Building a framework for strategic architecture to foster the development of industrial ecology

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Abstract: Industrial ecology offers many opportunities to convert so-called waste into useful by-products and energy to save the use of virgin materials and nonrenewable resources. Most applications of industrial ecology are found on eco-industrial estates, but the concept has wide application at network and single or multiple building complex levels. Industrial ecology also has the potential to realise much greater economic, social and environmental benefits than it does at present. The application of the concept has been frustrated by the lack of industry and public agency knowledge about it, the conservativeness of planning systems and community attitudes related to industry development. The paper examines planning issues which affect the application and acceptance of industrial ecology. A planning framework comprising six elements of strategic architecture to support the development and application of industrial ecology is presented. The key elements of such a framework focus on:

- knowledge development and management
- the building of enabling environments to foster industrial ecology
- effective policy and planning systems and practices
- the development of waste markets
- risk management
- research to develop new tools, strategies and technologies.

The framework draws upon lessons gained from successful and unsuccessful applications of industrial ecology.

Keywords: planning for industrial eco-parks; socialisation of industrial ecology; strategic architecture; enabling environments.

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1 Introduction

The application of industrial ecology shows considerable promise as a means of supporting sustainable development; however, there are issues emerging in the theory and practice of it which suggests there is still a way to go before the concept is more widely accepted. While industrial ecology has been demonstrated as technically and economically feasible, the mainstreaming of industrial ecology shows slow progress and its real potential is still to be realised (Desrochers, 2004; Gibbs, 2003; Vermeulen, 2007). There is need for more research to understand the nature of the spatial stocks and flows of industrial and consumer waste and by-products in metropolitan and regional areas, and to identify how these can be captured and utilised.

While many technical and economic issues associated with fostering the development of industrial ecology can be solved through better research, technologies, regulation and infrastructure, there are governance, social and behavioural issues which are significantly inhibiting progress on the development and application of the concept. The governance issues centre on the conservativeness of planning systems, risk management, legislative systems and societal attitudes towards industrial development. Resolving these issues will involve significant changes to governance and human behaviour. This will take time. However, unless these issues are addressed, progress on the development and application of industrial ecology as a sustainability tool will continue to be frustrated. It seems the technological advances in industrial ecology are well ahead of the governance and social changes needed to win acceptance of the concept. We need to be reminded that the planning and realisation of industrial ecology as a tool for sustainability is as much an art as it is a science.

A new strategic approach is needed to sell the virtue of industrial ecology and foster its development. This paper sets out a planning framework to help make this happen. It examines some of the issues which have made it difficult to foster the development of industrial ecology, with a focus on economic, governance and community attitudes (Baas, 2005; Roberts, 2004; Roberts and Greenhalgh, 2000). The paper brings together the findings of successful applications of industrial ecology to outline a planning framework, the strategic architecture, to progress the development of industrial ecology as a tool for sustainable development.

2 Application of industrial ecology

2.1 Types of industrial ecologies

Industrial ecology is a concept that can be applied at different levels of industrial development (Korhonen, 2002; Korhonen *et al.*, 2004a). Several authors have attempted to develop typology boundaries for industrial ecologies (Baas, 2005; Roberts, 2004; Roberts and Greenhalgh, 2000). Boons and Baas (1997) have developed a categorisation on product life cycle, material life cycle, geographic area and sector. Roberts (2004) proposes a hierarchical structure for industrial ecology: micro-level (single enterprise/complex), meso-level (eco-industrial parks), and the macro-level (regional and wider industrial ecology global networks of manufacturing activity centres). The broad categorisation into three levels is useful when it comes to planning or supporting the development of industrial ecologies.

The most promising opportunities to apply industrial ecology are at the eco-industrial park level. Industrial ecology is most commonly associated with manufacturing industries, where the clustering or co-location of complementary industries/businesses provides the scale and complexity of activities for industrial ecologies to function best. However, the principles and practices of industrial ecology can be applied equally as well at the macro-region or national level (Roberts, 2004). At this scale, however, transportation, other operational costs and markets for waste and reprocessed materials can significantly influence the economics of industrial ecology developments. Boons and Baas's (1997) typology suggests that industrial ecologies develop levels of specialisation, which is not dissimilar to what occurs with industrial clusters (Chertow, 2007; Nielsen, 2007).

2.2 Planning issues affecting the development of industrial ecology

When the concept of industrial ecology was first developed, it showed considerable promise as a means of addressing the growing industrial waste problem. The Klundborg eco-industrial complex was extolled by many (Frosch and Gallopoulos, 1989; Heeres *et al.*, 2004; Graedel and Allenby, 1995) as a model for industrial ecology which could be applied universally. However, despite many promising initiatives globally to promote the concept, broader community, government and industry acceptance of industrial ecology has been slow (Gibbs, 2003; Vermeulen, 2007; Gibbs and Deutz, 2005). Gibbs and Deutz (2005) investigated 63 eco-industrial complexes in the USA and Europe and concluded "that initiatives aimed at fostering the development of waste exchange and energy cascading were few in number and difficult to organize". Other studies have drawn similar conclusions (Tudor *et al.*, 2007; Chiu and Yong, 2004).

