literature.* International Journal of Technology Management, 3 (5), 597-603.

Gouldson A and Murphy J, 1997. *Ecological Modernisation: Restructuring Industrial Economies.* In: Greening the Millennium? The New Politics of the Environment (edited by Jacobs, M). The Political Quarterly. Blackwell Publishers.

Gouldson A and Murphy J, 1998. *Regulatory Realities. The Implementation and Impact of Industrial Environmental Regulation.* Earthscan.

Graedel TE, & Allenby BR, 1995. *Industrial Ecology.* Prentice Hall, Eaglewood Cliffs, NJ.

Graedel TE. *Streamlined life-cycle assessment.* Englewood Cliffs (NJ): Prentice-Hall, 1998.

Grint 1997. *Fuzzy Management: Contemporary Ideas and Practices at Work.* Oxford University Press.

Gronow B, Phillips PS and Bates MP, 2000. *East Midlands countywide waste minimisation initiatives: are they successful?* Institute of Waste Management Scientific and Technical Reviews, 3: 4-8.

Guest DE, 1992. *Human Resource Management and Industrial Relations.* Journal of Management Studies, vol. 24, no. 5: pp 503-21.

Hammer M, 1996. *Beyond Reengineering.* London: Harper Collins.

Harris S, 2000. *The Influence of Legislation and Enforcement on Environmental Innovation in Manufacturing.* MRes Thesis, Cranfield University

Harris S and Mirata M, 2003. *The Development of Industrial Symbiosis Networks – experiences and lessons from regional UK projects.* Paper presented to the 2003 International Society for Industrial Ecology Conference, Ann Arbor, Michigan, USA, 28th June - 2nd July, 2003.

Hawken P, 1993. *The Ecology of Commerce: A Declaration of Sustainability.* Harper Business, New York.

Herres RR, Vermeulen WJV and Walle FB, 2004. *Eco-industrial park initiatives in the USA and the Netherlands: first lessons.* J. of Cleaner Production, 12, pp. 985-995.

Hiessl, Harald (1998): "Schließung von Energie- und Stoffkreisläufen durch Unternehmensvernetzung in der TechnologieRegion Karlsruhe (EIP Karlsruhe)", Fraunhofer Institut für Systemtechnik und Innovationsforschung (ISI), www.isi.fhg.de/abtlg/u/pb_html/eip.html

Hoffman (1997) *From Heresy to Dogma: An Institutional History of Corporate Environmentalism.* San Francisco: The New Lexington Press.

Holt CP, Phillips PS, Bates MP, 2000. *A critical appraisal of the role of Resource Efficiency Methodlogy in reducing water demand in the UK.* Resources, Conservation and Recycling 30: 315-331.

Houghton J T, Jenkins G J, and Ephraums J J (eds), (1990). *Climate Change, the IPCC Scientific Assessment.* Cambridge University Press.

Howes R, Skea J and Whelan R, 1997. *Clean and Competitive? Motivating Environmental Performance in Industry.* Earthscan Publications.

Hunt D, Johnson C, 1995. *Environmental Management Systems.* McGraw Hill.

IChemE, 2003. *The Sustainability Metrics. Sustainable Development: Progress Metrics recommended for use in the Process Industries.* Institution of Chemical Engineers.

IGBP 1992. *Global Change: Reducing Uncertainties.* The Royal Swedish Academy of Sciences, Stockholm – IGBP (International Geosphere-Biosphere Programme.

Indigo Development, 2001. Website: (Last visited 31/01/01): www.indigodev.com.

Innovation Unit, 2003. Website (last visited 15/12/04) http://www.innovation.gov.uk/ projects/partnerships_with_people/ paths_to_ success/ paths_to_ success.htm)

Jackson T, 1994. *Cleaner Production Strategies.* Stockholm, Environmental Institute/Louis Publications)

Jürgensen A, 2000. *Technology, Sustainability and Development.* Bulletin of Science, Technology and Society, Vol. 20, No. 3, June 2000, 225-234.

Kass, G, 2000. *Cleaning Up? Stimulating Innovation in Environmental Technology.* Parliamentary Office of Science and Technology, Report No. 136, April 2000.

