JYVÄSKYLÄ STUDIES IN BUSINESS AND ECONOMICS 5

Jouni Korhonen

Industrial Ecosystem

Using the Material and Energy Flow Model of an Ecosystem in an Industrial System

Esitetään Jyväskylän yliopiston taloustieteiden tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston Villa Ranan Blomstedt- salissa
marraskuun 9. päivänä 2000 kello 12.

Academic dissertation to be publicly discussed, by permission of
the School of Business and Economics of the University of Jyväskylä,
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JYVÄSKYLÄN YLIOPISTO

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Publishing Unit, University Library of Jyväskylä

ISBN 951-39-0826-7 (nid.), 978-951-39-5111-5 (PDF)
ISSN 1457-1986

Jyväskylä University Printing House, Jyväskylä
and ER-Paino Ky, Lievestuore 2000

ABSTRACT

Jouni Korhonen
Industrial Ecosystem - Using the material and energy flow model of an ecosystem in an industrial system.
Jyväskylä: University of Jyväskylä, 2000, 131 p.
(Jyväskylä Studies in Business and Economics,
ISSN 1457-1986; 5)
ISBN 951-39-0826-7 (nid.), 978-951-39-5111-5 (PDF)
Tiivistelmä
Diss.

Industrial Ecology (IE) is a concept for understanding and management of the interaction between industrial systems and natural ecosystems. The concept arises from the metaphor of the material and energy flow model of an ecosystem, in which organisms use each other's waste material and waste energy flows through cooperation. The only external input to the system as a whole is the (infinite) solar energy. In an *industrial ecosystem*, the environmental burden of the system as a whole is reduced. Analogously to recycling of matter and cascading of energy typical for a mature ecosystem, this industrial system would develop material cycles and employ energy cascades through cooperation between the companies in the system. When successful, an industrial ecosystem substitutes raw materials and energy that industry takes from nature with wastes and hence reduces the virgin input of the system and the waste and emission output from the system. Economic gains arise in the reduction of raw material and energy costs and waste management costs. In this study, the basic industrial ecosystem principle is understood as *roundput* for describing recycling of matter and cascading of energy in an industrial system. The ecosystem material and energy flow model including the flows of matter, nutrients, energy and carbon is used for constructing an industrial ecosystem. Case studies on the material flows of the forest industry of Finland and on the Jyväskylä regional energy supply system in Finland are presented. The industrial ecology material and energy flow model of the study includes the four ecosystem principles of *roundput, diversity, interdependency* and *locality*.

Keywords: industrial ecology, industrial ecosystem, forest industry industrial ecosystem, Jyväskylä industrial ecosystem, four ecosystem principles

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PREFACE

The purpose of this book is to try and explore the learning embedded in the emerging concept of industrial ecology, a neologism or a metaphor that grasps our attention. Industrial ecology and an industrial ecosystem are attractive expressions. To construct a term that carries with itself components from economics, business studies and ecology is certainly interesting. The first assumption I had when I first encountered the term was that it must be about environmentalism. The second idea one thinks of is the relation of business and the environment or industrial development and its relation to natural evolution. But why do we need to call corporate environmental management as industrial ecology? Is it really necessary to have just another metaphor for the sustainable development discussion?

I grew to love the concept of industrial ecology during my studies. For me, it seemed easy to understand the argumentation behind the use of this neologism when considering the possible paths toward sustainability. The modern society, the economic or the industrial system will always be only a subsystem of the larger ecosystem. Our systems will always be embedded in the system boundaries of the mother system, which provides us with life support. The term industrial ecology informs the student that its aim is to contribute into the societal sustainability discussion and it does this by expressing the need to acknowledge our interdependency with the mother system.

The idea of creating an industrial ecosystem, to use the model of a natural ecosystem and to apply this in industrial environmental management is very appealing. Can industrial systems operate as nature does? Such an endeavor may perhaps seem overly ambitious at first. However, one could also argue that it actually is quite logical to try and learn from Mother Nature. Nature has been here much longer than we have. When reflecting on the common interpretations of the term of sustainability, some would argue that nature has demonstrated its ability to sustain itself while the development of societal and industrial systems seems unsustainable. The depleting natural resources and the reduced capacity of the natural life support system to tolerate industrial waste and emission outputs are the result of the development of modern society that does not take into account the natural limiting factors of cultural evolution.

When I was reading the industrial ecology literature, I thought that one could put it that environmental problems occur, because the two systems the societal, economic or industrial and the natural ecosystem operate in a different way. Nature recycles, we do not. Nature respects natural reproduction, when we rely on non-renewable natural resources. One could also argue that we are similar to all organisms or to ecosystems as we will use resources or food from the environment and put back products or wastes. To follow this line of reasoning, maybe we should try and capture the wisdom offered to us by nature and mimic the natural model. In other words, we should adapt it as a model of a sustainable system. For me, this is the idea that makes the concept of industrial ecology so fascinating. This is also the reason why my biggest problem and failure has been and continues to be to promote the concept as an absolute an-

swer to all the environmental problems of modernity. I thank all those who have showed me that there is a lot of complexity involved in the conceptual development of industrial ecology, which needs to be carefully studied before we can even begin to address the application of the concept in practical environmental management, which itself is a multi-dimensional and continuously changing focus of study.

I am happy having had the opportunity to read the industrial ecology literature and to try and learn from the authors that have alerted people to think about the possibilities in this rich metaphor. The analogy makes it exciting to read. I hope I can continue to study the field in future. I know so little about ecology or about management that there is lot to learn for me. Industrial ecology can be understood as a combination of the two fields and of many others and hence it will continue to yield interdependent areas for future study.

In substance, I understand this book as an introduction to industrial ecology for myself, which I need to try and lay out before I can learn more about the potential paths to achieve industrial ecology in practice. In think it is important to first try and reflect on industrial ecology as a metaphoric goal on top, as a vision or as a paradigm for sustainability whether we intend to proceed by addressing the more pin-pointed questions related to environmental policy instruments, environmental management systems, material flow models or life cycle assessment, environmental and ecological accounting or specific cases in corporate environmental management.

The fact that even a very initial attempt to touch the interacting surface of such different fields of study as ecology and economics or ecology and management is a difficult goal for a thesis became clear for me during my studies and throughout the project of writing the thesis. I have not a background in ecology. The effort in the thesis would have been impossible without the insight of my academic supervisor, Research Professor Ilkka Savolainen at VTT energy (The Technical Research Center of Finland, and formerly at Jyväskylä University corporate environmental management program). I am grateful for having had the opportunity to try and learn from his deep vision in environmental issues, which covers such a wide array of topics across disciplinary lines. He has been incredibly patient with me when having to take me through even the very basics of ecology and environmental engineering. In addition, his experience in writing articles has helped me a great deal in the presentation. I simply thank him.

The way I want to see it, we have had a small research team with Ilkka Savolainen and with Margareta Wihersaari from VTT. Ilkka and Margareta, thank you for sharing your experience with me on industrial material flows, for lively discussions and for being so patient with my hurried and undeveloped ideas and too long article drafts. Thank you for teaching me about issues I knew so little about. Our team, as I like to call our collaboration, has showed me what industrial ecology research is about; it is about co-operation.

I would like to express my warmest gratitude to Professor John R. Ehrenfeld at Massachusetts Institute of Technology for the review process of the thesis that was so valuable for me. I want to thank him for reading my draft and the following versions so carefully. This book would have been impossible without the insight of professor Ehrenfeld. The thesis was almost completely rewritten based on his guidance. The experience of John Ehrenfeld on industrial ecology and his extensive comments and suggestions for the thesis were a learning experience that only happens once during my studies. I greatly value this opportunity that I have had. I am greatly indebted also to Professor Richard Welford at Huddersfield University for the review process. His reflection on the thesis showed me that although the world of industrial ecology might be wonderfully attractive and seem to provide the solution for all environmental problems, the corporate environmental management domain and concepts such as industrial ecology will always have to be tested in their particular context, in different situations with different factors affecting the outcome. Thank you also for hosting interesting conference from which I have managed to gather lots of important material for the thesis and where I met interesting scholars and fellow Ph.D. students.

My six months at Harvard University with professor Donald W. Oliver have been the starting point of my studies. I am so happy that you let me to study with you and offered me so much through discussion and literature and through teaching me about the writing process. I greatly value the time with Donald and the talks that showed me that it is possible to combine concepts, methods or everyday things that seem so separate from each other like work and play or ecology and economics. I thank Donald's family for letting me visit and helping me in so many ways throughout my stay. Joelle Pelletier at Harvard Graduate School of Education helped me a great deal during my visit. I miss the many invaluable discussions with Ben Williams and thank him for introducing me to wonderful literature on environmental issues.

There is no expression equal to my gratefulness to my sister professor Outi Korhonen at Helsinki University, Erik Castren Institute of International Law and Human Rights. Outi has been my big sister and so much more. I thank her for the mental support throughout the process and for being my friend. I thank Outi for being my teacher. Her insight on scientific literature is in a category of its own. Outi has been my example and also my advisor in the Ph.D. She has shared her experience on studying and on the process of writing a thesis with me and showed me how to present one's argument. I look forward to our discussion on her new book *International Law Situated* (Kluwer Academic Publishers 2000).

My indebtedness to Professor Ari-Veikko Anttiroiko at the University of Tampere for his encouraging words during a period in which they were crucial cannot be overemphasized. I thank him for being so supportive with regard to my studies and giving me advice with his wonderful knowledge on literature. I greatly value the teaching, the provocative lectures and the advice on environmental policy and environmental and ecological economics given by Professor Jussi Raumolin at the University of Tampere environmental policy program. Professor Juha Varto took the time to read my student paper and gave me so important words for my self-confidence. I have profited greatly from the discussions with Professor Marja Järvelä and I am grateful to her for her advice.

Dr. Fredrik Burström has been a wonderful fellow student. He has always been ahead of me in the Ph.D. process and I have greatly benefited by learning from him. I remember the conferences and the joint debates and writing. I look forward for reading his book *Municipalities and Environment – Towards a Theory on Municipal Environmental Management* (Royal Institute of Technology, Stockholm, Sweden. 2000). Fredrik has so kindly let me to introduce myself to some of the articles in the book. These have helped me a great deal. I miss studying environmental issues together with Eero Antikainen and I hope we will reinitiate 'our philosophy on environment and life', which surfaced just around the same time, when I first learned about the concept of industrial ecology. Thank you for sharing your ideas with me.

I remain greatly indebted to the following persons for lively debates, teaching and words of encouragement I have received during the project and throughout my studies: Ulla Koivusaari, Matti Leinonen, Philip Grappe, Risto Sänkiaho, Jukka Akselin, Jarkko Lumio, Niilo Frilander, Ari Paloviita, Tapio Pento, Juha Näsi, Mika Tuunanen, Kimmo Hyrsky, Christoph Bey, Frank Boons, Hannu Kurki, Lassi Linnanen, Kyösti Pulliainen, Sirpa Pietikäinen, Juho Korhonen, Juha Honkatukia, Kari Heimonen, Olavi Uusitalo, Ruben Kuzlovski. Dr. Matti Estola and Professor Kalle Määttä have been stimulating discussion partners, commented my ideas and helped me in the presentation of the argument. I look forward to future collaboration with them in my new home Joensuu. I remember and value the inspiring words of encouragement and the support from Professor Matti Koiranen at the University of Jyväskylä. University of Jyväskylä School of Business Economics supported my studies and my conference trips, which have been vital for the thesis. Each of the conferences contributed greatly to my effort to learn.

ERP Environment conference organizing team, Elaine White and Tina Newstead, thank you for hosting such important conferences. These are wonderful learning opportunities, and specially, ideal places for testing one's ideas and receiving feed-back on one's argument during a Ph.D. project. Similarly, the conferences hosted by the International Society for Ecological Economics (ISEE) have been innovative events and perfect places for interactive discussion. I will remain grateful for the many anonymous reviewers of the journals to which I have submitted my article drafts. I am honored having had the possibility to benefit from the deep vision and the thoughtful insights by the referees on industrial ecology, who have taken the time to read my undeveloped arguments and who have showed me some of the basics of scientific writing. I think it is essential for a Ph.D. student, for one's self confidence that the journals provide comments on one's work even in case of article drafts that clearly do not suit the journal's scope or are still weak in the argumentation, substance or style of writing.

I owe a special gratitude to all the students at the University of Jyväskylä who have kindly shown interest in and attended my courses on ecological economics, material flows and industrial ecology. This opportunity that I had to reflect on various aspects of my work in the lectures has been a challenge for me. My teaching experience is still very limited. I hope I have been able to construct my writing drawing from the feed-back and the important critique received in the lectures. Professor Oliver taught me that the best way to learn is to first process your arguments by talking about them and simultaneously testing them in a situation in which there exists an opportunity for immediate feedback.

This Ph.D. process has been possible because of the support from The Finnish Foundation for Economic Education, Emil Aaltonen Foundation, Foundation for Municipal and Regional Development, Finnish Culture Foundation, Academy of Finland, Tampere City Scientific Foundation, Tampere City, Jyväskylä City, Jyväskylä Business Foundation, University of Jyväskylä and University of Joensuu. This backing that has made it possible for me to continue my studies and meet various teachers and fellow students has been invaluable for the process.

