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SOME SUGGESTIONS FOR REGIONAL INDUSTRIAL ECOSYSTEMS – EXTENDED INDUSTRIAL ECOLOGY

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Industrial ecology (IE) is an emerging concept from industrial environmental management arising from a provocative ecosystem analogy of recycling or *roundput* systems. The systems approach in the concept, i.e. to facilitate the emergence of entire industrial systems based on cooperation in waste material and energy utilization between the actors involved in the system, has been applied in only a few case studies. These have been conducted with regional industrial systems. In this paper the ecosystem analogy in IE is extended to include also the three other basic principles or metaphors of system development of ecosystems besides roundput: diversity, locality and gradual change. The four ecosystem metaphors constitute the *extended industrial ecology* approach, in which the metaphors are considered in industrial systems. An example of a regional industrial ecology study with the Jyväskylä industrial ecosystem is considered with the thesis. Some initial suggestions for developing the extended industrial ecology approach are presented. Copyright © 2001 John Wiley & Sons, Ltd and ERP Environment.

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INTRODUCTION

The emerging concept of industrial ecology (IE) was made popular by an influential article in *Scientific American* by Frosch and Gallopoulos (1989) and further developed for instance by Ayres and Ayres (1996) as well as Ehrenfeld and Gertler (1997). The most famous IE case study is a regional approach: the industrial district at Kalundborg in Denmark (see Ehrenfeld and Gertler, 1997).[1] The concept of IE adapts the ecosystem analogy in industrial systems. Ecosystems are 'masters of recycling', recycling of matter and cascading of energy. The only input to the system is the solar energy from the sun and hence in theory the ecosystem metaphor provides a sustainable model of system development for industrial systems. In this article, we understand IE as a *systems approach* for facilitating cooperative regional industrial systems, which are based on recycling of matter and cascading of energy between the actors in the system. We begin with an approach that we call *extended industrial ecology* and continue with an example of the Jyväskylä Regional Industrial Ecosystem in Finland.[2] We conclude with some initial suggestions for facilitating regional sustainability with the extended industrial ecology approach.

[1] For an overview on regional industrial ecology case studies, which are still only few, see Cote and Cohen-Rosenthal, 1998; Baas, 1998; Wallner, 1999.
[2] This is based on our previous study.

EXTENDED INDUSTRIAL ECOLOGY

In this part we are going to try and extend the industrial ecosystem analogy. The industrial ecology metaphor is commonly understood as *roundput*, i.e. the ecosystem is a master of recycling, recycling of matter and cascading of energy. In theory, a succesful application of the roundput metaphor to an industrial system can reduce the virgin material and energy input to the industrial system as well as the waste and emission output from the system; i.e., roundput can reduce the environmental burden of industrial activity. Here the regional IE thesis is reflected also on the three other basic principles of system development of ecosystems: *diversity*, *locality* and *gradual change*. This approach or a concept is called *extendend industrial ecology*, in which the industrial ecosystem analogy includes the four ecosystem metaphors. Table 1 sums up the concept.

Roundput

In ecosystems waste equals food; i.e., recycling of matter happens and energy is cascaded in the food chains. The human economic or industrial systems in turn are operating according to a throughput direction, i.e. from raw materials to products to wastes. Note a paper industry example, where the throughput 'happens' with the extraction of the 'natural income' from the natural capital stock (see Costanza and Daly, 1992, Daly, 1996, Wackernagel and Rees, 1997), i.e. timber from the forest, processing the raw-material into a paper product, which eventually will end up at landfills. In the case of energy the fossil fuel stock provides us with natural income in the form of fuel input to energy production, and airborne emissions arise as end result. The main objective of industrial ecology then, the roundput, is to achieve ever increasing levels of reliance on waste material (recycling of matter) and energy recycling (cascading of energy), on renewable material and energy resources, i.e. to adapt the industrial (sub)systems to the (mother) ecosystem.

Diversity

Biodiversity, diversity in species, in organisms, in information, interdependency or co-operation can be seen as the basic condition of the ecosystem survival and sustainability. Human economic systems are also diverse: consider the diversity of product structures and supply for instance. However, when understanding the system under one single denominator, that is the monetary value, the diversity

Table 1. Extended industrial ecology. Ecosystem metaphors in industrial systems.