Kemp R, 1997. *Environmental Policy and Technical Change: A comparison of the technological impact of policy instruments.* New Horizons in Environmental Economics. Edward Elgar.

Kincaid, J. 1999. *Industrial Ecosystem Development Project Report.* Triangle J Council of Governments, Research Triangle Park. Downloaded from: www.tjcog.dst.nc.us/indeco. htm.

Korhonen J, 2001a. *Material and energy flows in corporate environmental management.* International Journal of Sustainable Development and World Ecology 8, 211-219.

Korhonen J, 2001b. *Four Ecosystem Principles for an Industrial Ecosystem.* Journal of Cleaner Production 9, 253-259.

Korhonen J, 2002. *Two Paths to Industrial Ecology: Applying the Product-based and Geographical Approaches.* Journal of Environmental Planning and Management, 45 (1), 39-57.

Korhonen J, 2004. *Theory of industrial ecology.* Progress in Industrial Ecology, Vol. 1, Nos. 1/2/3, pp.61–88.

Krajewski LJ, 1999. *Operations Management-Strategy and Analysis.* 5th ed. Addison-Wesley Publishing Company.

Kytzia S, Faist M and Baccini P, 2004. *Economically extended—MFA: a material flow approach for a better understanding of food production chain.* Journal of Cleaner Production 12 (2004) 877–889.

Lahaye N and Llerena, 1996. *'Technology and Sustainability: An Organisational and Institutional Change.'* In: Models of Sustainable Development, 1996, Edited by Faucheux S, Pearce J and Proops J. Edward Elgar, Cheltenham UK.

Legge K, 1995. *Human Resource Management – A Critical Analysis.* In: J Storey (ed), New Perspectives in Human Resource Management, London: Routledge.

Lifset R, 1997. *A Metaphor, a Field, and a Journal.* Journal of Industrial Ecology, vol. 1, no.1, 1997. MIT Press.

Lifset R and Graedel TE, 2002. *Industrial Ecology: goals and definitions.* In: *A Handbook of Industrial Ecology,* edited by Ayres RU and Ayres LW, Edward Elgar

Lowe E, 1993. *Total Quality Environmental Management.* Autumn, 73-84.

Lowe E, Moran S, Holmes D, 1995. *A fieldbook for the development of eco-industrial parks.* Report for the US Environmental Protection Agency, Oakland (CA): Indigo Development International.

Lowe, Ernest A. / Moran, Steven R. / Holmes, Douglas B. (1998): *"Eco-Industrial Parks – a handbook for local development teams",* Draft. Indigo Development, RPP International, Oakland, CA.

Mabey C, Salaman G and Storey J, 2001. *Beyond Organisational Structure: the end of classical forms?* In: Understanding business: organisations. Rouledge Publishing, London, 2001.

Major EJ, and Cordey-Hayes M, 2000. *Engaging the Business Support Network to Give SMEs the Benefit of Forsight.* Technovation, 20:11, Nov 2000, 589-602.

Meadows D, 1991. *The Global Citizen.* Island Press, Washington.

Meadows D, 1992. *Beyond the Limits.* Earthscan Publications Ltd.

Michaelis L, 2003. *The role of business in sustainable consumption.* Journal of Cleaner Production, Volume 11, Issue 8, December 2003, Pages 915-921.

Mirata M, 2004. *Experiences from early stages of a national industrial symbiosis programme in the UK: determinants and coordination challenges.* Journal of Cleaner Production, Vol. 12, Issues 8-10, Pages 967-983.

Nash J, Stoughton MD. *Learning to live with life cycle assessment.* Environ Sci Technol 1994;28(5):236A–7A.

Nicholas M, Azapagic A and Clift R, 1998. *IPPC and Producer Responsibility- A Possible Way to 'Embed' Industrial Ecology?* Journal of Industrial Ecology, Vol. 2, Issue 4 - Fall 1998.