What emerges from the literature is a range of issues affecting the planning and adoption of industrial ecology, which are preventing its development. Many of these issues are common to most developed countries (Korhonen *et al.*, 2004b). There is genuine interest in the approach, but few examples of an overall plan at central and local government levels to support the development of the concept. The following addresses briefly some of the main issues which are affecting the economics, planning and slow development of industrial ecology.

2.2.1 Spatial economics of industrial ecology development

Historically, industrial areas had a high level of vertical and horizontal integration of firms and businesses associated with one or more core export industries. Historically, cities were dominated by an agglomeration of firms associated with one or two major industries, such as steel, automobiles, chemical or clothing manufacturing. Marshall (1890) recognised the benefits of agglomeration economies in fostering competition and efficiencies in industrial production systems, observing that in major manufacturing centres these were able to achieve economies of scope and scale that provided some form of competitive advantage. Because of the proximity to many firms associated with these major industrial complexes, there were many opportunities for smaller firms to recover waste materials and convert these profitably into usable materials or sources of energy, which were often absorbed back into industry supply chains.

Globalisation fundamentally changed the traditional means of production. It led to greater concentration and specialisation of production systems, and resulted in a significant hollowing out of local industrial complexes, as local firms and businesses sourced materials and components at more competitive prices from the global suppliers. The effect has been that most firms engaged in industry supply chains, *e.g.*, electronic or aircraft manufacturing, are less spatially dependent on local suppliers.

Demand for materials by industry is also variable and changing. With the control that multinationals now have over production and supply chains, local branch factories can be mothballed or closed depending on decisions made somewhere else in the world. The effect of this is that local industrial production systems face high levels of uncertainty over the continuance of business, which significantly reduces opportunities for local firms to gain access to highly controlled corporate supply chains. Local firms are not in the position to sell reprocessed products and materials in small quantities to multinational corporations that tend to bulk buy at lower unit prices in global markets.

The dispersal of global production systems, however, does not preclude opportunities for the application of industrial ecology. Collection distance is a major cost constraint to fostering the development of industrial ecology activities; but as urban systems become larger and more dispersed, opportunities to create waste nodes of sufficient critical mass to support networked colonies of industrial ecologies will improve. The separation and collection of household and industrial wastes and together with the development of sub-regional waste transfer and sorting stations (decentralised waste management collection centres) enables the storage and reprocessing of recyclable materials to be undertaken efficiently and profitably. For example, in Australia, several of the state capital cities have small-scale (100 000 tonne plus) recycled cardboard manufacturing mills which are supported entirely by local urban waste streams.

By developing a network of waste collection stations, dispersed production and consumption patterns can create local opportunities for new and innovative industries that find niche markets for reprocess products and materials that can compete with imports. Examples of localised industrial ecology enterprises which capture opportunities for dispersal and diversity of production systems are recycled timber for furniture manufacturing, recycled concrete for public landscape and construction material use, and recycling effluent for use in electricity generation involving cogeneration.

Globalisation has changed the economic geography of production systems, making it more difficult to create industrial agglomerations of firms that might be able to capture or create opportunities for waste reprocessing and cascaded energy use. Opportunities for industrial ecology are significantly fostered by industry agglomeration, so that where possible economic and industry policies of government should try to encourage clustering of synergistic industrial activities as much as possible. This is particularly important for applications of industrial economy in the developing nations of Asia, especially China and India.

2.2.2 The development planning system

Since the early part of the 20th century, the focus of planning for industrial development has been on controlling risks and hazards associated with industrial activities, *e.g.*, waste disposal, pollution, and contamination. Most countries have planning laws, ordinances, codes, and regulations which impose tight controls on land-use activities associated with industrial development. The practice of segregating industrial uses into noxious, offensive, hazardous, heavy, general and light industry areas which began in the early 20th century is wide spread.

Growing car ownership and truck transport in the 1930s reduced the dependence on rail links into industrial areas and pushed industrial development to cheaper land on the urban fringe. The effect of these changes was that industrial estate areas began to take on a form of low-density spacious development, with wide roads and setbacks, minimalist landscaping, and low set buildings with very low site coverage. Spatially segregating land-uses led to the breakdown of the local material supply chains that were prevalent in older more mixed-use industrial areas. By the end of last century globalisation and national industry reforms had increased the length of supply chains and removed many opportunities for industry waste exchange synergies to develop. Waste simply became residual to production, with no value, to be disposed of off site in the most convenient manner.

In planning for eco-industrial areas, very little thought has been given to understanding logistics dependency between heavier and light industrial/service industries. Historically, there was a tendency for firms to agglomerate or cluster close to the suppliers, infrastructure hubs and labour pools to ensure efficient production and reduce transaction costs. The failure of city and regional planning to develop precincts which enhance the prospects for agglomeration and clustering has resulted in a less efficient distribution pattern of firms and a loss of value-adding potential. This very much limits prospects for the development of industrial ecology.

2.2.3 Risk management and eco-industrial the development

The development of eco-industrial parks poses economic, societal, technological and environmental risks to firms, which may be more significant than those affecting firms located on conventional industrial development areas. It is becoming easier to manage risks in industrial areas through improved environmental planning and increased transparency in development approval and control processes. Public notification of development proposals enables communities to express concerns and scrutinise technical details. In the past, development approvals were often made behind closed doors or at the discretion of Ministerial or special government approval. In few countries are governments prepared to support development proposals for industrial areas without a public environmental impact assessment report.