Ecosystem	Industrial system
Roundput	Roundput
recycling of matter	recycling of matter
cascading of energy	cascading of energy
Diversity	Diversity
biodiversity	diversity in actors, in interdependency
diversity in species, organisms, interdependency,	in cooperation
diversity in information	diversity in industrial input, output
Locality	Locality
utilizing local resources	using local resources, wastes
respecting the local natural limiting factors	respecting the local natural limiting factors
	cooperation between local actors
Gradual change	Gradual change
evolution using solar energy	using waste material and energy,
evolution through reproduction	renewable resources
slow time rates in the development of system diversity	gradual development of the system diversity
cyclical time, seasonal time	

is reduced. In the societal activity in general the diversity in ecosystems is considered through internalization of externalities or monetary valuation of the 'natural capital stock' (and the ecosystem services, i.e. the natural income). As the assumption is that with prices there exists a value for the natural capital stock, the natural capital is seen as finite in value. The problem is that the natural capital stock and the resulting ecosystem services, e.g. the life supporting functions, are clearly infinite in value; e.g., without water, there would be no life: similarly without air or photosynthesis etc (Wackernagel and Rees, 1997). Then, because of incomplete information and the tendency of the human economic or industrial society to develop towards specialization, human intervention into ecosystems tends to be focused on selected aspects, and the diversity of the ecosystem is reduced (see Ring, 1997).

The diversity metaphor could read 'diversity in actors' or diversity in interdependency and in cooperation in a regional industrial ecosystem. The waste utilization may be more likely to happen if there exists co-operation between many actors, e.g. inter-firm and inter-industry waste utilization, i.e. diversity in the actors involved, diversity in interdependency and in cooperation. Besides presenting an opportunity, increasing diversity (or scale in the number of the actors of regional IE) may also prove to be a barrier to industrial ecology. Diversity equals increasing complexity, and hence diversity in actors equals diversity of interests. This can become an obstacle when trying to generate a 'common goal for industrial ecosystem development'. On the other hand a large number of the actors involved in cooperation would seem to secure the sustainability of the system. Consider that in nature the smaller and simpler symbiotic systems are, the more fragile they become. Even the withdrawal of one organism can destroy the symbiosis. The larger and more complex the symbiotic systems are, i.e. ecosystems such as lakes, rivers and forests, the less likely they are to break down if one element is suddenly destroyed (Ulhoi and Madsen, 1998). Similarly, a relatively small regional industrial ecosystem that has evolved around a single key actor, which might be able to generate industrial ecology type activities with for example a heterogeneous fuel basis (also waste fuels) and diversity in the output products and wastes that are potential raw materials for others, may be relatively fragile if the key actor withdraws. A regional system, where there exists more diversity in actors, could have more possibilities to maintain the recycling symbiosis and sustain the system.

The diversity metaphor in the case of the production output of industrial activity may also benefit industrial ecology type activities. From the classical Taylorist–Fordist position it follows that diversity or variety of output is incompatible with maximum efficiency as the goal of mass production ideal obviously has dominated the industrial production paradigm (Ayres and Ayres, 1996). However, as Ayres and Ayres (1996) note, nowadays quantity of supply (of final goods and services) is becoming less and less important relative to quality and diversity or variety of output. In an industrial ecosystem, then, in order to enable diverse cooperation based on material and energy flow utilization between the actors involved, the diversity of output could mean that the waste output of a company, for example waste energy or heat from a power plant, is understood as a product with value. So here the output supply is understood with a more diverse perspective as wastes are interpreted as something with value instead merely something that are dumped into the local air or water system. Also a heterogeneous fuel basis, for example in a power plant makes the utilization of many different type of fuel possible, also waste material and energy flows, i.e. diversity in input.

Locality

Terrestrial ecosystems have to respect the local natural limiting factors. In an ecosystem an organism needs to fit in with its surroundings and 'cooperate' with other organisms of the local system. In modern regional economic or industrial systems the local natural limiting factors are not respected, because it has been possible (up to now) to import, for example, external fossil raw materials and fuels from distant regions or countries and the common assumption is that we can substitute the local natural limiting factors with technologcal innovation or with human-manufactured capital. Furthermore, the inter-region or inter-nation dependency in the spirit of globalization may overcome the awareness for local cooperation opportunities in industrial development (see M'Conigle, 1999).

The regional industrial ecosystem approach with an effort to reduce the virgin material and energy input as well as the waste and emission output of a regional industrial system, is the vision to go at when attempting to control or reduce the Ecological Footprint (Wackernagel and Rees, 1997) of a region. So locality in industrial ecosystem development would mean utilization of regional materials and energy resources, waste materials and energy of the region, respecting the local natural limiting factors (controlling the scale of the industrial activity burden on the environment) as well as co-operation between actors that are in close proximity with each other.

Gradual change

Natural processes are characterized by relatively slow time rates. For instance, generation and regeneration times of soil and groundwater run into hundreds and thousands of years (Ring, 1997). Similarly, biological or genetic evolution happens relatively slowly through the gene as the information storage medium in reproduction (Norton *et al.*, 1998). The fact that the cultural evolution or its subset the industrial (r)evolution happens much more rapidly when the information storage medium is the culture, e.g. oral tradition, books, films, internet, cellular phones and adverts, can be argued to be one of the fundamental causes of environmental problems. For example, raw materials needed to manufacture some product for which the demand is rapidly increasing can become increasingly scarce. In addition, nature relies on the renewable flow resource from the sun when industrial activity is based on the non-renewable stock resource of fossil raw materials and hence does not respect the renewal or reproductive 'time of nature'.