I thank Ismo Nurmi for being so patient with me during the editing of the manuscript. The service in the University of Jyväskylä library in the Kaukolaina section has been perfect. Thank you for helping me in the search for materials and being so flexible. I am grateful for the supportive and stimulating discussions on life and research with Docent Tuula Pahkinen, which have given me strength and kept me going at crucial times in the process.

My best friend Tero Nissinen has been involved in so many things that have happened in my life. I greatly value his continuous support, advice and guidance. During our times at the tennis courts and after those times to this very date you have been my friend, my coach, 'kept me in the team' and showed me an example. I cannot find words to express how important this has been for me and how grateful I am.

I owe so much to my mother and father and to my sister. Tuula, thank you for everything, for introducing me to literature and reading. Kalevi, thank you for the support and for the continuous discussions on life or on theory. Outi, thank you for all the support you have given to me.

Joensuu, October 22, 2000

Jouni Korhonen

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PART ONE

Industrial Ecology
A source for sustainability?

CHAPTER ONE

Industrial Environmental Management and Industrial Ecology

Introduction

It can be argued that 'environmental problems do not exist any longer', rather societal problems with an ever-increasing environmental dimension. Various societal actors, international bodies, governments as well as academics from philosophy to engineering and economics have addressed the problems resulting from the burden that the society is causing on the natural ecosystem.

But what does this discussion imply for firms, for industrial actors, industrial or product systems? Some have argued that nature does not have a 'voice' in a societal decision making process as it is always present in this process only through those who possess the means of language and societal power. Nature is present indirectly through our interpretation[1]. Societal knowledge on the natural ecosystem is based on uncertainty. But on the other hand, nature does seem to generate lot of noise in the modern everyday of companies, firms and industrial systems.

Industry takes in too much of natural resources from the environment that it will use for producing products. In economics or in business studies this could be understood that industrial actors and systems are obtaining the source functions that the natural life support system will provide it with. Some call these as 'natural capital' and 'natural income'[2]. Natural capital is the forest that through harvest yields the natural income for companies to use. Forests are able to reproduce and grow and therefore these are understood as renewable flow resources. The non-renewable resources such as coal and oil are stock resources in that they are not able to reproduce in a biological sense of the reproduction rate. Fossil coal and oil yield us natural income in the form of fuel input to energy production.

A modern industrial company also dumps wastes and emissions into nature. To use the terms above, one can understand this as obtaining or using the sink functions that nature will provide the economic systems with. These could also be understood as a form of natural capital, or perhaps more easily as ecosystem services. Nature is absorbing the wastes and emissions that we produce. More specifically, because of burning the fossil fuels of coal and oil in energy production, emissions that are very difficult for nature to tolerate amount. Particularly, carbon dioxide emissions (CO_2) from fossil fuel use are affecting the climate change, possibly the most severe environmental problem of today.

In the light of this simplified presentation, two very general goals can be determined for industrial environmental management. First, the amount of natural resources that industrial activity takes from nature should be reduced. Second, the amount of wastes and emissions that industry produces should be reduced. I argued above that nature seems to make lot of noise in the industrial environmental management questions of today. With this expression I want to emphasize that although a company would not feel any moral responsibility

[1] for discussion see Haila & Levins 1992.
[2] Costanza & Daly 1992, Daly 1996, Wackernagel & Rees 1997, Costanza et al. 1997

toward the environment, which often are presented as its primal stimuli to protect nature, it increasingly often has to do it anyway.

Using natural resources and energy implies raw material and energy costs. Producing wastes implies waste management costs. Environmental legislation, if not considered proactively, can result in 'panic costs', when a company is not prepared. In addition, other societal pressures, e.g. the image or the demand in 'green markets', may affect the competitive situation of a firm. Industrial environmental management is then increasing in importance when a formulation of a business strategy is considered.

Industrial environmental management has taken many forms during the last decade. It seems that in business studies we are able to create a new field of study simply by adding the word environment in front of the more traditional fields. There are courses on environmental management or corporate environmental management, environmental or ecological accounting and environmental marketing etc. The environment is a question that will affect all of these fields of study. All societal actors and their actions will create environmental effects. Therefore, in this respect, the development of various environmentally orientated disciplines must be seen as positive. Indeed, industrial or corporate environmental management as a field is beginning to be acknowledged in education, in the everyday of business and in the planning of national and international policy or legislation. However, this does not mean that industrial environmental management, environmental policy or the sustainability agenda of society in general has been able to solve the problems in the natural environment. The growing evidence from the environmental studies and indicators for this will not be discussed here.

Industrial Ecology and Industrial Ecosystems

The most famous environmental report is the so called Brundtland Report surfaced in 1987 from World Commission on Environment and Development, which defines sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). From an environmental perspective, societal development of today is not sustainable. As noted earlier, with regard to industrial development, too much natural resources are used and too much wastes and emissions are released back to nature from industrial and product systems. Sustainable development has been constructed as an international and national guide for various environmental agendas and programs, the goal on top, toward which societal environmental management must strive. Sustainable development discussion has then stimulated also the fields such as industrial environmental management. Concepts and tools as well as different management programs have been formulated in order to reduce the industrial burden on the environment.

Industrial Ecology (IE) is a concept that has gained increasing attention during the last decade, especially since the *Scientific American* article by Frosch and Gallopoulos (1989). The authors coined the term:

> ...the traditional model of industrial activity – in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of – should be transformed into a more integrated model: an industrial ecosystem.
> ...The industrial ecosystem would function as an analogue of biological ecosystems. (Plants synthesize nutrients that feed herbivores, which in turn feed a chain of carnivores whose wastes and bodies eventually feed further generations of plants.) (Frosch & Gallopoulos 1989, p95)

Ayres & Ayres (1996) reflected on the importance of constructing this neologism of an Industrial Ecosystem, which is a recycling system of co-operative industrial actors:

> Industrial ecology (IE) is a neologism intended to call attention to a biological analogy: the fact that an ecosystem tends to recycle most essential nutrients, using only energy from the sun to 'drive' the system...In a 'perfect' ecosystem the only input is energy from the sun. All other materials are recycled biologically, in the sense that each species' waste products are the 'food' of another species.
> ...The industrial analog of an ecosystem is an industrial park (or some larger region) which captures and recycles all physical materials internally, consuming only energy from outside the system, and producing only non-material services for sale to consumers. (Ayres & Ayres 1996, pp278-279)

Industrial ecology has been understood as a material flow management concept for industrial companies. It will focus on the physical material and energy flows that a company uses from its natural environment as well as from its co-operation partners. It will focus on the flows that a company will produce as its waste and on emission outputs that are dumped back to nature.

The works by Frosch and Gallopoulos and Robert Ayres have undoubtedly been a significant influence in industrial ecology research. The citations show that the IE community has used a natural ecosystem metaphor when trying to construct a strategy to facilitate sustainable development of industrial activity. One can interpret the often cited arguments by Ayres within the concept of 'industrial metabolism' (1994) to emphasize that what is important is that organisms, animals, humans, ecosystems, firms and industrial systems are all living systems and alike in that they take in raw materials or food from the environment and produce outputs back to the environment. In terms of what is understood by the common notion of sustainable development of a living material and energy flow system, one could argue that ecosystems are sustainable but industrial and human economic systems are not sustainable (see Ehrenfeld 2000[3]).

It is easy to understand why this analogy to a natural ecosystem is appealing, when designing industrial systems. It seems logical to try and learn from the model of a sustainable system. Industrial activity operates with the model of a 'throughput' flow of matter and energy; from raw materials, to products to wastes, e.g. from non-renewable fossil stock resources to heat or electricity to emissions to be dumped into air and water. As opposed to this throughput, William Ahsworth (1995) has used the term 'aroundput' for de-

[3] see also Bey 2000.

scribing the cyclical flow of matter or recycling of matter between organisms of a forest ecosystem.

For the purposes of my presentation in the thesis the term *roundput* will be used. The cyclic flow of materials and embedded energy typical for a sustainable mature ecosystem would be an 'environmental win' if achieved in an industrial system. An industrial ecosystem would arrive at this model through recycling of matter and cascading of energy between industrial actors. With roundput it is possible to reduce wastes and substitute the use of scarce virgin resources with wastes.

Since its popularization, many authors have elaborated on the concept and why it is useful in understanding environmental problems in general and, eventually, for constructing policy programs and management strategies in particular (Tibbs 1992, Allenby & Cooper 1994, Graedel & Allenby 1995, Benyus 1997). They will argue, that although the perfect industrial ecosystem will never be possible, consider the laws of thermodynamics, entropy, it is obvious that the analogy is the direction to which industrial environmental management should strive.

A Local Industrial Ecosystem

At some cases, authors in the industrial ecology community have attempted to systematically build a theory for industrial ecology by using the model of the system development of an ecosystem, a biological systems perspective (Allenby & Cooper 1994, Benyus 1997). The comparison has been divided into two broad perspectives. The first is based on a linear flow of materials in a developing or immature ecosystem. Such a situation could have existed when there was little life on earth and the resources were not scarce. This is argued to be similar to the throughput flows of matter and energy in industrial systems today. This first kind of a comparison between the industrial system and the ecosystem is known as 'Type I ecology' (Jelinski et al. 1992, Allenby & Cooper 1994).

The second is that of a mature ecosystem and the almost complete cyclic flow of matter and embedded energy (waste as non-existent), because resources are scarce as life and the need for food increases in the system. This model is compared to the material and energy flows of a visualized sustainable industrial ecosystem. The comparison here has been called as 'Type III ecology' as the middle phase between a developing and a mature ecosystem is coined Type II ecology (Jelinski et al. 1992, Allenby & Cooper 1994).

A suitable case for considering an industrial ecosystem would be a local collection of industrial actors. In a local system the companies are located in close physical proximity and may face some common environmental pressures or economic pressures that result from problems in the local natural resources, e.g. scarce resources, accumulation of wastes and the resulting waste management costs etc. Therefore, they can be more willing to engage in co-operative waste utilization than actors, which do not share same resources and are geographically separated from each other. The use of each other's waste may also be technically and practically easier for actors that are close to each other.

For me, in terms of the analogy of an ecosystem, a local collection of co-operative firms is easier to understand than some other form of an industrial or product system. The industrial ecosystem analogy is usually associated with a local/regional industrial ecosystem or an eco-industrial park[4]. The most often cited case is the recycling system at Kalundborg industrial district in Denmark (Ehrenfeld & Gertler 1997, Gertler & Ehrenfeld 1996). The system here is based on advanced recycling between actors in the Kalundborg community. The co-operation involves an electric-power-generating plant, an oil refinery, a bio-technology production plant, a plasterboard factory, a sulfuric acid producer, cement producers, local agriculture and horticulture, and district heating in Kalundborg (Tibbs 1992).

In **figure 1** a simplified model of the flow of matter in an ecosystem is presented (see Husar 1994). Plants as producers, animals as consumers and bacteria, decomposers or fungi as recyclers co-operate by using each other's waste materials both as a construction material input as well for source of energy[5]. In **figure 2** an idealized vision of a successful local industrial ecosystem is considered. Here the companies engage into a locally based recycling system or network in similar fashion to organisms in the ecosystem analogy.

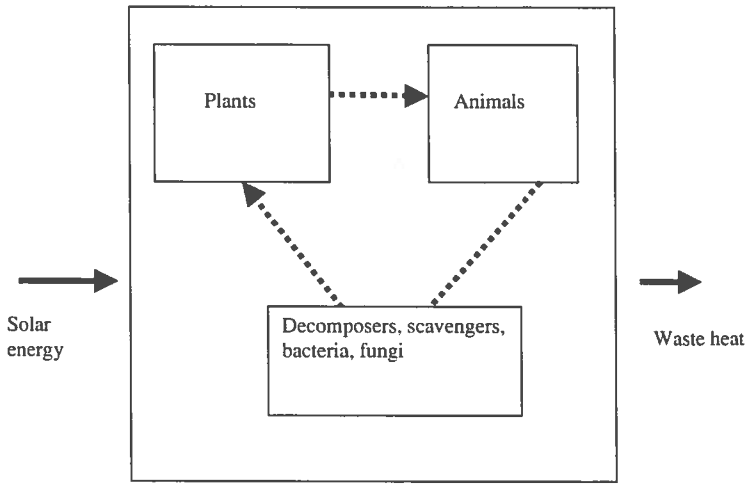

Figure 1 **Simplified flow of matter in an ecosystem.** The flow of matter in a natural ecosystem is cyclic. Plants bind solar energy into chemical form. Plants (producers), animals (consumers) and decomposers, microbes and bacteria (recyclers) are a system in which the actors utilize each other's waste material flows as a source for energy and as a construction material for organisms. The only external input to the system as a whole is the (infinite) solar energy and the system is materially closed. Eventually, the energy will be released as waste heat into air and into water from which it radiates back to space.

[4] Cote & Hall 1994, Cote & Cohen-Rosenthal 1998, Ehrenfeld & Gertler 1997, Baas 1998, Korhonen et al. 1999, Korhonen 2001a, b, Burström & Korhonen 2001

[5] see Korhonen 2000.