Technological risk is an important factor in the design of industrial and eco-industrial parks. Technological risk involves not only the risk of technology failure, but the risk of technologies used to service eco-industrial areas being inappropriate, unaffordable and unresponsive to change. For example, co-generation is supported in the development of most eco-industrial parks, however, the technologies and scale of facilities used for co-generation can affect the viability and operational performance of industries. There is a critical mass in demand loads for energy, raw and processed materials that will impact greatly on the performance of industry in an eco-industrial park. The inter-dependency of many industry processes located on an eco-industrial park means technology failure has the potential to be highly disruptive.

One of the greatest risks to eco-industrial park development is economic risk to individual enterprises. For eco-industrial parks to reach their full potential there is a need to establish a critical mass of industries to form the basis of an industry reprocessing and production system. These can be very specialised industries associated with a cluster of industry activities such as food, petroleum or chemicals. It is relatively easy to start building eco-industrial systems, but as these grow in terms of sophistication the risk of supply chain collapse becomes greater. If one industry in a supply chain were to fail due to a company going into receivership, or if cost structures make an industry in the chain non-viable, then there is a risk the system will collapse. Since industries are spatially dependent, substitution of a reprocessed product or energy from an alternative source may not be viable.

A failure of a link in the supply chain is a very significant risk for firms engaged in industrial ecology, as it is for all systems. For each down-stream entity added to an industrial ecology supply and distribution chain, the risk of systems failure will rise exponentially. The greater the number of vertically and horizontally integrated firms comprising an industrial ecology cluster, the greater the risk of systems failure, unless the switch to alternative suppliers or material substitution is possible and relatively cheap and seamless. In this situation, the loss of a direct or subsidiary supplier along the primary supply chain systems in an industrial ecology is not such a great risk.

A significant risk factor for industrial ecology is that as overall firm dependency on locally reprocessed materials and energy rises, risks rise, unless substitution is possible. Modern industries take advantage of globalisation to minimise costs and disruptions to supply chains. Companies which totally use virgin materials for production thus have a much lower risk exposure to supply failure than those using locally reprocessed materials and energy, simply because they have more options to choose from when a supply system fails. Those capable of running dual waste/virgin supply systems are least at risk, but this may add to the cost of production and may result in lower utility levels in industrial production systems. This may not be efficient, but it may be effective, as it ensures industries have material supply security. Without this assurance, a total reliance on industrial waste systems as the only source of resource and materials supply becomes very risky. Material supply security is one of the most significant risk factors to the development of Eco-Industrial Parks (EIPs) which aim to support industrial ecology.

2.2.4 Economics and the planning of industrial ecologies and eco parks

Eco-industrial park planning calls for a much deeper understanding of the way industrial processes interact and are managed, to ensure more sustainable development outcomes. The traditional concern of planners has been to control the environmental impacts of industrial development, not to seek opportunities for adding value. The fundamental difference between EIPs and traditional industrial development areas is that the former now seeks to encourage greater opportunities to add value to industrial systems on the production and waste side by encouraging localised synergies through the clustering of associated firms. Planning for traditional industrial estates has tended to constrain the prospects for synergies and innovation to develop and add to the time/cost factor of business operations, by forcing the materials supply and goods distribution networks to operate over a much broader spatial area. This practice is not efficient or sustainable, as studies on food miles have shown (Pretty *et al.*, 2008).

While the societal and environmental benefits of eco-industrial developments are laudable, there are still many economic uncertainties to be overcome. The intent of encouraging industrial ecology is to maximise the use of material and energy waste products as input into production processes in a geographic locality. The higher the content of locally reused or reprocessed materials and cascaded energy by firms, the greater the sustainability of industrial development: at least in theory. The extent to which non-virgin and virgin materials can be used in production processes varies significantly between industries. Some industries, for example glass and metals, need reprocessed materials as dross to extract impurities during the smelting process. Some materials like aluminium have a high recycling ratio. Other materials like paper have a much lower recycling ratio.

The level of dependence or willingness of industries to use non-virgin materials is a critical factor for industrial ecology. The inability to switch quickly to virgin materials or substitutes can severely disrupt other industries if supply or failure occurs in an industrial ecology chain. Many non-virgin materials are severely affected by big swings in price, quality and quantity and the availability of substitutes. These demand and supply side factors have a very significant effect on the economic viability of industries dealing with reprocessed materials within an industry cluster.

As industry clusters and industrial ecologies develop, the flexibility to substitute virgin for non-virgin materials or to change suppliers or purchasers is not as easy. Industrial ecologies can increase the local dependency factor on non-virgin materials, which in some cases increases economic risk. Localised factors such the seasonal nature of supply, critical mass, environmental regulation and planning controls on operating hours can affect significantly the economic viability of all or one of the many elements of a localised industrial ecology.

The most successfully planned industrial ecologies are those associated with larger core industries, such as a smelters, power stations and food processing, where the supplies of waste materials, water and energy are continuous and the likelihood of disruption to flows is low. Firms with a high dependency of waste sales to other firms within the industrial ecology may need to maintain stockpiles and be able to switch to external or raw materials in the event of systems failure from a supplier or distributor.