How could the gradual change metaphor help us to understand a regional industrial ecosystem then? Every industrial system, for example a regional industrial system, is a unique system. The system diversity includes economic, social, cultural and ecological dimensions. It is highly unlikely to be able to rapidly 'create' an industrial ecosystem from scratch. Similarly, rapid increase in the recycling rates of some materials, for example waste paper, may create new difficulties or displace the problem from one part of the system into another. Note that when there does not exist enough recycling or de-inking capacity for rapidly increasing amounts of waste paper, this may result in difficult and costly economic effects as the technological capacity must be created. Although it may be possible to provide the required capacity, the problem of increasing amount of recycling wastes follow the increasing recovery and recycling rates. Now de-inking sludge and incineration ash appear.

The gradual change metaphor would promote gradual development of industrial ecosystems with careful consideration of the system diversity and interdependency. One should build on existing strengths instead of trying to create IE rapidly from scratch. Increasing reliance on renewable resources, waste material and energy for moving closer to nature's time cycle or 'cyclical' time would reduce the burden on the environment.

JYVÄSKYLÄ INDUSTRIAL ECOSYSTEM

Here the Regional Energy Supply System of Jyväskylä Region in Finland will be reflected on the presented extended industrial ecology thesis. That is, to consider industrial ecology (or a regional industrial ecosystem) with the ecosystem principles or metaphors of roundput, diversity, locality and gradual change. The example of Jyväskylä IE here is based on our previous work.

Only in three countries in the world, in Finland, Denmark and the Netherlands, has the energy supply been organized to a large extent into a co-production of heat and electricity (co-production of heat and power, CHP, see Cogen, 1997; Lehtilä *et al.*, 1997). In this production method the waste heat formed in the electricity production is used for covering the heat energy demand of space heating or of industry instead of dumping it into local water system or into air. This results in reduced amounts of fuel used and in reduced costs when compared with the separate production of heat and electricity. The Jyväskylä regional energy supply system is based on the CHP method.

In Jyväskylä the waste energy flows and industrial and forestry wastes are used as resources between the actors of the region. As Figure 1 shows, the electricity and heat i.e. waste energy from electricity production are distributed to local households and other buildings by the Rauhalahti Power Plant, from which the Kangas paper mill derives industrial steam (waste energy). The paper mill in turn provides the local horticultural centre Greenlandia with heat energy through returning water. The plywood mill in the Säynätsalo suburb of the city of Jyväskylä provides the power plant with the waste of wood left-overs and receives energy (electricity) in turn. Waste wood for Rauhalahti plant is also derived from regional saw mills. The Säynätsalo plywood mill also utilizes the wood left-overs locally in a suburban boiler plant from which it obtains steam, the boiler providing