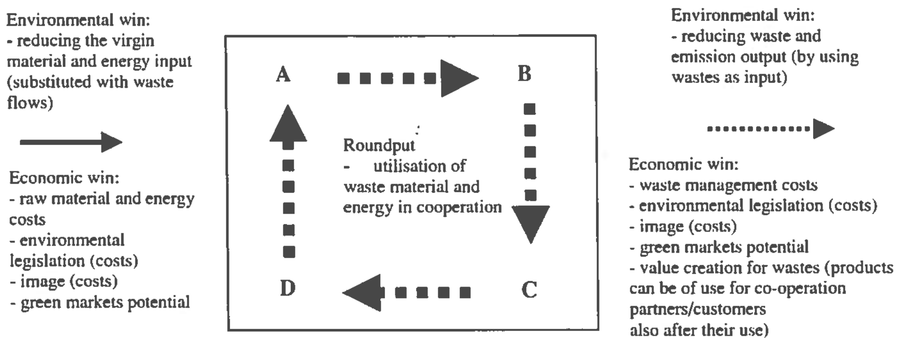

Figure 2 **The basic industrial ecology systems analogy.** Industrial systems are encouraged to move towards an interactive local system based on the system model of ecosystems i.e. 'a roundput system'. Through cooperative waste material and energy utilisation between the industrial actors A, B, C and D, the virgin material and energy input as well as the waste and emission output of this *industrial ecosystem* are reduced (raw material and energy substituted with wastes). By reducing the waste management costs, raw material and energy costs, costs resulting from environmental legislation and by improving the environmental image as well as the 'green market situation' of the system, the economic gains are possible. The economic gains can also be achieved as the value chain of the product is cyclic instead of the traditional linear chain. In an industrial ecosystem the product has after-use value. Wastes from a company are seen as important resources for its customers and co-operation partners. Waste material and waste energy: ....

If this model would be achieved in practical industrial environmental management, it could be understood as a 'business-environment win-win situation' (see Porter & van der Linde 1996[6]). The environmental win arises as the actors use waste as a resource and thereby reduce the needed virgin raw materials and energy input in the system that is derived from nature. The amount of waste and emission output from the system to the natural environment is also reduced. This is because waste is used in production. Further, in the case of energy production, the emissions such as carbon dioxide (CO_2) that are the main cause of the climate change and occur because of fossil fuel use for energy, can be reduced. Forms of waste fuels, e.g. saw-mill wastes or other wood derived wastes are less emission intensive than fossil coal and oil.

The economic gains are possible, because the cheap local waste resources are used as inputs in industrial processes, in production. These substitute the often imported and expensive virgin material and energy. Similarly, the costs that a company has to face, because of direct environmental legislation or green taxes that are focusing on the use of fossil fuels or on the generation of wastes and emissions can be reduced through substituting the fossil fuels with waste fuels derived from a co-operation partner. Because waste is used as a resource, the waste management costs are reduced.

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[6] See discussion by various authors in Welford & Starkey 1996. *Business and the Environment.*

In this highly idealized picture, also the green image or the green market potential of the individual companies in the system, and more importantly, of the system as a whole, can be improved. In economic terms an industrial ecosystem would have a circular value chain instead the traditional linear value chain[7]. Products have also after-use value, or wastes have value. Further, other economic opportunities may arise in the system through industrial ecology, because of increasing co-operation between the actors involved.

Ecosystem principles for an industrial ecosystem

To author's knowledge the industrial ecology analogy, when considered in terms of the material flows of an industrial system, is in most cases associated to the principle of roundput or closed loops, the recycling of matter and cascading of energy. The aim of this thesis is to consider does the ecosystem material and energy flow model provide the industrial ecosystem thesis with other beneficial principles or metaphors. The *four ecosystem principles* that will be studied include the basic *roundput* as well as the additional three; *diversity, interdependency* and *locality* [8].

Industrial ecology is still only an emerging concept, and at most, on a stage of a metaphor in terms of the ecosystem analogy. Therefore, these four ecosystem principles that are given below are not intended to describe the ecosystem operation in any absolute terms. Rather, very general characteristics are considered in order to facilitate discussion on the industrial ecosystem analogy.

Roundput (waste utilization). As discussed in the first part of the chapter with figure 1, the ecosystem is a recycling system. Organisms use each other's waste material and waste energy and hence waste does not exist in an ecosystem in the industrial sense of the term. Ecosystem relies on recycling of matter and cascading of energy. The possibility to use this principle in industrial environmental management will be studied.

Diversity. It is commonly agreed that the sustainability of an ecosystem depends on diversity, on biodiversity, diversity in species and organisms. Diversity of species and their genetic variance within the groups of plants, animals and decomposers forms the basis of the system operation. The ecosystem is able to sustain itself, because of its capacity to adapt into changing environmental conditions through diversity, e.g. number of species or organisms. I will try and consider whether this principle could be used alongside roundput in an industrial ecosystem project.

Interdependency. Diversity in organisms and species present in an ecosystem has lead into co-operation and interdependency between them. Different organisms have developed symbiotant relations between them to be able to adapt to the environmental conditions etc. Also this principle is added to the working hypotheses of an industrial ecosystem in the book.

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[7] see Linnanen 1998.

[8] The work by Irene Ring has influenced the formulation of the study question here. She has compared the ecosystem to economic systems. See Ring 1997, Korhonen 2001c.

Locality. An ecosystem needs to adapt into local conditions. It will use local natural resources by respecting their reproduction rates and will produce for local consumers. The ecosystem principle of locality will be the fourth element of the industrial ecosystem in the study question.

Structure of the book

Figure 3 describes the structure of the thesis. This first part is intended as an introduction and the presentation of the working hypotheses, the effort to draw from the natural ecosystem model in IE by including also other ecosystem principles besides roundput into the concept. The second part will consist of two case studies. In the first case the material and energy flows of the forest industry of Finland are considered. We will focus on the flows of matter, nutrients, energy and carbon. The aim is to construct a Forest Industry Industrial Ecosystem[9]. The second case considers industrial ecology with a local/regional energy supply system of heat and electricity in Finland. Industrial ecology is reflected on the flows of waste (residual) energy and waste materials in the system. The effort will be to construct an industrial ecosystem for the Jyväskylä city, Jyväskylä Industrial Ecosystem[10].

In the last part, the experience from the cases will be reflected on the study question. Here chapter four will present my understanding of an industrial ecosystem. The industrial ecosystem concept that is given in this chapter will be divided into three parts. The final chapter considers some barriers of industrial ecology or industrial ecosystem projects. It is intended as a conclusion for the thesis and as a discussion on the presented approach and arguments.

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[9] see Korhonen et al. 2001.
[10] see Korhonen et al. 1999.

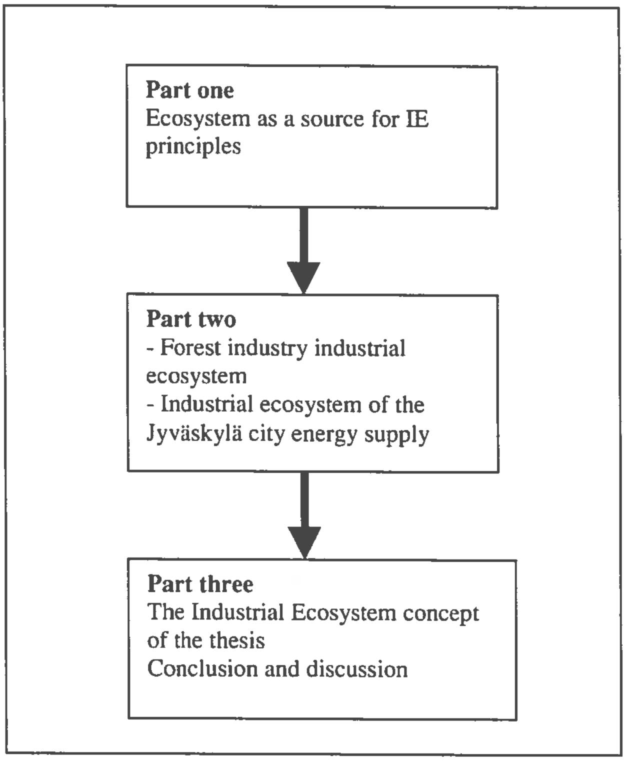

Figure 3 The structure of the thesis

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PART TWO

Industrial Ecology in Practice

CHAPTER TWO

Industrial Ecosystem in the Finnish Forest Industry: Using the material and energy flow model of a forest ecosystem in a forest industry system

Introduction

In chapter one I defined an Industrial Ecosystem as a local collection of industrial actors that utilize each other's waste material and waste (residual) energy through co-operation. The model for this system comes from the material and energy flows of an ecosystem. The motivation of industry to engage into these kind of efforts would seem to be a possibility. As discussed earlier, in theory, the environmental benefits of an industrial ecosystem arise by reducing the virgin material and energy input to the system as a whole as well as the waste and emission output from the system. When successful, this effort can result in cost reductions, e.g. raw material costs or waste management costs. In this chapter, the concept of an industrial ecosystem is studied in practice with a case study. I will reflect on the Forest industry of Finland with regard to the main material and energy flows.

There are 11 local/regional forest industry systems in Finland, which are called as 'regional forest industry integrates'. Such a local industrial system is a community of interacting firms. Forestry companies, a saw mill, a pulp mill, a paper mill and a power plant form a forest industry integrate. We will reflect on the industrial ecology of the main material and energy flows that constitute the operation of the entire national forest industry. These flows are also present in a local forest industry system, and therefore this chapter can be understood as a study on a local/regional industrial ecosystem concept.

The forest ecosystem as a model for industrial ecology

To construct an industrial ecosystem for forest industry, we take the model of the material and energy flows of a forest ecosystem as a starting point. We will then reflect this on the operation of the national forest industry of Finland. In other words, to follow the industrial ecology philosophy, *the material and energy flow model of a forest ecosystem is used to arrive at an industrial ecosystem in the forest industry system*. The emphasis will be on recycling of matter and cascading of energy, i.e. on closing the loop and redirecting the throughput material flow model of industrial development toward the cyclic or 'roundput' model of an ecosystem.

Below, the flows of matter (biomass), nutrients, energy and carbon in a forest ecosystem are presented in general terms. Also other substances or fluxes could be studied or these flows could be approached with different emphasis, e.g. on particular (harmful) substances. Arguably these four, when taken in general sense, are among the most important flows in the industrial ecosystem development. Industrial activity consumes matter and with the throughput philosophy dumps waste material into nature, often in forms that nature has difficulty in tolerating. Industrial production, or wood harvesting for forest industry, is disturbing the circular flow of nutrients in nature, such as the flows of base cations (BC) of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}. Production activities of society take these from the ecosystem circle and can put them in the waste dumps where they are isolated from the ecosystems or put them into nature in a form that is less suitable for use (for the operation of the ecosystem) than the form in which the natural flows have originally been. Industrial activity is driven by energy and to a large extent by the use of non-renewable natural stock resources such as coal and oil. The use of these creates emissions such as CO_2 and SO_2 that are the main cause of climate change and acidification. Natural ecosystems have difficulty in binding the CO_2.

Flows of matter in a forest ecosystem

Figure 1 describes the forest ecosystem flow of matter. Trees and other green plants or producers form biomass, mainly carbohydrates and H_2O through photosynthesis. Biomass of green plants is used by other organisms as food. Respiration and decay of all organisms releases the CO_2 and H_2O back to the physical surroundings of the organisms. Plants also use water in large amounts for transporting nutrients and other substances. Oxygen (O_2) is released through photosynthesis and bound in respiration and decay.

In addition to CO_2, water (H_2O) is used as input material in photosynthesis. Water will be released back when biomass is decomposed. That is, both the carbon cycle and the hydrological cycle are connected to the main material flows of forest ecosystems.

It is obvious that this circular flow of matter has been the most commonly used model for material flow management of industry in the literature on the IE analogy. In industrial ecology, the recycling of matter between different organisms is usually described as the flow that starts from the plants as producers, continues to animals as consumers and through the decomposers, bacteria and fungi that recycle matter back to plants (Husar 1994). Or the carbon-oxygen cycle is used to exemplify the idea in that plants consume carbon dioxide and produce oxygen as a waste, when animals require oxygen for respiration and produce carbon dioxide as a metabolic waste (Ayres & Ayres 1996).

The disturbances in natural processes, from which feed-backs have now begun to occur and which are increasingly observed by society, result because industry takes in lot of inputs from the material flow of nature, often exceeding the reproduction rate. For instance, a strong deforestation has taken place in Europe and North-America in the 19th and 20th century, and is presently taking place in many tropical countries. The matter that originates from nature might not be used efficiently in industrial processes. In addition, the waste materials that are dumped back into nature can be in harmful forms. The producer-consumer-recycler model is incomplete in the industrial system, because the flow that goes to the recyclers from production and consumption is small when compared to the ecosystem.

Therefore, three goals for industrial ecology could be presented with regard to the flow of matter. First, the IE goal is to develop industrial systems in a way that the use of virgin inputs of matter are kept within the renewal capacity of the flows. The use of non-renewable materials should be limited strongly, below some acceptable level, the determination of which takes into account intergenerational equity. Second, the virgin materials, as well as materials and products that are refined or manufactured from them, should be used efficiently. As much as is possible of the potential embedded in them should be used to reduce the total intake to industrial production. Third, industrial and consumption originated waste outputs of matter that are released to nature should be in a form that nature can reuse or tolerate.