2.2.5 Socialisation of industrial ecology

Modern industries are generally much cleaner and safer than those of the Industrial Revolution, yet most people still have very negative perceptions about industrial development. There is a strong stigma against industrial activities located too close to residential and business areas. ‘Nimbyism’ (not in my backyard) is very prevalent in developed countries when governments are confronted with decisions about industrial development. The negative perceptions and concerns held by local communities about industrial development are a significant constraint upon planning systems being more innovative and supportive of industrial ecology.

In most situations, prejudice concerning industrial development does not match the reality of the risks affecting industrial areas. In most industrial areas, activities are strictly controlled and regulated – at least in developed countries. The idea that so-called incompatible land-use activities should be co-located is thus an anathema to conventional planning practice. Despite the overwhelming evidence of the benefits of industrial ecology, societal attitudes prevent major changes to regulation, policy and best practices that will ensure more sustainable forms of industrial development. Many industry risks and concerns associated with industrial development, given current regulation and practice, are small compared with common everyday occurrences involving accidents (Graedel and Allenby, 1995).

There is a very poor understanding by society, planners, and industry in general, of how to capture value from industrial production and waste management processes. Changing social attitudes to industrial development are probably the greatest challenge facing the acceptance of industrial ecology and support for mixed-use eco-industrial parks. There is a poor understanding of how to socialise the process of engagement with communities and firms associated with eco-industrial developments (Hill, 2006).

Another important social component of eco-industrial development involves strengthening the physical and social linkages between the industrial estate and the wider community (Ashton, 2008). One reason that EIPs have received significant support in the USA, Canada and the Netherlands involves the focus on the development of social and community engagement networks. The integration of community resources and values into eco-industrial development design means that each eco-industrial park tends to be unique in terms of structure and operation. Although general system principles for EIP design have been postulated (Oh *et al.*, 2005; Schlarb, 2001; Musnikow and Schlarb, 2002), comprehensive design strategies that evaluate local resources and optimise EIP structures and design are still in the initial stages of development.

2.2.6 Managerial arrangements for eco-industrial development

Most eco-industrial projects involve the development of large greenfield sites (usually more than 40 hectares). Land will normally be in government or private ownership. Industrial ecology projects can be undertaken successfully for smaller scale developments – including older redevelopment areas. Many organisational modalities can be used for overseeing the management and development of eco-industrial parks. These range from private or state owned and operated development to various forms of partnership between government, industry and the community.

The successful development of eco-industrial projects will require the establishment of a strong and engaging management organisation. International best practice suggests that many social risks associated with the development of eco-industrial parks and eco-industrial ecology clusters can be reduced if the organisational arrangement involves some form of partnership or alliance between the developer(s), government(s) and community stakeholders. Engaging governments, business and communities in the organisational management process during the planning and design of eco-industrial parks is advantageous in overcoming community concerns. This practice is common in the USA and Europe.

3 Planning framework for fostering industrial ecology

Traditionally, a reductionist approach has been taken to planning industrial ecology projects by mapping waste material and energy flows and potential opportunities for developing symbiotic networks for waste and energy exchange between industries located on an eco-industrial park or within a region. The mapping of industrial symbioses is useful in gathering information to analyse and define possibilities for trade and exchange; however, materials flow mapping does not necessarily lead to firms and businesses becoming engaged in eco-industrial development activities. The adage 'you can lead a horse to water but you cannot make it drink' holds true for industrial ecology, as it does for many other new ideas that have the potential to generate public good.

Similar lessons have been gained from mapping supply chain networks to identify the potential to facilitate industry cluster development (Klein Woolthuis *et al.*, 2005; Casper, 2007). The lesson gained from the study of successful industrial ecology initiatives is that a focus on human and social capital development has been the principal factor driving their development (Lowe *et al.*, 1996; Lowe, 2001; Ayres and Ayres, 2002). This does not suggest we cannot design successful industrial ecology complexes from scratch.

Many authors have suggested ways to foster the development of industrial ecology (Korhonen *et al.*, 2004a; Gibbs and Deutz, 2005; Chiu and Yong, 2004; Yang and Lay, 2004). Some of these have worked: but if industrial development is to become more mainstream, it is essential we develop planning frameworks which are more proactive in encouraging industrial synergies; focus on adding value to firms located in eco- and traditional industrial parks; develop more integrated approaches to waste exchange and energy cascading across industrial systems; and recognise the potential for industrial ecology beyond industrial systems to foster its development. The role of planning in supporting the development of industrial ecology should be to define the strategic architecture (Hamel and Prahalad, 1994) or blueprint that creates the right combinations of industrial activities, firms, infrastructure, technologies, skills, resources and legal frameworks to ensure industrial ecology becomes common and good practice.

In mainstreaming industrial ecology, we need a better planning and development framework which sets out priorities for action, including commitment, and follow-through by leaders in business and government. The industrial ecology concept provides an ideological framework to move forward in developing sustainable solutions to waste management problems facing cities and regions; however, what the concept lacks is a clear set of policies and strategies to make it happen. Industrial ecology needs to be become embedded in the language of planning schemes, local economic development and industry policy documents. With few exceptions, it is still not part of the vocabulary of planners and economists in most countries.