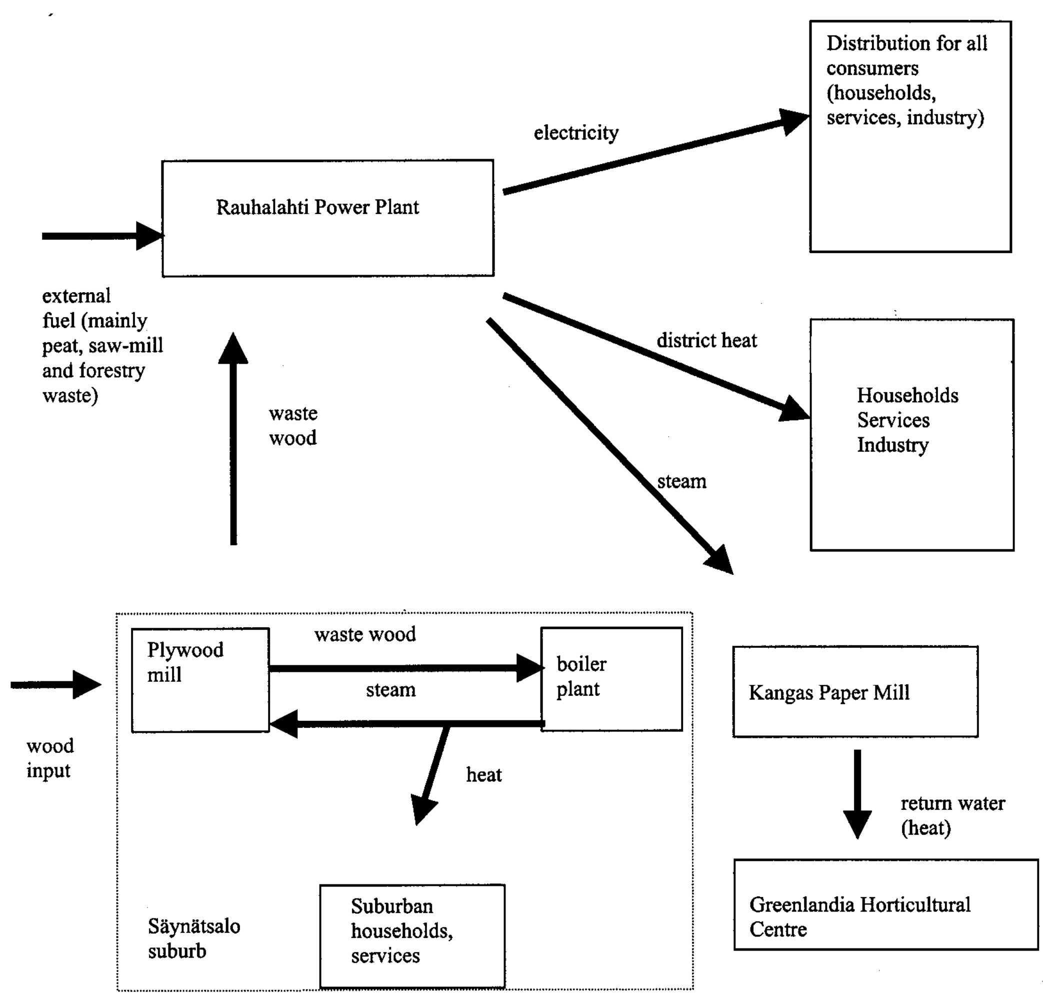

Figure 1. Jyväskylä industrial ecosystem (Korhonen *et al.*, 1999).

also the households and buildings in the immediate vicinity with heat. The waste ash from the Rauhalahti power plant is currently used nearby the plant to build a model for green gardening and green construction in the 'Green Land' project of Jyväskylä. Forest residues from regional cuttings are used as fuels in the energy production in the Rauhalahti power plant. Finally, there used to be a saw-mill in the town area, which provided wood waste for energy production. (Korhonen *et al.*, 1999).

The two main industrial ecology characteristics of the Jyväskylä system are the co-production of heat and electricity (cascading of energy) and the utilization of the industrial wastes such as wood waste as fuels (recycling of matter). The combined effect of these two features is that the consumption of external fuels in the system is 40% lower than without these features. The SO_2 emissions are over 50% and CO_2 over 30% lower than without the cascading of energy and recycling of waste material in the system. Naturally, also the costs have been reduced.

The metaphor of roundput decribes the system in Jyväskylä i.e. recycling of wood wastes as well as cascading of energy in the CHP method. There is considerable diversity in the actors of the region and diversity in their cooperation. A power company, a power plant, a paper mill, a plywood mill, forest companies and a horticultural centre have 'created' an inter-firm and inter-industry network system based on waste utilization. Diversity is an important metaphor also in the case of the technological capacity (fluidized bed burning technique) of the Rauhalahti power plant, i.e. 'technological diversity'. In Rauhalahti plant, in addition to CHP, a heterogeneous fuel basis is possible. The fuels can include peat, oil and coal but also waste wood, forest residues and the use of REF (recycled fuel) from households and further from industries is a future possibility. In other words, the inputs and outputs (electricity, district heat and steam) can be argued to be relatively diverse and the plant serves as the 'driving force' of industrial ecology type efforts in the region. The locality metaphor seems to serve for describing the system as well. The main actors are located within the radius of 50 kilometres and the fuels, besides peat, are transported from within approximately 50 kilometres. Peat is derived from 80–90 kilometres. The external consumption of fuels, which has been reduced considerably, was based mainly on coal and oil transported over thousands of kilometres.

One could also consider the evolution of the system in Jyväskylä with nature's principle of gradual change. The Jyväskylä system has evolved since the 1960s. Until the 1960s and 1970s, it was typical that each house, as well as each block of flats, had its own heating system and heating was based to a large extent on oil fuel. To improve the efficiency of the heating systems and to lower the control costs of heating, the heating systems of separate houses were connected together and gradually district heating networks were created.

The national electricity consumption in Finland was mainly covered by hydro-power until 1960s, but thereafter power production based on combustion and later also nuclear power have fulfilled the major share of the electricity demand. The co-production of heat and electricity started as early as the 1950s in Finland. After the first oil crisis in 1973, there was a need to decrease the dependency on oil, all of which is imported. Initiatives and programmes for promoting the domestic energy resources and efficiency improvements both in energy production and consumption were established. The local municipal power company in Jyväskylä had in practice a monopoly of supplying electricity to the local customers of the area. As there were no strong pressures to push the price of the electricity down or pay high profits to the city and as the local district heat networks were growing, the power company invested in district heating and so extended its activities. Soon also the co-production of heat and electricity was recognized to be a worthy option and the co-production started in Jyväskylä in Savela Plant in 1974 and in Rauhalahti Plant in 1986. Coal and peat fuels as well as oil inputs to the Jyväskylä energy supply system have been reduced considerably because of CHP. The technique that is used now in the Rauhalahti power plant is fluidized bed burning. This technique makes it possible to use also low-grade solid fuels like forestry and saw mill wastes. The use of coal is practically non-existent. The technique enables very diversified utilization of energy sources.