In other words, the reproduction capacity of natural resources (or a fair amount of non-renewable resources) should be secured as well as the natural waste assimilation capacity, i.e. the source as well as the sink functions provided by nature. Some call these the natural capital stock and the resulting natural income (flows from the stock, ecosystem services) (see Daly 1996, Costanza et al. 1997, Costanza & Daly 1992, Wackernagel & Rees 1997). In theory, this could be achieved with recycling of matter, which is an efficient way of using the matter and which reduces wastes that are not utilized in production or in consumption processes.

These efforts would follow the way in which nature operates. Nature does not exceed its reproduction rate in the development of the ecosystem. Nature uses matter and wastes efficiently due to the scarcity of resources for increasing life on earth. An ecosystem does not produce harmful waste materials in such large concentrated amounts that continuously disturb the operation of the system as a whole (see Commoner 1997).

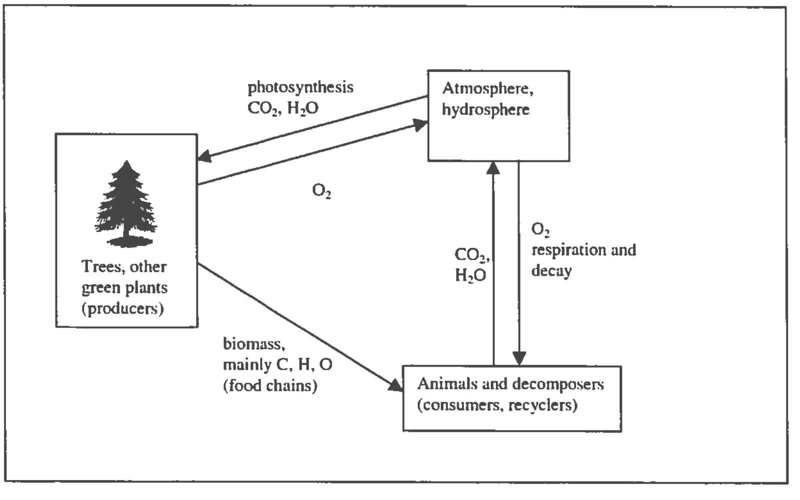

Figure 1 Simplified flow of matter in a forest ecosystem

Flows of nutrients in a forest ecosystem

In **figure 2** the flows of base cations (BC) of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} in a forest ecosystem are described in general terms to illustrate some of the main concerns for industrial ecosystem development of forest industry. Plants take base cation nutrients from soil. In decay of litter and of fine roots the nutrients are released back to the soil. Weathering of minerals forms new nutrients to soil and leaching with water removes them into ground water and into other water systems. These two processes are important parts of the geological cycle of the considered elements.

The operation of industrial and agricultural processes disturb the circular flow of nutrients in the ecosystem. The industry takes raw materials from nature and hence nutrients are removed from the natural cycle. The nutrients travel as embedded in forest industry raw wood products through processes of production and consumption and to a large extent end up in waste dumps. In many cases the nutrients that are returned to nature are in a form that nature has difficulty in using in its circle, because of e.g. too rapid release rates or because of 'non-natural' heavy metal concentrations in them and changes in $_pH$ levels. Lack of nutrients and imbalances in the ecosystem can lead to acidification, increases in aluminium and heavy metal concentrations and reduced growth of trees.

Two goals for industrial ecology can be defined with regard to the nutrient flows. First, an industrial ecosystem project should reduce the amount of important nutrients that industry takes in from nature. Second, an industrial ecosystem would increase the amount of nutrients that can be safely returned to nature, e.g. as fertilizer. Nutrients in industrial and societal production and consumption processes should be recycled between human industrial and societal actors. The amount of non-harmful flows of nutrients that are returned to nature should be increased. This would be similar to the model of the ecosystem. In an ecosystem, nutrients flow in a cycle and are kept within the system. The cycle is reproductive. In nature, nutrients are recycled and the harmful or poisonous flows or substances do not concentrate in a way that is the case in industrial wastes released to nature from the anthroposphere.

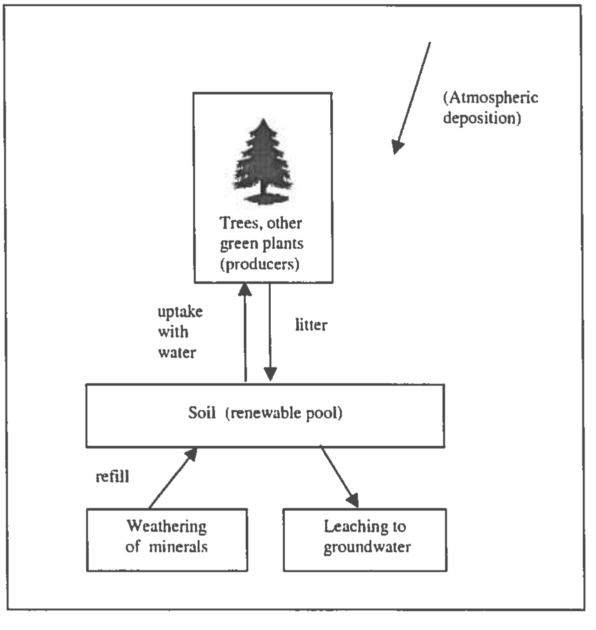

Figure 2 Flows of base cation nutrients (Ca^{2+}, Mg^{2+}, K^+, Na^+) in a forest ecosystem

Flows of energy in a forest ecosystem

In **figure 3** the flows of energy in a forest ecosystem are reflected. Trees and other green plants bind incoming solar radiation energy chemically into biomass in the process of photosynthesis. Other organisms utilize this energy in complex food webs. In food weds biomass transfers the chemically bound energy in cascade chains to various trophic levels for the use of organisms. Finally energy ends up as heat in the physical surroundings and it is radiated back to space.

Trees or plants work like decentralized power plants using renewable solar energy and providing the food chain with energy (Ring 1997, see Zwölfer 1991). In industrial development the non-renewable geological stocks of coal and oil are been utilized and the energy is produced and used often in only few or one quality, temperature or pressure levels. In a cascade chain of an ecosystem the energy or waste energy is used in several quality levels.

In case of energy production and consumption, the goal for industrial ecology in order to reduce the burden caused by industrial activity to nature, is to reduce the use of non-renewable fossil coal, oil and gas in industrial production and in societal consumption, and the emissions that this use generates. The stocks of fossil coal, oil and gas will eventually run out, if their use continues, despite they may last considerably longer than predicted in the 1970s (see Linden 1994). The capacity of the ecosystems to tolerate changing climatic conditions, CO_2 emissions, which affect the radiation energy balance of the earth, is the limiting factor of industrial outputs. The climate change is perhaps the more severe question than issues related to the maintenance of the earth's stocks of fossil raw materials (see Linden 1994). The global energy production is still to a large extent, e.g. approximately 80 %, based on fossil fuels. In addition to the CO_2 emissions, emissions such as NO_x and SO_2 from fossil fuel burning also create other environmental risks, e.g. acidification. Acidification depositions from NO_x and SO_2 emissions speed up the BC nutrient flow from ecosystems to ground water systems, and hence, accelerate acidification.

We could define four interrelated general goals for industrial ecology with regard to the production and consumption of energy in industrial and in societal consumption systems. First, industrial systems should use solar energy directly or indirectly through using renewable hydropower, wind power or biomass, e.g. renewable natural resources such as wood embedded energy instead of non-renewable fossil energy. This use rate of renewable energy sources must be kept within the renewable capacity of the system. Second, the non-renewable stock use for energy in industry and in society should be substituted also by using industrial and societal wastes as fuels. Wastes in this sense are a renewable flow resource that can serve to substitute the non-renewable stock resources.

Third, energy should be used in a cascade-like connection, which would contribute to the effort to reduce the use of non-renewable stock resources of coal and oil. This means that energy should be utilized in many different quality levels to minimize the losses and the increase of entropy (see Sirkin and ten Houten 1994). The lower pressure levels and temperature levels of thermal energy should also be utilized instead of dumping the waste (residual) energy into the ecosystem. For example, waste energy from the thermal electricity production should be used in the production of industrial steam/heat and district heat, when possible (see chapter three). To note on the concepts discussed by Robert Ayres (1998), this goal for energy use can be understood with the concept of exergy. Exergy is a concept that defines energy quality as the amount of work the energy from a given resource can perform. Exergy is the useful part of energy (Ayres 1998). In theory, the cascade-type use of energy would minimize the reduction of exergy as the amount of energy that is embedded in a resource and that can be used in industrial activity is increased, the utilization time or the economy of the resource is increased.

The fourth goal that can be defined for industrial and societal energy production and use in terms of industrial ecology can be achieved more easily if the previous goals will be reached. This goal is that the amount of emissions from industrial energy production and use and from end-consumption is reduced. In case of CO_2, the main emission leading to the climatic change, the renewable natural resource flows as fuels instead of the non-renewable stock resources, are less emission intensive. If the use of renewables is kept within the sustainable yield, the amount of CO_2 released from harvesting and utilization of biomass can be absorbed by the renewable resources, in this case the forest ecosystem.

Utilizing wastes as fuels helps the industry to keep the use of renewables in accordance with sustainability, because less pressure is put on the harvesting or extraction of these resources as they can be substituted with wastes. From the viewpoint of IE, recycling of wastes as products or raw material is, however, more favorable, than their use as energy source. Wastes can serve to substitute also the fossil fuels. This will reduce the carbon and CO_2 that will be released from the geological cycle (stock resources) into the organic or biological reproduction cycle (flow resources). This will help the ecosystem, e.g. the forest ecosystem, to tolerate the amount of CO_2 that is circulating within its cycle, i.e. in the organic cycle. Some industrial wastes, e.g. wood wastes from saw-mills are completely CO_2 neutral if based on biomass from sustainable forestry. The combustible fraction of household wastes in industrialized countries, however, consists of wood based wastes (paper products etc.), which are CO_2 neutral and of plastics wastes, the origin of which is fossil oil. The effective CO_2 emissions per energy unit in case of household wastes are about one fourth of fossil fuels.

These four goals serve to describe also the way in which the ecosystem operates. An ecosystem uses solar energy directly and indirectly through binding it into renewable biomass, the use rate of which (with organisms) respects reproduction. One could also put it, that nature uses wastes. The food chain is organized into a cascade type connection, where energy is passed from an organism or from a trophic level to another. Nature does not seem to create concentrated poisonous emissions that harm its operation or the system diversity (see Commoner 1997).

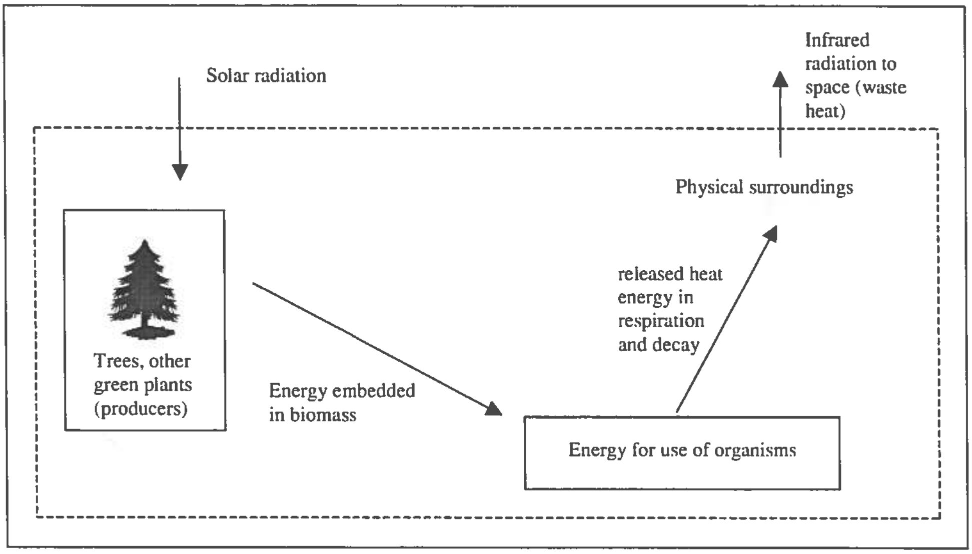

Figure 3 Flows of energy in a forest ecosystem

Flows of carbon in a forest ecosystem

In **figure 4** the carbon cycle of the forest ecosystem is given. Carbon flows follow the flows of matter shown already in Figure 1. CO_2 is bound by photosynthesis in trees and is released back to the atmosphere by respiration and decay of organisms.

The goals in industrial ecology in the case of the carbon cycle are similar to those with the flow of energy. The ultimate goal could be that the carbon stock in the geological cycle is kept intact or constant or no fossil fuels are consumed. In theory, the ways to achieve this, include the use of solar energy, renewable resources, waste fuels and the cascade-type use of the amount of work (energy) embedded in resources, for example between different industrial processes or between those and end-consumption (see chapter three on the Jyväskylä energy supply system industrial ecology). The second (interrelated) goal would be that the amount of CO_2 that is released into the atmosphere, because of industrial or consumption activities, can be absorbed by the ecosystems. As noted, the key questions here are that the renewable rate of renewables is secured and the amount of 'external' carbon i.e. the carbon from the geological cycle (stocks) that is released into the biological or organic cycle (flows) is minimized. This is, because in the long term, the renewable ecosystems can only absorb the carbon that originates from their own flows, from the organic cycle.