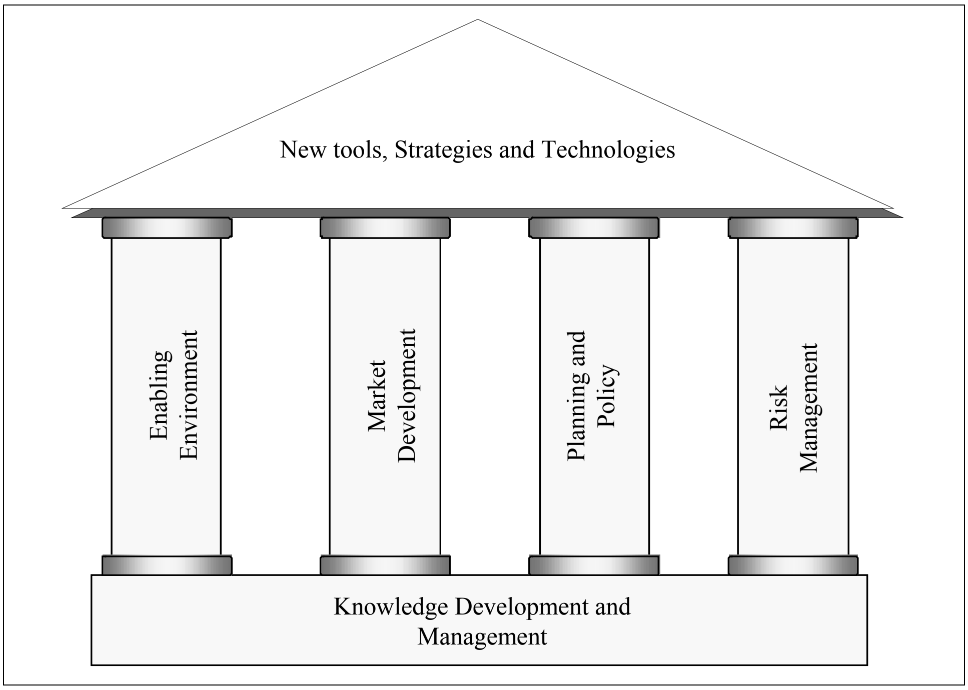
In formulating a planning framework for fostering industrial ecology as a tool for sustainable development, a multiple set of strategies is required which builds upon the experience and knowledge of the concept derived from both theory and good practice. The key elements of such a framework should focus on:

- knowledge development and management
- the building of enabling environments to foster industrial ecology
- effective policy and planning systems and practices
- the development of waste markets

- risk management
- research to develop new tools, strategies and technologies.

These elements form the strategic architecture needed to support the development of industrial ecology at an enterprise, EIP and regional network level (Figure 1).

Figure 1 Strategic Architecture to support the development of industrial ecology



The following outlines a framework; comprising strategies and initiatives which can help foster the development of industrial ecology.

3.1 Element 1: knowledge development and management

Few planning, economic and industrial development policy documents include statements on industrial ecology and how to apply it in practice. The concept is not widely known or understood except by public agencies, academics and some parts of industry which have an interest in it. Surprisingly, there is no reference to industrial ecology in the Kyoto Protocol or the Stern Report (Stern, 2006) on climate change.

Educating communities and disseminating information and knowledge about industrial ecology to key policy decision-makers, highlighting the benefits of the approach, is essential if the concept is to have wider application and appeal as a tool for sustainable industrial development. This will call for the development of partnerships between governments, business and communities to identify and develop new ways to improve knowledge management in support of industrial ecology. Key initiatives to achieving this are discussed in the following four subsections.

3.1.1 Develop an industrial ecology knowledge management system

Knowledge management comprises a range of practices used by organisations, associations and professions to identify, create, represent, and distribute knowledge for reuse, awareness and learning. The modalities for doing this are wide and varied and include: multi-media and publications, networks, education and training. Knowledge management programmes are typically tied to business, institutional and community learning and development objectives and outcomes, such as shared intelligence, improved performance, competitive advantage, or encouraging higher levels of innovation and learning.

Most countries lack knowledge management systems to support the development of the theory and practice of industrial ecology. What is needed to support greater interest and support for the concept is shared, publicly accessible, repositories of knowledge on industrial ecology theory, technology, best practice, market information and management practices. Russia has developed a national institute for industrial ecology (IEE, 2007), while some cities and universities have centres for industrial ecology research and development. The development of a national knowledge management facility for industrial ecology is a key element of the strategic architecture needed to support its development in all countries.

3.1.2 Develop community learning

Communities have often expressed strong opposition to industrial development. Fear and resistance to innovative mixed-use industrial development involving waste and energy exchange will only be overcome through the introduction of learning processes that engage local communities in the planning of eco-industrial development at the conceptual design stage. The use of charettes and other action learning design tools are helpful in engaging communities and in helping to reduce unfounded fears, myths and suspicions about the dangers of mixed eco-industrial development.