The development of the cooperation between the Rauhalahti power plant and the Kangas paper mill surfaced during the 1970s. It was encouraged by the energy crisis. The Kangas paper mill was interested in reducing the dependency on oil when trying to meet its demand for process heat. The city and the publicly owned power company made an acceptable offer to build the Rauhalahti power plant. Now the waste energy from the energy production can be used to satisfy the heat demand in the Kangas paper mill. So in a sense an economic value for waste has been created here. Without the establishment of the co-production effort between Rauhalahti and the Kangas paper mill this proportion of waste energy from Rauhalahti would be dumped into the local air or water system.

The cooperation between the Rauhalahti power plant, the Säynätsalo plywood mill and the Säynätsalo power plant has been recently enhanced by changes in the ownership structures. The owner of the power plant in Säynätsalo is now the same as that of Rauhalahti. This has led to efficiency improvement as for instance the energy production is now controlled remotely from the Rauhalahti plant. Savings in service and control costs are achieved, because the same personnel can be used to control the activity in Rauhalahti as well as in Säynätsalo. The change in the ownership structure is contributing to the cooperation between the two power plants as now wood left overs from Säynätsalo power plant are used in Rauhalahti.

The ecosystem metaphor of gradual change can be argued to serve to describe the 'self organizing' characteristics of the Jyväskylä industrial ecology towards reducing the use of imported non-renewable fossil raw materials (coal and oil). In this sense, the gradual system development in Jyväskylä has 'moved' the industrial development toward nature's cyclical time i.e. increasing the use of renewable resources and wastes. Economic reasons have formed the basis on which the Jyväskylä system, and the cooperation between the actors involved have evolved. The environmental pressure has not been a specific cause for the development of the system and there have not been any specific environmental management efforts or environmental programmes in the system development.

SOME SUGGESTIONS FOR EXTENDED INDUSTRIAL ECOLOGY

Industrial ecology seems to be a fruitful metaphor, particularly for opening up the eyes of the industrial actors or policy makers for learning about the environmental and economic possibilities that in theory are embedded in the IE approach. The approach here with the extended industrial ecology concept is intended to serve as a potential starting point for learning about some of the fundamental problems of the industry–environment question. In this part some initial suggestions on how could we 'strive' towards the extended industrial ecology are considered. Table 2 sums up the suggestions that are given under each metaphor.

Roundput

The challenge of roundput, i.e. recycling of matter and cascading of energy, has implications for the corporate environmental management interpretation of the value chain of a product. The traditional value chain is a linear chain, where the value of a product increases during its processing, i.e. value is added. Products are seen to have little or no value after use. With the IE metaphor of roundput this view is challenged as wastes are seen to have value. So an industrial ecosystem would in this respect follow a 'circular value chain approach' (see Linnanen, 1998).

The popular call for sustainable development requires that sustainable development discussion needs to focus on environmental, but also on economic and social, issues. So, in addition to environmental concerns, a company or a network of companies needs to take into account also economic and social issues

Table 2. Some suggestions for extended industrial ecology.

Roundput circular value chain the triple bottom line in the role of a company environmental policy with interdependent environmental, economic and social policy objectives and goals	Diversity facilitating environmental management of suppliers extending producer responsibility facilitating cooperation with a 'support system', an 'anchor tenant' from organizational learning to network learning
Locality municipality as a driving force, a support system beyond EMS of a single company, toward regional environmental management systems	Gradual change facilitating (gardening) the system diversity building on existing strengths of environmental management (on anchor tenants, support systems, driving forces) education, information gathering, economic incentives, infrastructure building gradually increasing taxation on fossil fuels

when planning industrial ecosystems, i.e. the so called 'triple bottom line'. For instance, consider the recently debated issue in the United States and Canada regarding the pressure to move towards the use of paper made from non-wood fibre, paper with fibre made from agricultural waste and fibre crops (Allenby, 1999). The conflict emerged between industrial actors and an environmental activist coalition. Here the industrial actors need to consider whether it is really environmentally preferable to use non-wood fibre and what the consequences are of using agricultural waste for paper. For instance, shifting agricultural biomass away from soil enrichment and into fibre production and disruption of the nitrogen cycle when enhanced demand results in greater agricultural activity to raise fibre crops may ultimately prove to be something that make the situation worse in environmental terms. When it comes to economic effects of the suggested move towards using agriculture for paper products instead of wood fibre, we find that a shift of capital and employment from forestry to agriculture may follow. In addition, distributional effects may arise as some regions dependent on forestry lose and those dependent on agriculture gain. Furthermore, cultural effects of these 'industrial ecology efforts' may appear when certain logging communities are affected by the change.