These goals related to the carbon cycle seem to be in line with the industrial ecosystem analogy. The organic or biological cycle of nature does not use carbon stocks from the geological reserves. Therefore, it does not generate (external) stock originated emissions that cannot be absorbed by the renewable resources. As noted above, nature is able to function in this way, because of solar energy, biomass and renewable resource utilization, waste utilization and cascading of energy.

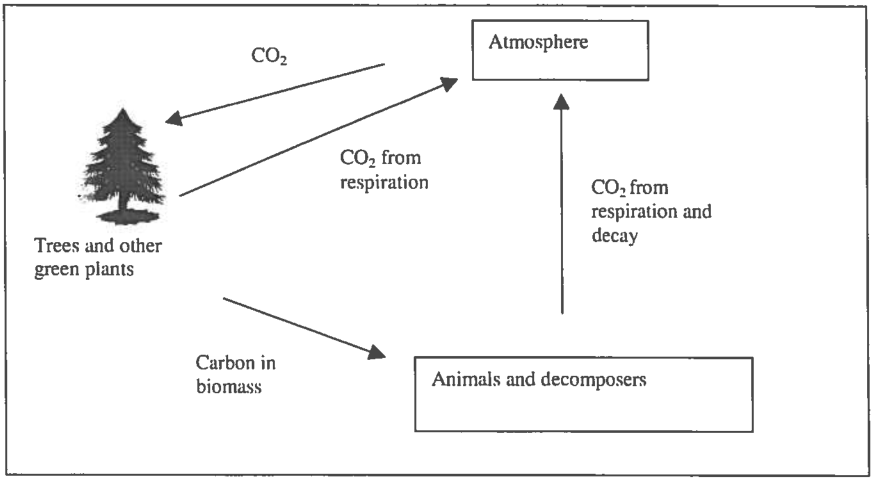

Figure 4 The flow of carbon in a forest ecosystem

Forest Industry Industrial Ecosystem

In this part a Forest Industry Industrial Ecosystem is constructed from the flows of matter, nutrients, energy and carbon in the context of the national forest industry of Finland. The method is to use the model of these flows as they happen in a forest ecosystem described above. Hence the emphasis will be on the industrial ecology of the forest industry operation. Recycling of matter and cascading of energy that takes place between different industrial actors through co-operation in an industrial system are considered to mimic the flows of a forest ecosystem. We try and illustrate how industrial ecology happens in the forest industry and how IE type development could be enhanced.

Flows of matter in a forest industry system

Figure 5 describes the main material flows of the Finnish forest industry, which are based on wood resources. The annual cuttings of forests in Finland are less than the annual growth of the trees (Kauppi et al. 1992). In addition, round-wood is imported from Russia to be used in the industry . The total cuttings in Russia have decreased considerably during the last ten years. At the present level they are below the growth rate of forests. Saw mill wastes i.e. wood wastes (bark, dust etc.) are used in the production of pulp as well as in the production of energy. Wastes from pulp mills, namely bark and black liquor are incinerated as input in the energy production. Also wastes from saw mill industry mechanical products, such as furniture mill wood waste, are used as fuel in energy production. The recovery rates of paper are relatively high in Finland (61 %).

Totally, about 59 % of wooden material of the harvested round-wood ends up in the products, and 40 % is used for energy. Because of waste material utilization as inputs in the manufacturing of products and as fuels in the energy production, less than 2 % of the harvested wooden material ends up as wastes that are not used in the industry operation.

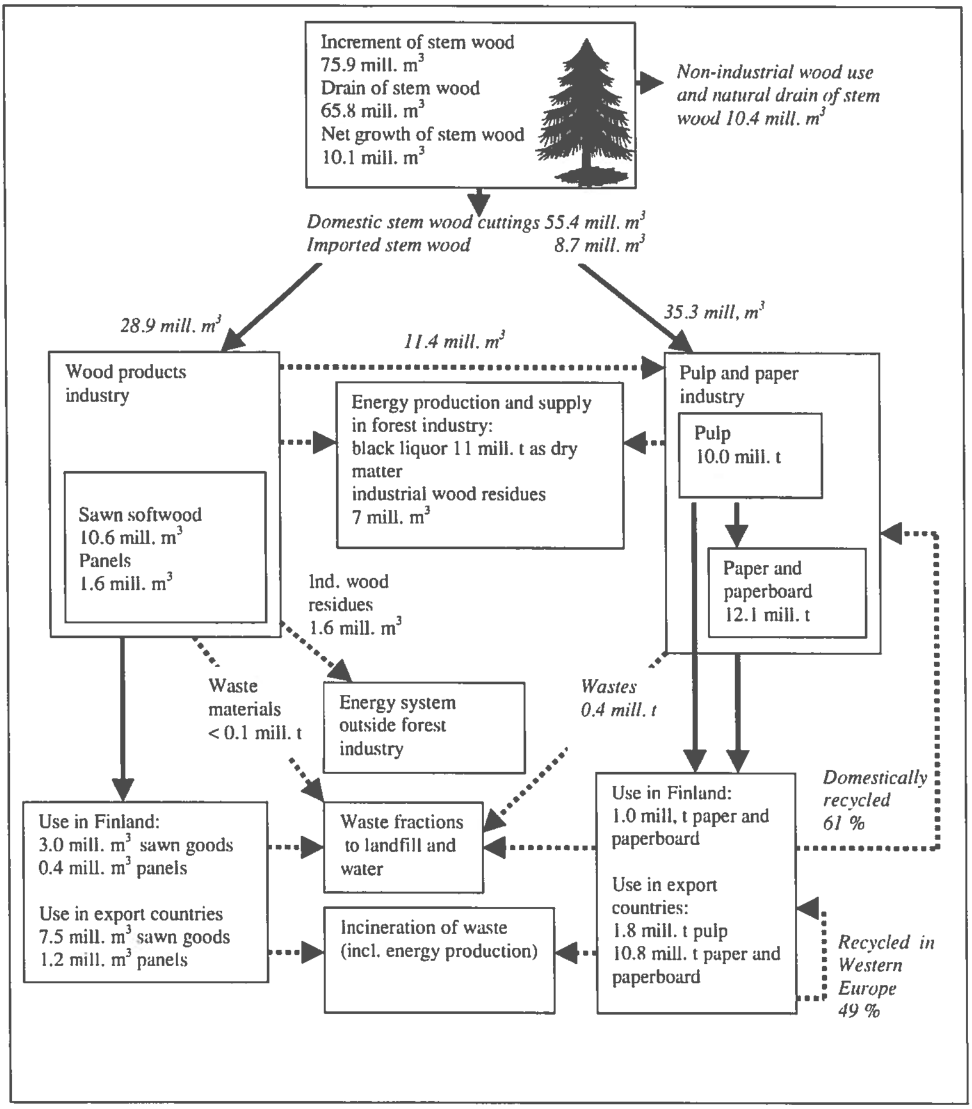

Figure 5 **Flows of wooden materials in the Finnish forest industry in 1997.** In Finland the annual cuttings are smaller than the annual growth of forests. Saw mill wastes are used in pulp production and in energy production. Also wastes from pulp mills (black liquor) are utilized as fuel in energy production, which is conducted in CHP plants (co-production of heat and electricity). In addition, large amounts of paper products are recovered and recycled back to paper production. Totally 59 % of wooden material end up to products and 40 % to energy production. Waste flows from industry to landfills and waste waters is less than 2 % of input flow.
Abbreviations: mill. t = million tonnes, mill. m³ = million cubic metres
Round wood and products ———— Wastes and by-products ....

Flows of nutrients in a forest industry system

Figure 6 describes the nutrient flows in Finnish forest industry that originate from forests. Until recently, the flows of base cations (BC) of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} embedded in wood based products have flown through the industry and ended up at landfills or as wastes that cannot be used. Phosphorus (P) is also an important nutrient, which follows the flows of base cations. Nitrogen (N) in nitrate or in ammonia form is of importance, but presently relatively abundant due to anthropogenic atmospheric deposition. The flows of base cations are expressed in calsium equivalents. The flows are calculated on the basis of typical base cation contents of parts of the trees, stem wood, bark, branches and foliage for three common tree species in Finland (Scots pine, Norway spruce, Birch). The atomic weight and valence are accounted in the calculation of equivalency.

Recently some studies have indicated that it is possible to recover the wood-waste-based ash from forest industry power plants and return it to the forest ecosystem to serve as fertilizer (Ranta et al. 1996). Also the first pilot plants at the forest industry mills are currently in operation for processing wood-based ashes for fertilizer use. The forest industry activity is hence beginning to participate into the cycle of nutrients in the forests, because base cations in the energy production ash are returned as fertilizer into the forests. In the future, this effort should be increased to complete the natural-industrial nutrient cycle.

The problem here may be the heavy metal content of the ash, e.g. cadmium. Also the ash should be conditioned into a form in which it can be easily stored, used and spread. Furthermore, the release rate of base cations from fertilizer should be appropriate in order to avoid rapid changes in the pH value of the soil. Base cations in a natural forest ecosystem have a renewable pool, which is made up by weathering of minerals and, to some extent, also by atmospheric deposition. Acidic deposition, on the other hand, can remove base cations from the pool and cause disturbance in the nutrient balance of the trees. Returning of ashes back to the ecosystem increases also buffering against acid rain.

Theoretically, it would be possible to return almost all of the wood-waste-based ash from the energy production back to the forest ecosystem. This would mean about 60 % of the base cations removed from the forest ecosystem through harvesting. In practice the figure will be much lower and the need to return ash is still small. The base cation content is highest in bark, branches, twists, and specially in needles. The recent developments in the efforts to increase the use of forest residues as an energy source in the forest industry power plants thus increases the base cation flow from the ecosystem. Therefore, the need for recycling of nutrients will increase. Here one must weight the importance of substituting the fossil fuels with the use of forest residues as fuels against the importance and the above noted difficulties involved when the nutrient cycle of the forest ecosystem is concerned.

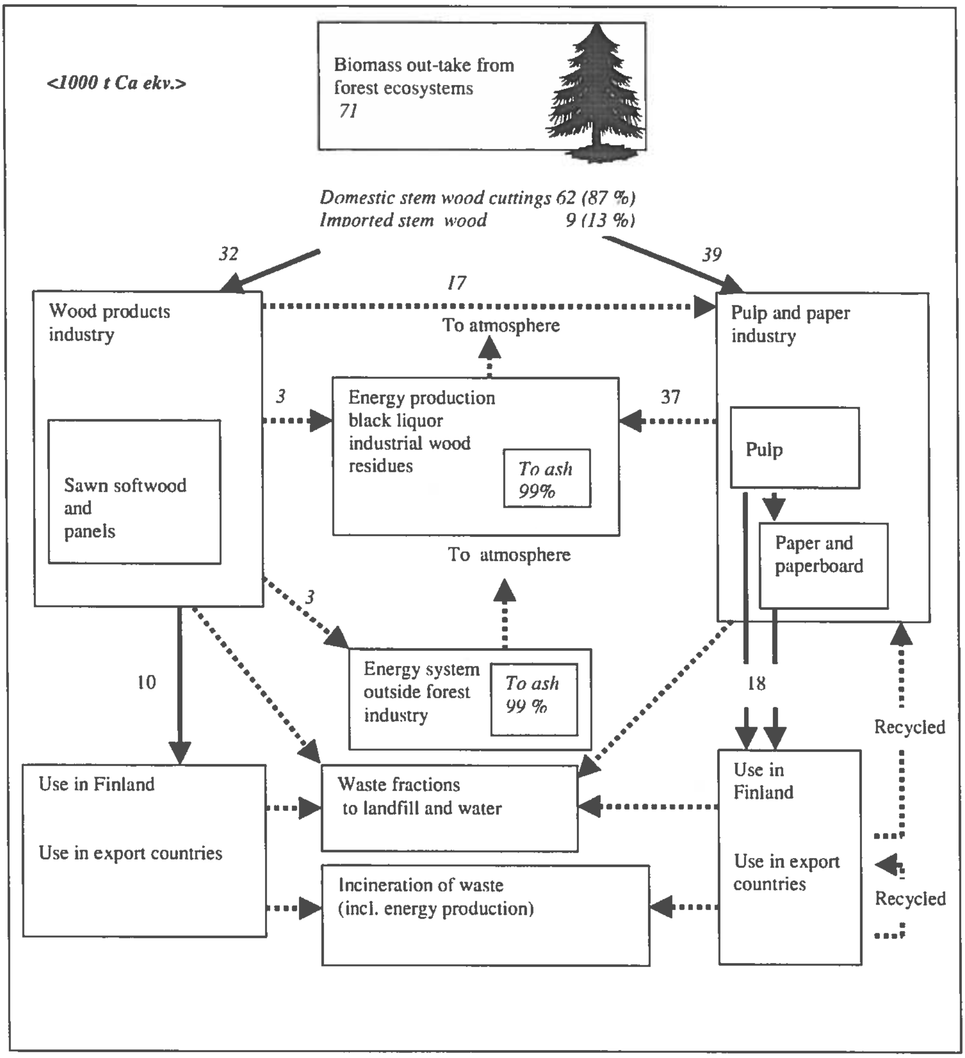

Figure 6 **The flow of nutrients in the Finnish forest industry** (unit 1000 tonnes of Calsium equivalent, see text). The flows of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} (Base Cations, BC) follow a throughput direction, starting from forests and ending up as ash of energy production and at landfills. The use of incineration ash from the industry power plants as fertilizer is possible. Because the waste wood fraction has higher nutrient content than wood fractions used for products, about 60 % of the nutrients end up in ash from energy production.
Round wood and products ——— Wastes and by-products ....