3.1.3 Build local eco-industry networks

Part of the strategy to develop knowledge management is local eco-industry network development. This is a tool commonly used to foster the development of industry clusters (Cowan *et al.*, 2004). Local eco-industry networks can be fostered and developed through formal industry associations, but the most successful approach is when the process is organised by industrial park management, often using estate management and security or planning concerns as the catalyst to bring directors and senior management of firms together to introduce the concept of industrial ecology and explain its benefit to local business. The application of roundtable or open-space facilitation techniques is particularly useful. The bringing together of senior management from a wide range of industries leads to informal networks and associations. Park management events are a means of facilitating both formal and informal networking processes. One of the success factors attributed to the development of successful industrial ecology complexes such as Kalundborg and Kwinana in Western Australia (Van Beers *et al.*, 2007a; Van Beers, 2007) is the development of informal and semi-formal networking leading to the realisation of business opportunities.

3.1.4 Research and development

The development of more accurate accounts of the size and structure of current industry resource use, and a deeper understanding of the environmental implications of the manufacture, distribution, use, and disposal of present products are indispensable to all industrial ecology activities. Therefore developing a comprehensive understanding of the temporal and spatial flows and stocks of materials within local, regional, and global economies must be an important aspect of any future industrial ecology research. Particular attention should be paid to assessing material and product lifecycles of firms and industrial sectors that are economically and environmentally important to a region.

3.2 Element 2: developing an enabling environment

The creation of an enabling environment is one of the key elements of strategic architecture needed to encourage the development of industrial ecologies. To create the enabling environment, there is need to develop a greater understanding of the social, legal, technical, and economic systems that impact upon the governance of industrial systems. These elements vary significantly between states and regions, depending on the structure of local economies. To build enabling environments that are supportive of industrial ecology requires the particular characteristics of synergies between industrial waste exchange systems to be identified, along with possible evolutionary processes within those systems, and to examine the impact on economic, planning, and regulatory structures and policies upon the implementation of industrial ecology principles (Lowe, 2001). These assessments will require a review of practices by all levels of government.

To establish the enabling environment necessary to support the development of industrial ecology will require investment in the following areas.

3.2.1 Building strategic infrastructure

Two types of strategic infrastructure (Hamel and Prahalad, 1994) are needed to support industrial ecology cluster developments. Hard infrastructure comprises physical infrastructure, such as roads and water supply, as well as telecommunication services. Soft infrastructure is less definable, but includes services, human capital, skills and networks needed to support the growth of firms and businesses that find advantage in being part of an industrial ecology. Planning guidelines for the planning of infrastructure for eco-industrial parks have been developed for the Queensland Environmental Protection Agency in Australia and were published in the edited book *Planning for Sustainable Industry* (Roberts, 2001; Roberts *et al.*, 2001).

3.2.2 Engaging stakeholders in the planning process

The sensitivities that embrace the issue of waste management and disposal require governments and developers involved with an eco-industrial project development to consult widely with stakeholders before proceeding with detailed feasibility and planning studies. Key stakeholders likely to be involved or affected by an eco-industrial development project are:

- government regulation and approval agencies
- potential customer firms producing or utilising industrial waste products

- waste industry service providers
- research and development firms and institutions
- supporting dependant service industries
- local community interest groups.

The engagement of community interest groups is essential if eco-industrial development projects are to have a good prospect of success. Guidelines for engaging community interest groups are part of the tool kit necessary to win stakeholder support for the concept.

3.2.3 Fostering commons

Commons are shared facilities and knowledge management systems that assist in fostering the development of local networks, interest groups and events for people to interact and solve problems, discuss, exchange and develop ideas for innovation, commercialisation and collaboration between firms. Commons allow companies to share and reduce the cost of training, childcare and service facilities. The fostering of commons is a best practice and applied in many countries to facilitate the development of soft infrastructure needed to support industrial development.

Fostering commons to support industrial ecology requires careful attention to physical and social planning. The focus of physical planning will be on mixed-use activities, but these need to be linked to the employment, social, physiological, psychological and behavioural needs of people employed in or associated with eco-industrial areas.

For small eco-industrial parks (less than 40 ha) the fostering of commons is not easy because the costs of supporting some activities could be marginal. Commons co-located with other community facilities servicing a much broader population can help overcome problems with the economic viability of commons. The lessons learned from the development of new industrial and eco-industry areas in Europe and the USA is that access to commons is one of the most important factors considered by businesses in making choices about business location. The development of commons is a key success factor in fostering industrial ecology.

3.3 Element 3: planning policy reform

3.3.1 Greater spatial integration of industrial systems

The intent of planning schemes to segregate the elements of industrial systems over the past 50 years has greatly reduced the opportunities for industry agglomeration and clustering. Industry clustering creates economies of scope and scale, resource sharing, value adding and innovation. Industrial ecology developments need similar elements of strategic infrastructure. Governments responsible for industrial development should foster a shift from segregated to integrated mixed-industrial use development. This represents a major paradigm shift, and should not be conducted before the implementation of a wider community and education engagement strategy as described above. The focus on integrated planning introduces greater flexibility into planning systems for mixed-use development.