For the environmental policy maker in the case of various recycling initiatives, a similar dilemma may emerge. First, in the case of national large scale paper recycling systems for example, the policy maker must avoid problem displacement. Here one must consider and weight the environmental impacts of recovery, recycling and de-inking against an option where one chooses not to recycle, e.g. de-inking sludge versus waste paper. One must also consider the effects of incinerating the recovered paper against an option where paper is not recovered for incineration and left at landfills, e.g. incineration ashes versus waste paper. Second, increasing recovery rates of paper, common in many industrial countries in Europe at the moment, have economic effects in the form of increasing recycling and de-inking capacity requirements and possible reductions in the imports as domestic production increases with more recovered material. Third, increasing paper recovery may also generate social implications that must be taken into account, when recovery, sorting, transportation, de-inking and production create domestic job opportunities. Therefore, it would seem that the interdependent relationship of environmental, economic and social policy objectives (see also Stewen, 1998) must be acknowledged when planning recycling initiatives, similarly when trying to achieve industrial ecology and sustain the operation of regional industrial ecosystems.

Diversity

Adopting a circular environmental value chain type approach in a industrial system, requires reconsideration of the interaction between the actors involved (Whiston and Glachant, 1996). So 'post-consumption actors' such as waste management companies and municipalities and industrial actors such as manufacturers and consumer good industries need to interact, i.e. actors that may usually not cooperate with each other. Linnanen and Halme (1996) suggest three approaches for environmental value chain management. In upstream steering the pressure originates from customer requirements. Also a particular company can try and facilitate its suppliers in the production chain to adopt environmental management efforts. A method in upstream steering could also be something like eco-labelling. In downstream steering the environmental efforts are promoted by the producer's responsibility over the entire life cycle of the product. Finally, the authors suggest a need for a certain 'separate' coordinating unit or an 'external agent' for enhancing environmental management co-operation in the circular value chain system. In industrial ecology community such a coordination unit has been called also a 'support system' or a 'symbiosis institute' (Baas, 1998), an 'anchor tenant' (Chertow, 1998) or an 'initiator/stimulator' (Brand and de Bruijn, 1999). The idea is that an industrial ecosystem needs a 'driving force' to facilitate collaboration and cooperation between the actors involved. This could be a strong and influential single private company already engaged in some environmental management activity, coalition of industrial actors with a 'common goal' or a public entity such as a municipal organization.

Diversity in the actors involved requires also reconsideration of learning in industrial networks. The concept of 'network learning' as opposed to 'organizational learning' has been proposed by Ulhoi and Madsen (1998). The purpose is to go beyond the boundaries of a single company when understanding learning in industrial ecosystems. The argument would be here that as an industrial ecosystem is one with economic, social, cultural and ecological diversity, the network of learning must allow flexibility, dynamics to enable each member of a (new) individual symbiotant company to bring into the symbioses new knowledge, experiences etc.

Locality

To enhance the emergence of local and regional industrial ecosystems, we feel the role of an 'impartial' public body like a municipal organization is important. This could facilitate the interaction between private sector actors that otherwise may be reluctant to cooperate, because of competitive attitudes. In addition, the natural role of a municipal organization includes consideration of economic, social and ecological issues of the region, something that is not considered, at least not holistically, in a single private company located in the region. Taking economic, social, ecological and cultural dimensions into account is vital for sustaining diverse regional industrial systems or regional industrial ecosystems. Furthermore, the municipality may provide a forum, where data regarding the material and energy flows of the industrial and other actors in the region may be gathered and analysed. The municipality would also in principle seem to provide the needed institutional or political basis and support for cooperation efforts in a certain region.

Welford and Gouldson (1993) have suggested the concept of regional environmental management systems (REMS) for regional environmental management. In REMS the familiar business world model of an environmental management system (EMS) is extended beyond the boundaries of a single company to develop an environmental management system, where the essential regional actors, private companies, public authorities, research institutions, the local university, citizen and environmental groups engage in cooperation. The gains of a REMS effort could arise, when the region can be promoted as 'a green region', or with a 'regional green label'. In other words, when successful, REMS could help to achieve environmental and also economic improvements through cooperation. We feel that in REMS, the role of a municipal organization as a facilitator or a support system becomes important.