Flows of energy in the forest industry system

Figure 7 presents the flows of energy and the structure of the forest industry energy production. About 70 % of the fuels used in the Finnish forest industry energy production are industrial wood wastes and waste liquors. About 94 % of the fuels are used in combined heat and power (CHP) plants, where the waste heat from electricity production is used to produce process or space heat instead of dumping it into the ecosystem (for CHP see Lehtilä et al. 1997, Cogen 1997, Cogen 2000). This reduces the primary energy consumption considerably as about 30 % of the electricity consumed by the forest industry is produced within the industry using waste fuels. In addition, the use of residues from cuttings is increasing rapidly, and this tendency is substituting the use of non-renewable fossil fuels. The power plants produce heat and electricity for pulp and paper mills as well for saw mills, which in turn provide the power plants with waste bark and waste liquor, and saw mill wastes for fuels. The use of waste pulping liquors as fuels also recovers the pulping chemicals back to the pulping process and therefore the need for costly external chemical inputs, and harmful outputs to ecosystems are reduced.

The operation of the forest industry of Finland is arranged to a large extent into regional or local industrial systems, i.e. collaboration and cooperation networks between actors that are in close proximity to each other. As noted earlier, in Finland these are called 'forest industry regional integrates' and there exists approximately 11 such regional industrial systems in the country. It seems that such a local co-operation system would be in line with the local industrial ecosystem analogy or an eco-industrial park, i.e. a system that is based on co-operation between the actors in the system in waste material and waste energy utilization (see chapter one, see Cote & Hall 1995, Cote & Cohen-Rosenthal 1998, Ehrenfeld & Gertler 1997, Gertler & Ehrenfeld 1996). The CHP plants of these local systems are key actors or what the IE literature would call 'anchor tenants' or support systems of the local industrial ecosystem (Lowe 1997, Chertow 1998, Baas 1998, see discussion in chapter five).

In a local forest industry integrate, a saw-mill, a pulp mill, a paper mill and a CHP power plant construct a local cooperation network based on waste material and energy flow utilization. In addition, forestry companies (or harvesting departments and their subcontractors) are located within a close proximity of the other actors in the system. These can provide the system with waste of forest residues from cuttings. The most important "actor" in such a local industrial (eco)system, that is the forest natural ecosystem, is located in close physical distance from the producers and consumers in this industrial system to serve as the source of round wood input to the system.

One could consider the possibility to connect the forest industry local system to the energy supply of a local residential area, households or a city with its services and other buildings as well as that of other local industrial activities, besides forest industry (e.g. chemical and food industry etc.). In such a vision one can argue that a relatively diverse local/regional industrial system based on waste material and energy utilization would exist. In this idealized picture the forest industry CHP plant provides the heavy (forest) industry actors with heat and electricity in CHP. The CHP plant also provides the local city, the residential concentration, the households, the services and other buildings in the area with electricity, the waste of which is used as heat to satisfy the demand with these same actors (see chapter five). In fact, heat is already sold from the forest industry to district heating networks in Finland. The precondition of this vision would be that the forest industry increases the efficiency of its energy production, which enables that the amount of waste energy in the form of heat that is sold outside increases, e.g. to the household and city requirements. The power plant and the actors of the heavy forest industry processes as well as the city, households and other buildings should be located within a close physical proximity to each other. Heat can be transferred only over relatively short distances (e.g. about 20 kilometers).

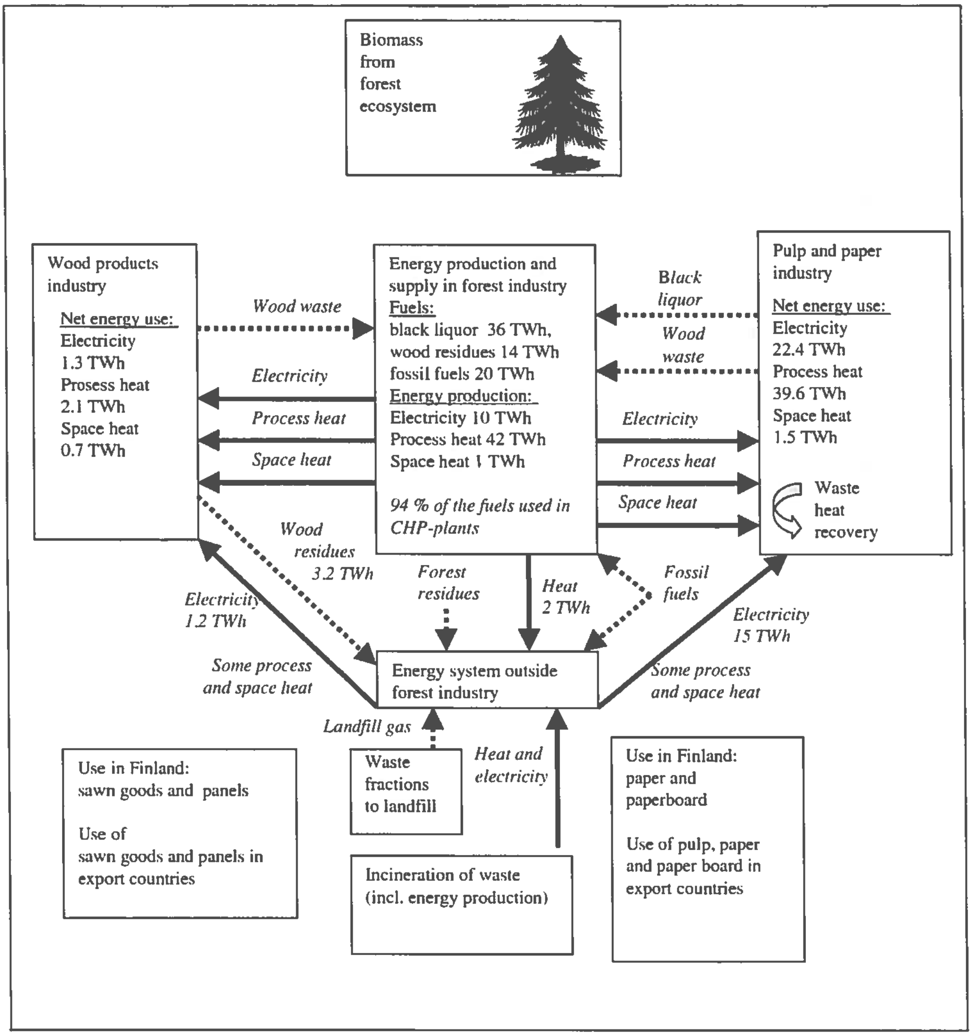

Figure 7 **Fuels used and production of electricity, process heat and space heat in the Finnish forest industry (1997)** (unit Twh = terawatt – hours = billion kilowatt – hours). The use of wood waste fuels is reducing the need of external fossil fuels. In CHP plants the production of heat and electricity is combined. The waste energy from electricity producton is used in the production of heat. The forest industry of Finland is arranged to large extent as regional or local industrial systems or integrates, where a saw-mill, a pulp mill, a paper mill and a CHP power plant are in close proximity to each other and engage in cooperation through waste material and energy utilisation. Also fossil fuels and externally produced electricity are used.
Energy ———— Fuels ....

Flows of carbon in the forest industry system

In **figure 8,** the forest industry activity is described with regard to the carbon cycle of the forest ecosystem. The forest ecosystem binds atmospheric CO_2 and solar energy to wooden biomass. This biomass is utilized as products and as energy in the industry, and finally the carbon is released to the atmosphere as CO_2 from energy production or as landfill gas from the decay of products at landfills consisting of both CO_2 and CH_4.

The total amount of CO_2 bound annually into the forest biomass is about 48 mill. t C[1] (million tons of carbon). The cuttings, non-industrial wood use and natural drain of stem wood in 1997 were about 65.8 mill, m^3 corresponding to a total carbon release from forest biomass of 42 mill. t C[1] . Hence the forest ecosystem served as a carbon sink of 6 mill. t C[1] in 1997. The sink reduces the atmospheric CO_2 concentration and limits the greenhouse effect.

Through harvesting carbon is released and transferred in wooden material to products or burnt during the industrial processes resulting in CO_2 emissions to the atmosphere. The life time of main paper products is on average quite short i.e. less than a one year (Pingoud et al. 1996). Also the major part of the sawn timber has a relatively short life time, from one year to some decades (Pingoud et al. 2000). About 60 % of the carbon (13 mill. t C) inflow to the industry ends up to the products and will be to a large extent released back to the atmosphere either from incineration of used products or from landfills where the products decay. About 40 % of the carbon inflow ends up in energy production and is released to the atmosphere as CO_2. The fossil fuel use within the industry causes CO_2 emissions of about 1.5 mill. t C and the generation of electricity bought into the industry causes CO_2 emissions of about 1.0 mill. t C. The CO_2 emissions from bought electricity are estimated on the basis of average CO_2 emissions per produced electricity (250 g CO_2/kWh) in Finland. The CO_2 emissions from transportation activities due to forest industry can be estimated to be in order of 0.5. mill. t C[11].

The used products lie in landfills in anaerobic conditions and emit landfill gas, which contains methane (CH_4) and carbon dioxide. Methane will oxidate to CO_2 in the atmosphere. The methane emissions from landfills are nowadays often collected. This is because CH_4 can be used as an energy source (CH_4 is burnt to CO_2) and because methane emissions enhance the greenhouse effect. Therefore, the emissions should be limited according to the coming requirements of the Kyoto Protocol.

The most important industrial ecosystem feature with regard to the flow of carbon in the forest industry of Finland is that the annual cuttings of forests are lower than the annual growth. The cycle of carbon starts in cuttings and is completed when CO_2 and methane emissions (that will oxidate into CO_2) from forest industry energy production and from landfills is bound into the forest ecosystem. Through photosynthesis, the forest ecosystem binds more of CO_2 than the amount of carbon that is released from the cuttings into the industry activity. This binding capacity should be maintained through respecting the sustainable yield of the forests in cuttings.

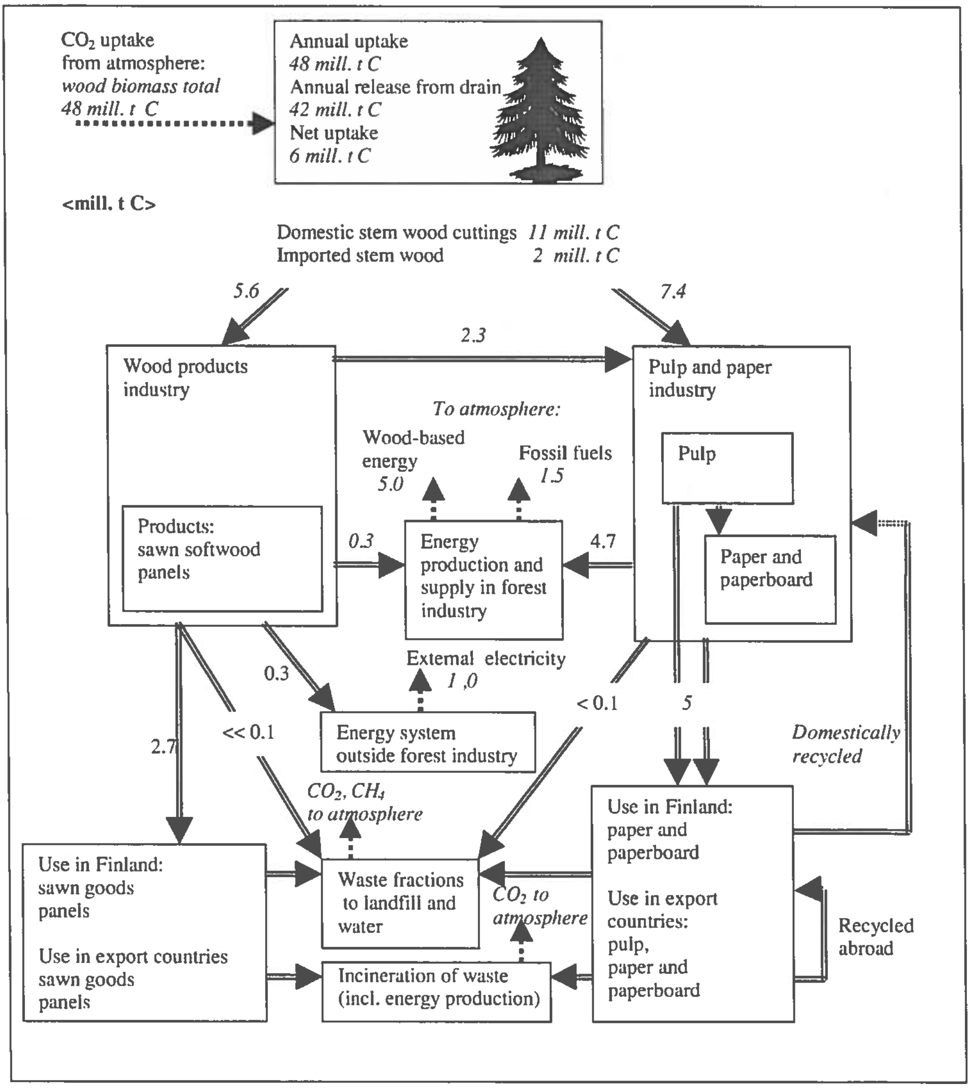

Figure 8 **The Carbon flows in The Finnish forest industry in 1997** (unit mill. t C = million tonnes of carbon). The annual carbon uptake from the atmosphere to the forests exceeds the drain due to cuttings and natural processes. The net growth of the carbon pool in Finnish forest ecosystems was about 6 million tonnes. The inflow of carbon from the forests will be embedded in round wood that is used in the industry. The carbon then ends up as embedded in products and as CO_2 emissions back to the atmosphere through waste-based energy production within the industries. The carbon in products is finally to a very large extent released back to the atmosphere due to decay of products at landfills. Flows of carbon in round-wood, products or wastes ═══════
Flows of carbon as CO_2 ....