National Engineering Laboratory (NEL), 2002. *A Sustainable Solution for Grangemouth Industry.* Report for GWUG

National P2 Roundtable, 2003. *An Ounce of Pollution Prevention is Worth 167 Billion Pounds of Cure – A Decade of Pollution Prevention Results: 1990-2000.* Website last visited Jan 2003: http://www.p2.org/p2results/2418_historyfinal.pdf

Patel CKN, 1992. Proceedings of the National Academy of Sciences. February 89.

Pauli, G, 1998. *UpSizing - The Road to Zero Emissions.* Greenleaf Publishing, Sheffield, UK

Peters TJ and Waterman RH (1982). *In Search of Excellence: Lessons from America's Best Run Companies.* Harper & Row, London.

Pauli, G, 1998. *UpSizing - The Road to Zero Emissions.* Greenleaf Publishing, Sheffield, UK

Philips PS, Read AD, Gronow B, 1998. *A regional perspective on waste minimisation: a case study from the East Midlands of England.* Resources, Conservation and Recycling, 23: 127-161.

Philips PS, Read AD, Green AE, Bates MP, 1999. *UK waste minimisation clubs: a contribution to sustainable waste management.* Resources, Conservation and Recycling 23: 217-247.

Philips PS, Adams KT, Read AD and Green A, 2000. *The UK draft waste policy and waste minimisation: regional trends in waste minimisation strategies.* Regional Studies, 34(3):216-222.

Philips PS, Pratt RM and Pike KP, 2001. *An analysis of UK waste minimization clubs: key requirements for future cost effective developments.* Waste Management 21 (2001) 389-404.

Philips PS, Holley K, Bates MP, Freestone NP, 2002a. *Corby Waste Not: an appraisal of the UK's largest holistic waste minimisation project.* Resources, Conservation and Recycling Vol. 36, Issue 1, July 2002,pp 1-31.

Philips PS, Clarkson P, Adams J, Read AD, and Coggins PC, 2002b. *County Waste Minimisation Programmes: A Case Study from Northamptonshire, UK.* Sustainable Development, 11, 103-118.

Pongracz E and Pohjola VJ, (2004). *Re-defining waste, the concept of ownership and the role of waste management.* Resources, Conservation and Recycling, Vol. 40:2 pp141-153.

Porter, M. E. (1998) *On Competition.* Harvard Business School Press, Boston, MA

Porter M, 2003. *UK Competitiveness: moving to the next stage.* DTI Economic Paper, May 2003.

POSTnote 212, (Jan, 2004). *Environmental Policy and Innovation.* Parliamentary Office of Science and Technology, London. Http://www.parliament.uk/post

POSTnote 213, (Jan, 2004). *Climate Change and Business.* Parliamentary Office of Science and Technology, London. Http://www.parliament.uk/post

Pratt RM, Phillips PS, 2000. *The role and success of UK waste minimisation clubs in the correction of market information failure.* Resources, Conservation and Recycling, 30: 201-219.

PSRAST, 2004. *Alternatives to genetic engineering of food.* Physicians and Scientists for Responsible Application of Science and Technology. Website: http://www.psrast.org/ alt.htm, last visited May 2004.

Odum HT and Pinkerton RC, 1955. *American Scientist.* 1955, 43, 331-343.

OECD, 1985. *Environmental Policy and Technical Change.* Organisation for Economic Cooperation and Development, Paris.

OECD, 1996. *Networks of Enterprises and Local Development: Competing and Cooperating in Local Productive Systems.* Organisation for Economic Cooperation and Development, Paris.

Oerlemans N and Assouline G, 2004 *Enhancing farmers' networking strategies for sustainable development.* Journal of Cleaner Production, Vol. 12 Issue 5. pp 469-478.

O'Rourke D, Connelly L and Koshland C, 1996. *Industrial Ecology: A Critical Review.* International Journal of Envirnment and Pollution, Vol 6, Nos 2/3, pp.89-112,1996.

Owens JW, 1997. *Life cycle assessment: constraints on moving from inventory to impact assessment.* J Ind Ecol 1997;1(1):37–49

Quinn JB, 1990. *Beyond products: Service-based strategy.* Harvard Business Review, vol. 68, no.2, pp 58-64.

Ozyurt DB and Realff MJ, 2001. *Combining a Geographical Information System and Process Engineering to Design an Agricultural-Industrial Ecosystem.* Journal of Industrial Ecology, Vol. 5, No. 3 pp 13-31.