3.3.2 Embedding industrial ecology into policy documents

Much greater intention should be given to embedding policies supporting industrial ecology in economic development and statutory planning documents. These call for the development of coherent definitions of industrial ecology for planning schemes outlining key objectives, scope, and methodological frameworks for achieving it in practice:

> "It also needs to be emphasized that the concepts of cleaner production and industrial ecology have not become sufficiently deeply embedded into most corporate systems to have the system-wide impacts that would be optimal. This is because they were perceived as non-core business concepts and as such were not usually addressed at the policy and strategic decision making." (Baas, 2005)

3.3.3 Performance-based planning

To encourage flexibility and innovation to support the development of industrial ecologies there should be a shift away from formal rule-based land-use development control type instruments to manage industrial development, to more performance and emissions-based planning instruments. This will enable land-use activities which have the potential for symbiosis in waste and energy exchange to be collocated, provided operational safety standards can be met. For this to occur, planning systems should become more flexible, responsive to changes in industry and materials and technologies, and should document incentives to encourage greater integration of industrial development and waste and energy exchange processes.

3.4 Element 4: facilitating the development of markets

Building capacity to facilitate opportunities for waste exchange and trading, and the identification of new sources and markets for materials recovery and processing, are vital pieces of infrastructure needed to support the development of industrial ecology. The following four subsections discuss initiatives that could help support the development of waste and energy exchange markets.

3.4.1 Establishing national and local waste and energy exchange markets

Many governments have helped establish waste exchange registers to support the development of markets for waste exchange. The development of a national network of local waste exchange registries listing exchange opportunities is an essential step to developing national waste exchange markets linked to international markets. Waste exchange registers offer an excellent way to make information available to businesses engaged in the purchase or trade of industrial by-products. A feature of increasing specialisation in industrial production systems is that surplus to production concentrations of waste are increasing, which may provide opportunities for reverse mining materials now for use in the future.

3.4.2 Strategies for mining the built environment

The urban built environment represents a major resource for the recovery of minerals and materials which can support the development of eco-industrial park networks involved in specialised materials handling and reprocessing. Our cities, as Jacobs (1969; 1985) wrote many years ago are the mines of the future. In most post-industrial societies, infrastructure and other built assets are reaching the point where replacement of these will be required over the next 20 years. Van Beers *et al.* (2007b) states:

> "about 70–75% of waste copper and waste zinc in Australia is generated in urban areas…..Residential applications account for about 40% (copper) and 60% (zinc) of the generated discards; commercial and industrial applications account for the remainder. By 2030, the discard flows are predicted to increase by about 105% and 155%, to 150 Gg Cu/year and 145 Gg Zn/year."

Priority targets for mineral and material recovery in cities are areas scheduled for redevelopment and buildings under renovation, urban infrastructure, the transportation sector, and consumer and business durables. While mineral concentrations in our cities have been mapped (Van Beers *et al*., 2007b) recyclable building material quantities and recoverability remain unknown. The mapping and modelling of these resources will greatly assist planners in identifying where to locate eco-industry exchange depots and potential parts of the built environment to plan for redevelopment.

3.4.3 Developing minerals recycling and processing centres

Some urban centres in countries like Australia are particularly attractive locations for developing large scale recycling facilities for minerals, especially in Australian cities like Perth and Adelaide (Van Beers *et al*., 2007b). However, there is also need to develop more specialised centres for recycling and extracting precious metals, organics, plastics and synthetic waste products. These centres should be developed near multi-modal ports/rail/road transport terminals, to support ease of material transfers and packing for export.

As a means of reducing transport costs for dry waste, opportunities for back loading trucks or rail freight wagons on routes between major population centres should be investigated. There is currently significant underutilised capacity within most national transport systems, to make the transport of dry waste to reprocessing centres viable. The development of partnerships between the waste management and transport industries would enable this opportunity to be realised.

3.4.4 Incentives to foster industry symbiosis

Fostering the growth of networks has been a key success factor in the development of industry clusters (Enright and Roberts, 2001). Many successful industrial ecology developments have followed the same path. However, business and information networking is only a first stage in facilitating industrial symbioses, and not all will be successful. Many ideas do not progress to the realisation of a commercial business transaction because the risks of developing potential business opportunities applying the concept of industrial ecology are considered too high for interested parties to proceed.

There are several ways governments can reward businesses to encourage greater symbiosis for resource sharing and waste exchange in support of sustainable development. These include: R&D taxation breaks to facilitate new and innovative ideas that lead to the development of cleaner or more efficient industry development processes involving waste exchange; grants to support the same; and support for industry cluster facilitation to support resource sharing and waste and energy exchange and development.

Symbiosis is not something which is achieved at one time. Symbiosis requires the initial presence of catalyst firms and strategic infrastructure, which stimulates investment and innovation, providing the magnet that draws in new firms and industries into a cluster or industrial ecology complex.

3.5 Element 5: risk management

Firms involved in using waste and cascaded energy products as their primary feed stock for production face risks which may be greater than firms using virgin materials and disposing of waste by conventional means. If governments wish to promote the application of industrial ecology, some means of mitigating risks should be identified. It is unreasonable for government to expect firms and businesses to bear the risks of becoming engaged in an eco-industrial ecology project if the risks are considered high.

There are several initiatives governments could adopt to reduce the risk to firms becoming engaged in eco-industrial development projects. These include the following two initiatives.