Industrial Ecosystem flows of the forest industry

Recycling of matter and cascading of energy are the basis of the operation of a mature forest ecosystem. The presented forest industry system has some important features, which are similar to the way in which matter and energy flow in the forest. This reduces the burden that the industry is causing to the natural environment. First, the annual cuttings of the forest in Finland are smaller than the annual growth of forests. Round wood and wood wastes are utilized in an effective way in the network of saw mills, pulp mills and energy plants. Second, although still mainly on the experimental level, studies indicate that the amount of nutrients that can be returned to the forest ecosystem as fertilizer from the forest industry energy production waste ash can be increased considerably in the future. Third, energy production is organized effectively by using the co-production method of heat and electricity, i.e. cascading energy at different quality levels.

Finally, as a consequence of point one, the annual binding of CO_2 in the forests of Finland exceeds the amount of carbon that is released from cuttings and from the natural drain. This is only a short term situation. In the long run, over time horizons of several decades, the forest ecosystem can only absorb the equal amount of carbon than the amount that is released from cuttings and natural drain. If the cuttings are lower than the growth for a long time, the natural drain increases, which saturates the amount of carbon at a certain level.

One must also note the concerns with regard to the biodiversity in the forest ecosystem. There exists discussion in Finland on whether the management of commercial forests pays enough attention on biodiversity. However, efforts are beginning to be implemented to better preserve the ecosystem biodiversity. The tree species in the forests in Finland are mainly domestic natural species, i.e. not imported species from other parts of the world. Also the reproduction is to a large extent natural. There are efforts to include the protection of the biodiversity into the forestry practices. The certification of good forestry respecting natural values is increasing commonly, and 7.6 % of the total forested area is protected on the basis of different conservation programmes. Cuttings are being reduced particularly at areas, which can be defined as sensitive with regard to biodiversity.

Arguably, the forest industry of Finland has some important features on which the industrial ecosystem theory can be reflected in future case studies. The industry could serve as an example of an entire national industrial branch, that is to a large extent based on the sustainable use of renewable flow resources and has reduced the use of fossil raw materials as well as the generation of wastes and emissions. However, the fossil fuels are still used to some extent in the industry. The use of fossil energy can be reduced by the development of technology and by increasing the share of renewable energy sources. One such renewable resource will be the forest residues from cuttings. But here the problem can arise, because needles, twicks and branches are rich in their nutrient content and therefore disturbances in nature can occur if these nutrients are increasingly released from the natural cycle. If more of the residues are used in the energy production, more of the nutrients from the waste ash of the power plants should be returned to forests as fertilizer.

When an ecosystem development is compared to that of an industrial system, the question of feed-back mechanisms has been presented as one of the important differences that the IE community should consider (Smart 1992). Industrial actors respond mainly to the feed-backs of information about prices, which cannot reflect all of the scarcities or problems in the natural capital stocks or in the flows that it yields. In an ecosystem, organisms in turn, react to physical stimuli and information related to one's survival; lack of food, presence of a predator or environmental conditions and weather conditions etc.

Although in many cases prices are poor feed-backs with regard to environmental problems, in the case of the industrial ecology-type development of the forest industry of Finland, they have played a role. This shows in the flows of matter, energy and carbon in the forest industry. The industry has responded to the increase in the price of round-wood in the market, when the amount of the cuttings have approached the growth rate of the forests. The industrial actors have developed material cycles and more efficient ways of using the harvested wooden materials and the cuttings respect the reproduction time of the trees. The use of wastes as fuels in the energy production and the CHP method have reduced the amount of fuels that are required and specially the amount of imported non-renewable fuels of coal and oil. In other words, as fuels are reduced also the fuel costs are reduced. The price of round-wood has directed the carbon cycle of the forest industry in a way that it mimics the way in which carbon is circulating in the organic cycle of the forest ecosystem. Because of the price of round-wood, the cuttings are lower than the growth of the forests and its capacity to bind CO_2 is secured.

But in the case of the nutrient flows, the feed backs in prices are yet to occur. This is perhaps, because the amount of forest residues used as fuels in the energy production (and the amount of nutrients released in them from the ecosystem) has begun to increase only recently. In the near future, however, feed backs might appear in the costs of fertilizer use necessary to compensate for lost nutrients. However, feed-backs as such are not enough for environmental management in general. Despite the society would have clear feed-backs from natural processes, the societal response to construct an environmental management programme and its successful implementation process can take a long time (see Ehrenfeld 2000).

Industrial ecosystem case studies are still only few and it is clear that every case is a unique case with unique material and energy flows as well as societal drivers of these flows. Countries that have vast reserves of renewable resources, e.g. forests or peat reserves (for discussion of peat as a slowly renewable resource see chapter on the Jyväskylä Industrial Ecosystem), might provide the IE community with fruitful starting points for case studies. In such a context the flows of the ecosystem could be compared with the material flows in the industrial system in question. In countries, where the natural resources are more limited, industrial ecosystem-type development will be more difficult to achieve. On the other hand, wastes do exist everywhere and their value as a resource should be taken into account. The industrial ecology analogy can serve as an eye-opener in this process and its theory can be developed through theory building alongside comparative case studies.

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CHAPTER THREE

Jyväskylä Industrial Ecosystem:
Industrial ecology of a regional energy supply system

Introduction

The few case studies on the systems approach in industrial ecology have been conducted in a regional or local context. As noted in previous chapters, some use the notion of an eco-industrial park, or a regional industrial ecosystem. For me, such a local collection of firms that co-operate by using each other's waste material and waste energy flows is easiest to understand in terms of the ecosystem analogy. Here it seems to be possible to draw a systems picture, which will illustrate the main waste flows that flow and circulate in the system as well as the main drivers of these flows, the companies, possibly consumers or for example local public organizations. It can also be possible to consider whether recycling or cascading activities have been successful in achieving environmental gains. The effort is to minimize the virgin raw material and energy input to the system as whole and the waste and emission output from the system as a whole.

In this chapter a case study on the regional energy supply system of Jyväskylä city in Finland is considered (see Korhonen et al. 1999, Korhonen & Savolainen 2001, Korhonen et al. 2001, Korhonen 2001). The aim is to study the industrial ecology characteristics of this system. Recycling of matter and cascading of energy between the actors in the system will be the focus points. In chapters that follow, the chapters four and five, I will try to consider the Jyväskylä case as well as the forest industry case in light of the study question of the thesis. This chapter on the Jyväskylä case is mainly focused on the IE potential of the system, i.e. to identify possible positive features. The final chapter of the thesis attempts to discuss both of the case studies, the Jyväskylä and the forest industry systems with a consideration of the problems in these and barriers of developing similar structures in other industrial settings and industrial systems.

Industrial Ecology of the Jyväskylä energy supply system

Co-production of heat and power

There are approximately 75 000 inhabitants in the city of Jyväskylä. The area of the city covers 135 km^2 of which 31 km^2 is water (lakes). The city serves a as a commercial and administrative centre of a province of 250,000 people. There is a university and mainly light industry in the city.

In Finland, Denmark and the Netherlands, the regional energy supply has been organized to a large extent as co-production of heat and electricity (Co-production of heat and power, CHP, see Cogen 1997, Lehtilä et al. 1997). Currently (1999), the share of co-generation from the total national electricity generation in Denmark was 50 %, in The Netherlands 40 % and in Finland approximately 35 %, while the EU average is little under 10 % (Cogen 2000). In this production method the waste heat from the electricity production is used to satisfy the heat energy demand of district or space heating and of industrial processes instead of dumping it into local water system or into air. This method has great potential in reducing the fuel use in many industrial countries, where the electricity generation is based on separate production of power in condensing power plants.

The power generation can be connected to the production of district heat or industrial heat/steam (or even district cooling for commercial/office buildings) resulting in decrease in the total fuel use and therefore, in reduced costs, when compared with the separate production of heat and electricity. With CHP one can decrease the CO_2 emissions from energy production and contribute to the tasks of reaching the objectives of UN Framework Convention on Climate Change and Kyoto Protocol. The Jyväskylä regional energy supply system, which will be described below, is based on the CHP method.

Waste utilization in the Jyväskylä energy supply system

If we consider the thesis in IE, the Jyväskylä energy supply system is based on two key features. First, as noted above, the system uses the CHP method for the production of heat (waste energy) and electricity. Second, industrial wastes from the local plywood mills, saw mills and forest cuttings are utilized as fuels. In this process the technique of fluidized bed burning has been important. When fluidized bed burning techniques are compared with the older techniques of pulverized coal burning in use in some CHP plants, one can note the potential in the method to use several solid fuels, also fuels that are relatively inhomogeneous fuels, e.g. biomass, wood wastes and other waste derived fuels with high combustion efficiency and relatively small emissions. On the basis of the two IE characteristics, one could argue that similarly to the often-cited Kalundborg industrial ecosystem (Ehrenfeld & Gertler 1997, Gertler & Ehrenfeld 1996, see chapter one in part one) a relatively diverse collaboration effort in waste energy and waste material utilisation exists between the actors of the Jyväskylä region.

In figure 1 the Rauhalahti power plant distributes electricity and heat through CHP to local households as well as to other buildings, services and industry in Jyväskylä. This is typical for many regional energy supply systems in Finland. In Jyväskylä another important feature occurs in the energy supply when waste energy utilization or cascading of energy is concerned. In addition to satisfying the district heat demand of households, the residual energy from the Rauhalahti power plant is used to fulfill the requirements for industrial steam in the local paper mill, the Kangas paper mill.

The paper mill provides the local greenhouse horticultural centre Greenlandia[12] with heat energy through hot returning water.

The plywood mill, which is located 15 km away from the Rauhalahti power plant in the Säynätsalo suburb provides the power plant with the waste of wood left-overs. It will receive energy (electricity) in turn. It is economical

[12] Greenlandia centre is also engaged in various environmental education activities.

that the plywood mill is also able to utilize the wood left-overs locally in a suburban boiler plant. The boiler provides the plywood mill with process steam and the immediate nearby households and buildings with heat.

Recently, an opportunity to use the waste ash from the Rauhalahti power plant has been recognized and first experiments are on the way. The ash can be used nearby the plant to build a model for green gardening and green construction or land building in the "Green Land" project of Jyväskylä. The material flows here are still small. To a some extent, the forest residues from regional cuttings are used as fuels in the energy production in Rauhalahti. However, the use of forest residues is still constituting a relatively minor feature of the system material flows and should be further developed. There used to be also a saw mill in the actual town area, from which it was possible to derive wood wastes to be used in the production of energy.

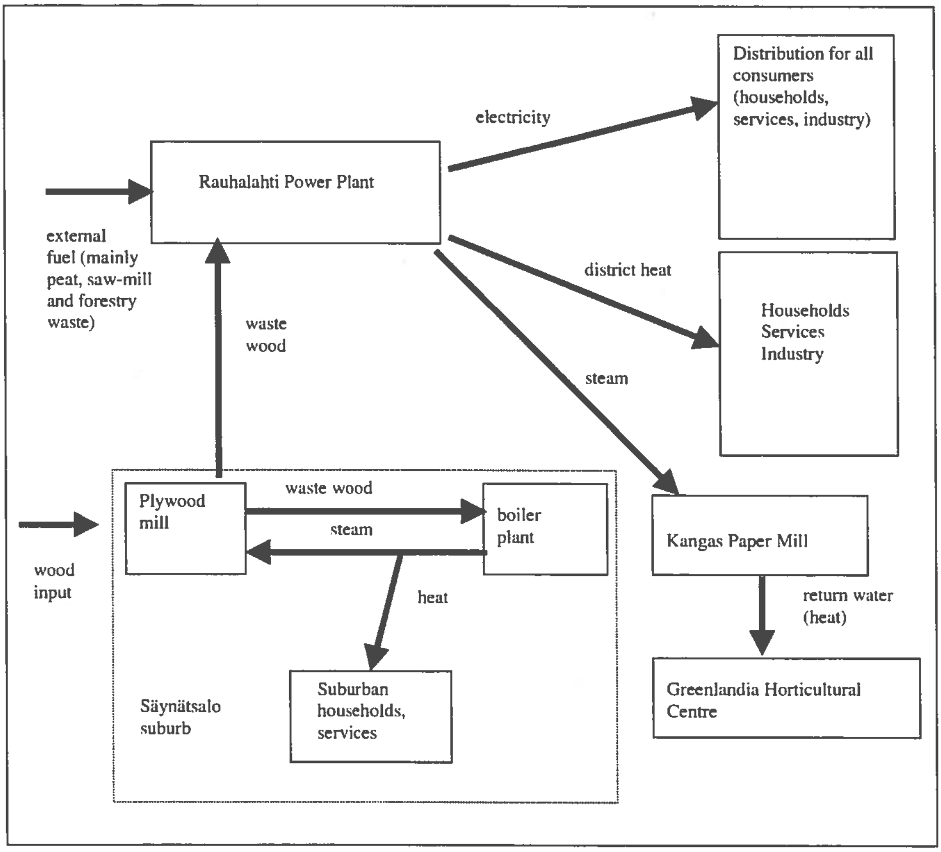

Figure 1 Jyväskylä Industrial Ecosystem

The way the production of energy and the CHP method is implemented in the case of Rauhalahti power plant and Jyväskylä energy supply system would seem to follow the goals that have been discussed in the cascade chain approach (see Sirkin & ten Houten 1994, van Berkel et al., 1997, see the forest industry chapter). The energy is used in many quality levels. It is used in several temperature and pressure levels in order to minimize the losses, or the increase of entropy. The highest level is used for generation of electricity, the next highest level is used to generate industrial steam, the next level to that to produce district heat and the lowest to produce heat for horticulture in Greenlandia.