Retrade, 2002. Website: http://www.retrade.org/uk/about.asp.

Revell A and Rutherfoord R, 2003. *UK Environmental Policy and the Small Firm: Broadening the Focus.* Business Strategy and the Environment, 12, 26-35.

Roome N, 2001. *Editorial: Conceptualizing and studying the contribution of networks in environmental management and sustainable development.* Business Strategy and the Environment. Bus. Strat. Env. 10, 69–76.

Rothwell, 1992. *Industrial innovation and government environmental regualtion: Some lessons from the past. Technovation,* Volume 12, No. 7 (1992) 447-458.

Sarkis, J, 2001. *Greener Manufacturing and Operations.* Greenleaf Publishing, Sheffield, UK.

Schön, Michael & Kuntze, Uwe (1999): *"Schließung von Energie- und Stoffkreisläufen durch Unternehmensvernetzung in der TechnologierRegion Karlsruhe (EIP Karlsruhe)",* www.isi.fhg.de, Fraunhofer Institut für Systemtechnik und Innovactionsforschung ISI)

Schwarz, Erich (1996): *"Verwertungssystem Ruhrgebiet"* Website: www.kfunigraz.ac.at/ inmwww/rg.html

Schwarz EJ and Steininger KW, 1997. *Implementing nature's lesson: the industrial recycling network enhancing regional development.* Journal of Cleaner Production. Vol 5, No 1-2, pp. 47-56.

Scottish Enterprise, 2004. Taken from the Scottish Enterprise website: www.scottish-enterprise.com/. Last visited: April, 2004.

Scottish Environmental Protection Agency (SEPA), 1999. *National Waste Strategy.* SEPA,1999.

Scottish Environmental Protection Agency (SEPA), 2003. *The National Waste Plan 2003.* SEPA, 2003, http://www.sepa.org.uk/nws/guidance/national_plan_2003.pdf.

Scottish Industrial Symbiosis Programme. http://www.vistest.co.uk/nisp/scotland/

Seager TP and Theis TL, (2002). *A uniform definition and quantitative basis for industrial ecology.* Journal of Cleaner Production. Vol. 10, pp 225-235.

Seaton RAF, and Cordey-Hayes, M, 1993. *The Development and Application of Interactive Models of Industrial Technology Transfer.* Technovation, 13:1(1993) 45-53.

SETAC, 1993. Consoli F, Allen D, Boustead I, Fava J, Franklin W, Jensen AA, de Oude N, Parrish R, Perriman R, Postlethwaite D, Quay B, Seguin J, Vignon B, editors. *Guidelines for life-cycle assessment: a "Code of Practice".* Pensacola (FL): Society of Toxicology and Chemistry Press, 1993.

Shearman C and Burrell G, 1987. *The structures of industrial development.* Journal of Management Studies. Vol. 24. pp 325-45.

Shrivastava P, 1995. *Environmental Technologies and Competitive Advantage.* Strategic Management Journal, Vol. 16, 183-200.

Singh J, 2000. *Making Business Sense of Environmental Compliance.* Sloan Management Review, Spring 2000, Vol. 41(3), pp91-105.

Smart Growth Network, 2000. *Report On The Brownsville Conference on Industrial Ecology and Eco-Efficiency.* Website (last visited 06/2004): http://www.smartgrowth.org/ library/brownsville_press.html

Smith D and Skea J, 2003. *Resource Productivity Innovation: Systematic Review.* Policy Studies Institute, Final Report, September 2003.

Snell R and Chak M, 1998. *The Learning Organisation: Learning and Empowerment for Whom?* Management Learning, 25(3), pp 337-64.

Stahel WR and Reday-Mulvey G, 1981. *Jobs for Tomorrow. The Potential for Substituting Manpower for Energy.* Vantage Press, New York.

Stahel WR, 1992. In: *Waste Minimisation and Clean Technology: Waste Management Strategies for the Furture.* Editors: WS Forester and JH Skinner. Academic Press, London, pp. 91-97.