Gradual change

As any system that sustains itself in long term, also a successful regional industrial ecosystem would be a diverse system. Hence we agree with authors that note, that to create such a system rapidly 'from scratch' borders the impossible (Chertow, 1998). In addition, the case studies of regional industrial ecology[3] are only few at the moment and every regional system is unique and differs from a certain another region. Therefore, to create some universal 'design principles' or manuals for regional industrial ecosystem management is very difficult. Further, consider the basis of the IE analogy, that is an ecosystem, which is a self-organizing entity with no 'master plans' or 'management' efforts. The experience from Kalundborg and also from the presented Jyväskylä industrial ecosystem support this line of argument.

In other words, the *gradual* 'facilitative management' or perhaps something close to the metaphor of 'gardening' seems to be the direction to follow, when developing regional industrial ecology, at least with current experience. Again, the role of an anchor tenant may be important here. An actor that is a powerful and influential actor in a certain region and has already taken steps toward environmental work, for example the adaptation of alternative fuels, or an EMS, could generate the symbiosis in waste utilization for instance (see Wallner, 1999). It would seem that, as the effort to 'develop' an industrial ecosystem is such an enormous one, the direction to follow is to build gradually on existing strengths. The Rauhalahti power plant in the Jyväskylä energy supply system with its technological capacity could serve as an example of a vital actor around which one could try and build the IE effort. The capacity in the power plant makes a heterogeneous fuel basis possible. In other words, with this kind of driving force, the industrial actors may gradually learn the possibilities of interaction and find uses for their waste products, for instance as fuels in energy production.

[3] For an overview on regional eco-industrial parks see Cote and Cohen-Rosenthal, 1998.

A municipality can also be seen as a kind of a support system in regional industrial ecology. It could promote the gradual development of the system with flexible methods such as continuous economic incentives, infrastructure building, education and information gathering, the functions that already are included in the agenda of a municipality. Finally, the policy maker could facilitate gradual development with continuing economic incentives, for example increasing taxation of fossil fuels year by year to enhance the reliance on regenerative resources and the use of waste material and energy flows (see Ring, 1997). This could suit the gradual change metaphor (renewal time of nature) and also reduce transportation and hence serve the goal of locality. Further, reducing the fossil fuel consumption promotes the search for alternative fuels i.e. diversity in industrial input. Finally, controlling the fossil fuel use makes it easier to achieve also the metaphor of roundput as the demand for recycling increases.

TOWARD A PERFECT INDUSTRIAL ECOSYSTEM

Our approach has been metaphoric. Metaphors can be helpful as 'eye openers' but it must be remembered that the industrial systems will never operate as nature does. However, in the Popperian sense of bold and provocative arguments and for generating discussion metaphors could at times be useful. One could briefly then try and envision what a 'perfect industrial ecosystem' would look like.

In Figure 2 an ideal of a perfect industrial ecosystem is considered. Such a system would be constructed from the two systems: the industrial subsystem and the mother ecosystem in which the industrial system is embedded. The only input to the system as a whole would be the (infinite) energy from the sun and waste heat would be the only output from the system. The inputs to the industrial system would include only renewable resources and recycling of matter as well as cascading of energy would then happen

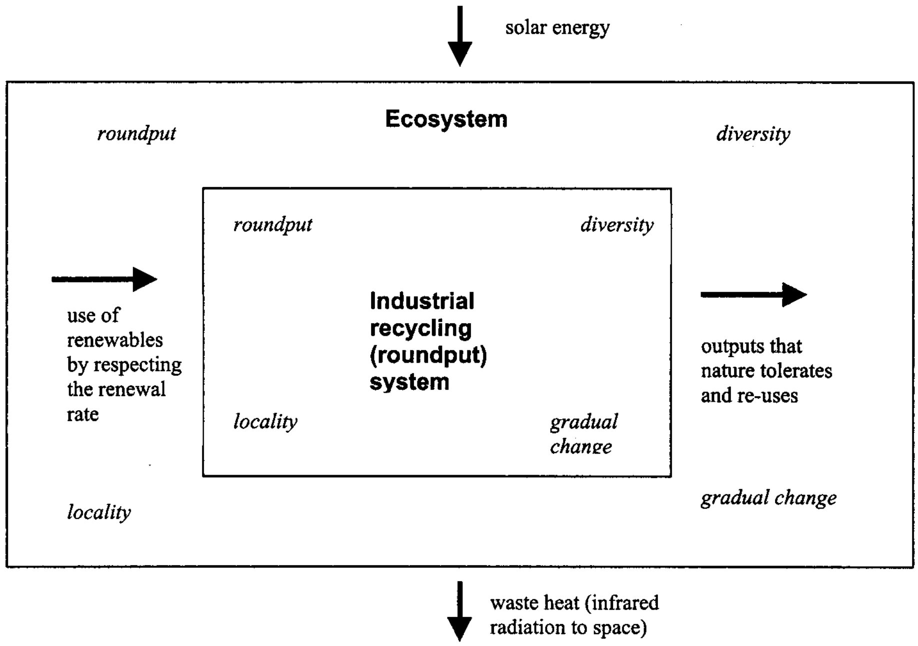

Figure 2. Extended industrial ecology and a vision of a perfect industrial ecosystem. An industrial subsystem and the mother ecosystem reaching industrial–environment win–win.