3.5.1 Tax incentives to support systems failure

A major failure by a supplier in a by-products, waste and cascaded energy supply chain could potentially result in the fatal collapse of an eco-industrial ecology complex. Where the risk of failure is high, firms need to be able to convert quickly to alternative sources of supply. The cost of installing parallel or backup systems or technologies may be expensive, and represent an overhead to a company or corporation. There are ways governments can help to off-set these costs through taxation, involving more generous rates of depreciation or tax write-downs on buildings, plant and equipment. Tax depreciation on plant and equipment is normally the responsibility of national governments, and requires a tax policy change to support this as a risk reduction strategy in support of sustainable industry development. State and local governments can also provide tax incentives to help reduce risk exposure to disruption of supply, by reducing land, employment and other local taxes. However, these are incentives that are relatively small and may not be sufficient to persuade firms to convert from using virgin to reprocessed waste materials as their primary feed stock used in production.

3.5.2 Waste banks – reverse mining

For some industrial ecology projects the supply of waste and cascaded energy may be hampered by uncertainty of supply due to the seasonality of waste streams, markets for waste by-products, price fluctuations and other constraining factors. Where there are uncertainties of supply, the risks of using reprocessed waste or cascaded energy may be high as both quality and quantity cannot be assured. Government can help firms engaged in waste exchange and trade to reduce supply risk by developing waste banks that would enable surpluses to be held (where this is practicable) and released when supply or markets become uncertain. This has been done by governments in Australia in the past for commodities such wheat, wool and sugar. As the volume of recyclable materials grows in future, where there are risks of market failure that may deter firms from engaging in waste use and exchange, this would provide a mechanism for assuring supply and stabilising markets. The concept of reverse mining of waste materials offers a way of developing waste banks for the future that should be investigated.

3.6 Element 6: new tools, strategies and technologies

Significant advances have been made in the development of new tools and cleaner production technologies to support industrial ecology. One of the major challenges of stocks and flows analysis is the identification of future waste material resource sinks and flows in cities. There are, however, other areas where new tools, strategies and technologies are needed to advance the development of industrial ecology. These include the following three areas.

3.6.1 Tools for integrated approaches to advance the development of industrial ecology

Further development of analytical and implementation tools that integrate social, economic, and environmental considerations into a stocks and flows model of the industrial system is needed. In particular, there is need to develop tools that incorporate local conditions into their assessment methodologies (for instance, the characterisation of the environmental burden of specific materials and products produced in a national or regional context).

3.6.2 Tools for advancing the development of eco-industrial parks and networks

There is need to improve the development of models, analytical techniques, policy instruments, and technical databases that assist in the assessment and development of eco-industrial parks. In particular, a greater understanding of optimal cluster, infrastructure, and managerial strategies should be promoted. These strategies may be highly localised.

3.6.3 Modelling urban ecology life cycles

One of the most challenging issues for the future management of cities is how to use the increasing volume of mixed waste that will be generated from the redevelopment of cities as infrastructure, houses and other buildings reach the end of their physical and economic life. Many of these buildings contain toxic materials, or materials involving health risks which make reprocessing and disposal difficult. An important planning issue for industrial ecology is to understand the nature, spatial location and timing of future waste flows that will occur in the revitalisation and redevelopment of cities. Modelling of these flows is important in providing information for the long-term planning of cities and regions, and optimising the location of waste processing and disposal areas in cities. It will also provide important information on the expected stocks and flows of materials which can be used by firms and industries interested in supporting industrial ecology.

4 Conclusion

Industrial ecology offers many opportunities to address a growing global waste problem and make a contribution to sustainable development. There are many exciting developments in the field of industrial ecology, and the application of it is becoming more widely accepted. Unfortunately, industrial ecology has not reached its full potential.

There are many reasons for this: the legacy of industrial development that stems back to the Industrial Revolution, the problem of applying the ecological metaphor to the architecture of modern industrial systems, the issues associated with the planning and development of eco-industrial parks and the technical and economic issues associated with creating a scope and scale for an ecology to make it viable have been covered in this paper.

The difficulty being experienced in mainstreaming industrial ecology does not mean it has a limited application in the future. The world's waste problems will get bigger, and our sources of virgin material are rapidly diminishing. Ultimately, we have little choice but to make greater use of by-products and cascading energy, and recycle our built environment as we move to an age of "peak minerals" (Gordon *et al.*, 2007). In seeking to develop industrial ecology as a tool for sustainable development we need to examine ways to redesign industrial systems to make them more efficient and effective to use reprocessed material and cascaded energy. Economics will eventually force us to do this, but we cannot dismiss opportunities to support the development of industrial ecology now, simply because the risks are too high, or communities do not like industrial development in their backyard. The issue of food miles is one of the greatest challenges to sustainability and may prove to be a valuable ally in supporting the development of industrial ecology.

This article has attempted to set out a planning framework to help support the development of industrial ecology. Implicit in the framework is the need for a more integrated and strategic approach to developing strategic architecture needed to make industrial ecology more of a mainstream practice for the development of future industrial areas. The framework proposed builds upon a platform of knowledge development and management about industrial ecology. Without this, the concept of industrial ecology will not win wider acceptance. From this, we must learn how to build a better enabling environment to support the process, improve the planning and develop markets for waste and energy exchange, and manage the risks associated with eco-industrial development. Finally, we must move forward in areas of cleaner production and waste management research if we are to see industrial ecology realise its full potential.

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