Strebel H, Schwarz EJ and Schwarz MM, 1996. *Externes Recycling im Produktionsbetrieb. Rechtliche Aspekte und betriebswirtschafliche Voraussettungen.* Manz, Wien, 1996.

Taylor TJ 1999. *"From Artificial Evolution to Artificial Life".* PhD thesis, Division of Informatics, University of Edinburgh. Available online at: http://www.dai.ed.ac.uk/ homes/ timt/ papers/ thesis/

The Commons, 1997. *Zero Emissions Considered: Introduction and point of departure.* The Zero Emissions Strategy Conference: http://www.the-commons.org/zero-ems/z-intro.htm

Therrien P and Leonard A, 2003. *Empowering employees: A route to innovation.* Statistics Canada, Canada. Available on website: http://www.statcan.ca/english/freepub/71-584-MIE/71-584-MIE03008.pdf, last visited 8th May 2004.

Thompson P and McHugh D, 2001. *Reinventing Organisation Man.* In: Understanding Business: Organisations. Edited by Salaman G, The Open University, Routledge.

Thoresen J, 2001. *Productivity 2005: Implementation and maintenance of ecopark co-operation.* Ostfold research foundation, Industrial Ecology Programme, Report No: 1/2001.

Tibbs H 1992. *Industrial Ecology: an environmental agenda for industry.* Whole Earth Review. Winter, pp.4-19.

Trott P, Cordey-Hayes M and Seaton RAF, 1995. *Inward technology transfer as an interactive process.* Technovation, 15(1) pp 25 -43.

Trott P, 1998. *Innovation Management and New Product Development.* FT Prentice Hall, London.

UK Cabinet Office, 2001. *Resource Productivity.* Cabinet Office, Performance and Innovation Unit, London, UK. Available online: http://www.number-10.gov.uk/su/resource/ downloads/resource-productivity.pdf

UNU ZE Forum, 2001. Website: http://www.ias.unu.edu/ecology/g_economy/ze_concept.htm

USBCSD, 2001. *By-Product Synergy.* Website (last visited 06/2004): http://www.usbcsd.org/byproductsynergy.htm

USC, 2001. *Sustainable Cities Program.* April 2001, Newsletter. Website (last visited 06/2004): http://www.usc.edu/dept/geography/ ESPE/documents/ newsletter_april_2001.pdf

United States General Accounting Office, 2001. *Environmental Protection, EPA Should Strengthen its Efforts to Measure and Encourage Pollution Prevention.* February 2001. http://www.gao.gov/new.items/d01283.pdf

USEPA, 1993. *Life-cycle assessment: inventory guidelines and principles.* EPA/600/R-92/245. Prepared by Battelle and Franklin Associates for the US Environmental Protection Agency, Risk Reduction Laboratory, Office of Research and Development. Cincinnati (OH), 1993.

USEPA, 2001. *XL Project.* Website last visited 06/2004: http://www.epa.gov/ProjectXL/

USGS, 2003. *Geographic Information Systems.* Website last visited 6/2/04: http://erg.usgs.gov/isb/pubs/gis_poster/

Wallace D 1995. *Environmental policy and industrial innovation.* Royal Institute of International Affairs and Earthscan Publications.

Wallace D 1998. *Sustainable Production Paradigms for Greenfield Economics.* In: Roome NJ, Sustainable Strategy for Industry, Island Press, Washington, USA.

Wallner, 2001. *Supply Chain Management and Logistics Outsourcing – Trends in the UK.* Business Briefing: Global Purchasing and Supply Chain Strategies. Oct. pp 35-38.

Webster's Revised Unabridged Dictionary, 1996, 1998 MICRA, Inc.

Von Weizacker E, Lovins A and Lovins L, 1997. *Factor Four: Doubling Wealth, Halving Resource Use.* Earthscan, London.

Welford R, 1997. *Hijacking environmentalism: corporate responses to sustainable development.* Earthscan, London.

World Commission on Environment and Development (WCED), 1987. *Our common future.* Oxford: Oxford University Press, 1987 p. 43

Zilahy G, 2004. Organisational factors determining the implementation of cleaner production measures in the corporate sector. Journal of Cleaner Production 12 (2004) 311–319