between the industrial actors of the system. The outputs from the industrial system would include only such that nature can tolerate or perhaps re-use and recycle (e.g. use of nutrient flows embedded in industrial waste ash as fertilizer[4]) in its own operation. In a perfect industrial ecosystem both of the systems operate according to the same principles of system development: roundput, diversity, locality and gradual change. In other words, as in extended industrial ecology, also the industrial system is based on recycling and diverse interdependency and cooperation. The industrial system would be arranged as a local cooperation system that respects the local natural limiting factors and develops gradually following the renewal rate or the reproduction cycle of the local renewable resources. The Forest Industry of Finland could provide us with an example of the entire national industry that relies on the renewable resource of the forests. The annual cuttings are lower than the annual growth in Finnish forests (Kauppi *et al.*, 1992). The annual binding of the CO_2 in the forests exceeds the amount of carbon released through forest industry cuttings. In other words, here nature is recycling the waste of industrial activity.

[4] In the Forest Industry of Finland some of the nutrients embedded in the industry power plant ash can be returned back to nature as fertilizer (Ranta *et al.*, 1996; Korhonen *et al.*, unpublished manuscript).

The perfect industrial ecosystem would, when successful, be a business–environment or industry–environment win–win situation (see Porter and van der Linde, 1996). As, in theory, recycling can reduce the virgin material and energy input to the industrial system as well as the waste and emission output from the system, the environmental win would happen. The economic gains here appear as raw material and energy costs, costs resulting from environmental legislation, waste management costs as well as 'image costs' are reduced and possibly the green market potential is better utilized.

With regard to the industrial ecology vision the biggest weakness in the Kalundborg regional system is the fact that despite the waste material and energy utilization between the actors involved, the system still relies on imported non-renewable fossil fuels; i.e., the two key actors of the system are a coal fired power plant and an oil refinery. The weak point in the Jyväskylä industrial ecosystem is the use of peat. However, peat used in the Jyväskylä energy supply system is a local resource and peat is rather abundant in Finland (Korhonen *et al.*, 1999). The possibilities for reducing the use of peat must be considered. This could be achieved for instance by increasing the use of waste fuels and forest residues from cuttings.

CONCLUSION

In the concept of extended industrial ecology the four basic principles of system development of ecosystems are included in the industrial ecology thesis with a metaphoric approach. The ecosystem analogy here includes the metaphors of roundput, diversity, locality and gradual change. The only case studies on the IE system approach have been conducted in a regional context. Also in this paper the regional perspective was considered, though we feel that to extend the system boundaries to larger/other industrial systems would also suit the discussed metaphors.

The Jyväskylä regional industrial system can be described with the extended industrial ecology approach. However, to derive some more 'universal' management suggestions for regional industrial ecosystems can be very difficult as the experience is still limited. In addition, every region is different from each other and therefore the 'transferability' of a successful IE model from one region to the next is always difficult. Some initial possible directions can be discussed to which the IE implementation can be developed.

Companies need to understand their wastes as potential valuable raw materials for others. Learning and cooperation should be enhanced and a firm must extend its vision to include the entire system of companies that it is embedded in. The border between public and private actors must also be crossed to provide industrial ecosystems with the needed institutional support. The policy maker can benefit when acknowledging that to sustain recycling or roundput systems the environmental issues should be reflected also in their economic and social or cultural implications, i.e. the societal context of the flows. It would seem that one should strive to build on existing strengths of environmental management of a regional industrial system when trying to facilitate the development of the system towards a cooperative system based on waste material and energy utilization.

Finally, we feel that the extended industrial ecology may benefit industrial environmental management and environmental policy in the following ways.

1. The fundamental cause of environmental problems is that the ecosystem and the industrial system operate according to different principles of system development although the industrial system is always only a subsystem of the larger ecosystem and dependent on it. With the four ecosystem metaphors reflected in industrial systems one can perhaps learn to understand some of the basic problems of the industry–environment interaction.
2. With the metaphors, e.g. roundput, we may be able to identify the weak points of a certain industrial system or the possible points of improvement with regard to this metaphor and then facilitate the emergence of industrial ecology (roudput or recycling systems).
3. With the four metaphors we can perhaps better 'evaluate' or assess the 'ecology' of an industrial system. Arguably, a system based on recycling of matter and cascading of energy, which is a diverse cooperation system arranged locally and mainly relying on renewable flow resources or wastes, may better 'fullfil' the conditions of sustainability than a system where these metaphors do not happen.

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