The gains of industrial ecology in Jyväskylä

The relatively expensive and environmentally harmful coal and oil inputs from outside the system and the waste and emission outputs that would go along have been reduced considerably in the Jyväskylä energy supply system. The consumption of heavy fuel oil has decreased from 963 GWh in 1980 to 122 GWh in 1997. Because of the waste energy and waste material use in the energy production, cut-downs in the sulphur emissions to the atmosphere have been achieved. The SO_2 emissions have decreased from 3700 tonnes in 1980 to 1700 tonnes in 1997. Studies on the local air quality indicate clear improvements in the Jyväskylä region[13].

Table 1 shows the fuel input to the energy supply system. The system covers over 90 % of the heating energy demand of the city of Jyväskylä. The rest of the heating demand is mainly in single family houses heated separately with fire-wood, oil fired boilers or directly with electricity. There are lots of peatlands near Jyväskylä and peat fuel is an important input to the energy system. Waste wood that is used as fuel is mainly obtained from the Säynätsalo plywood mill located in the city area and from the saw mills of the region.

Table 1 Fuel input of the Jyväskylä energy supply system in 1997

Peat	1579 GWh	73.5 %
Waste wood	439	20.4
Oil	122	5.7
Coal	8	0.4
Total	**2148 GWh**	100

The distances with regard to the input fuels of the energy production in the Jyväskylä system are described in **Figure 2**. Peat is transported from 80 – 90 kilometers away. The discards of the plywood-mill are transported to Rauhalahti Power Plant from Säynätsalo located 15 km away and wood wastes from saw mills of the region within the distance of approximately 30 to 50 km. The imported coal and oil used as main fuels earlier were transported over thousands of kilometers. The distance between Rauhalahti and Kangas Paper Mill is about four kilometers. The heat distribution to the local households usually cover maximum of 10-20 km. It is not technically or economically sensible to transport heat over long distances. The fuel production and distribution in Jyväskylä creates employment opportunities for local and regional inhabitants.

[13] Niskanen, I, et al. 1993.

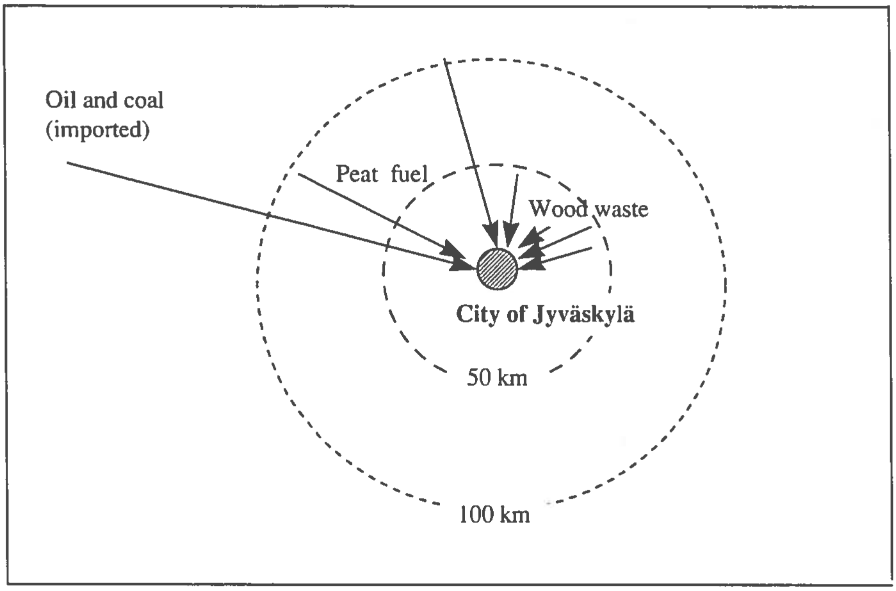

Figure 2 **Fuel procurement distances of the Jyväskylä energy supply system.** The use of imported coal and oil fuels has decreased considerably during the recent years

As already noted, forest residues from cuttings are used as fuel and there are plans for extending this to substitute the use of peat. Minor amount of oil is used in start-ups and shut-downs in the Rauhalahti Power Plant as well as in the Savela reserve and peak-load plant connected to the district heating system. The use of wood wastes as fuel has proven to be beneficial and economic for Jyväskylä. Now the energy supply system does not need to be solely dependent on the fuels bought from external sources. Without the use of wood waste fuels (flow resource) the total amount of external peat, oil and coal needed in the Jyväskylä system would be 26 % higher.

The energy produced within the Jyväskylä energy supply system based on the fuel input in table 1 is given in **table 2**. In 1997 the total efficiency of the fuel use in the energy supply system was up to 86 %. This is the fraction of the fuel energy, which was supplied to the distribution system and further transmitted to the consumers. The transmission losses are estimated to be around 2 % in case of electricity and 9 % in case of district heat. Also around 70 GWh of district heat was sold over the city border to residential areas of a neighboring municipality. If the local heat and electricity were produced separately and if the consumer demand of heat and electricity were the same, the total amount of fuels would be about 32 % higher. This is because in conventional condensing thermal power plant the efficiency is about 40 % in electricity production. The rest of energy, 60 %, is released to the environment, to air or into the local water system.

In a co-production plant the waste heat is utilized in space heating through the district heating network. This has only a very small impact on the electricity production. However, in the case of Jyväskylä, the amount of electricity generated within the system is not enough to cover the whole electricity demand of the city. Because of this, about 280 GWh of electricity was bought from the national electricity network in 1997.

Table 2 **Energy distributed in the Jyväskylä supply system based on fuel use in Table 1**

Electricity	445 GWh
Industrial steam	457
District heat	943
Total	**1845 GWh**

Table 3 shows the sulphur dioxide and carbon dioxide emissions in the Jyväskylä energy supply system. If the CHP was not used and the added demand would be supplied by heavy fuel oil, the sulphur dioxide emissions would be 70% higher. If waste wood could not be used and the fuel used instead was heavy fuel oil, the emissions would be 115% higher. In the case of CO_2, without both of the main IE-type activities in the system, i.e. cascading of energy (CHP and the use of waste energy) and use of wood wastes as fuels (recycling of matter), the CO_2 emissions would be almost 50% higher.

In conclusion, the combined impact of CHP and waste fuel use means that the use of external fuels is 40 % lower than without these features. The decreased fuel use results in decreased emissions and monetary savings. Because of the CHP and the waste fuel use, the SO_2 emissions are over 50% lower than without these features. The CO_2 emissions are over 30% lower.

Table 3 **SO_2 and CO_2 emissions in the Jyväskylä energy supply system in 1997, and the potential increase of emissions if the CHP and waste wood fuels were not used**

	sulphur dioxide	carbon dioxide
Emissions in the Jyväskylä energy supply system	1660 t	600, 000 t
1 Without CHP and with added heavy fuel oil (POR)	+ 70 %	+ 29 %
2 Without waste wood and substituted with heavy fuel oil	+ 45 %	+ 18 %
1 and 2 together	**+ 115 %**	**+ 47 %**

Adapting to the local renewable natural resources

The system in Jyväskylä differs from that in Kalundborg in one important aspect in terms of industrial ecology. When the Kalundborg symbiosis is based on two key actors that rely on imported non-renewable fossil (emission intensive) raw materials, a coal-fired power plant and an oil refinery, in the Jyväskylä energy production the use of coal and oil is practically non-existent. On the other hand, the fact that peat is used up to such high amounts in Jyväskylä might be argued to be a negative feature when the ideal of an industrial ecosystem is reflected on the system. Peat is a non-renewable or a (very) slowly renewable resource.

The peatlands, which are reserved now for peat fuel production in the Jyväskylä region, cover the peat fuel use for about 60 years at the present use rate. Totally in Finland, about one third of the land area is covered by peatlands. About 20% of peat volume could be harvested economically, but at the present use rate this would last for 400 years. This would constitute only about 2% of the original peat land area, because only the thickest layers can be harvested for energy production. However, the growth of peat, if integrated over all Finnish peatlands, exceeds the present use rate. (Selin 1999, Savolainen et al. 1994, Lappalainen & Hänninen 1993)

It can be argued that the use of a peat in Jyväskylä to substitute imported non-renewable fossil fuels is to be recommended. One must note that the peat used in Jyväskylä is a local resource. However, substitutes for peat fuels must be developed. Substitutes could be found by increasing the use of local forest residues as there exists lot of forests near Jyväskylä. The use of REF (recycled fuels) from households is a possibility, because the combustion technology in Rauhalahti plant enables the use of these kind of fuel inputs. However, the problem of source separation might prevent this strategy. Some argue for investing more on service-type activities in the regional energy company and the Rauhalahti power plant to promote saving of energy. For instance, energy audits and measures can be made publicly available. On the other hand, in many cases power companies might use services as a bonus when 'selling' the energy to customers with the underlying aim in increasing customer commitment.

The development of the Industrial Ecosystem

The energy supply system in the case study has evolved since the 1960s. There have been no special environmental management efforts or environmental management programs in Jyväskylä. There have been some concerns on air quality and anticipated tightening of emissions standards. The local conditions such as the fact that Finland is a relatively cold country, obviously have contributed to the system. Especially in winter the heating demand is great. The reduction of the needed fuels that has been achieved through CHP and waste material utilization means reduced fuel costs. This has been one of the driving forces in the system development and hence I will argue that the environmentally sound solutions have been economic in the case.

The system has developed over the course of approximately 30-40 years. Until 1960s and 1970s, it was common that each house as well as block of flats, had its own heating system. The systems mainly utilized oil for the fuel used for heating. Water circuits were used to transport the heat from boiler to dwellings. The heating systems of separate houses were connected together in order to reduce the control costs involved and to improve the efficiency of the heating systems. Gradually this process has evolved into district heating networks. Electricity that was used in the city was originally generated mainly with hydro-power. The hydro-power was bought from the national electricity network.

The national electricity consumption in Finland was mainly covered by hydro-power until 1960s. After this, the power production that relies on combustion and later also nuclear power have fulfilled the major share of the electricity demand. The co-production of heat and electricity surfaced in Finland already in the 1950's. After the first oil crisis in 1973, there was a need to decrease the dependency on oil. In Finland, oil is an imported (non-renewable) stock resource. Programs were initiated that emphasized the need to use domestic energy resources and the need for efficiency improvements both in energy production and consumption.

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 nor pay high profits to the city and as the local district heat networks were growing, the power company decided to invest in district heating and extend its area of activity. The co-production of heat and electricity was recognized to be a worthy option. The system adopted the method in Savela Plant in 1974 and in Rauhalahti Plant in 1986. The Savela Plant had been fired with heavy fuel oil. Originally the Rauhalahti Plant used techniques based on pulverized burning of coal and of peat fuel. Quite soon the technique was changed to fluidized bed burning. As noted above, this has made the utilization of low-grade solid fuels like forestry and saw mill wastes possible.

The development of the cooperation between the Rauhalahti power plant and the Kangas paper mill originates from the seventies. It was encouraged by the energy crisis. The Kangas paper mill was looking for ways to make its dependency on external oil smaller in the satisfaction of the process heat demand in the plant. Up to this point, the heat was produced with heavy fuel oil. The paper mill became interested in cooperation with the Jyväskylä city organization. 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. An economic value for waste has been created in the energy cascade chain. Otherwise this proportion of waste energy would be dumped into the local air or water system.

The cooperation between the Rauhalahti power plant and the Säynätsalo plywood mill has been recently enhanced by changes in the ownership structures. Until 1996, the plywood mill in Säynätsalo had its own energy supply system – an old boiler with rather low efficiency. In 1996, technical changes in the production system (a new fluidized bed boiler) were installed. Simultaneously, changes in ownership were made. Now the mill sells its waste wood to the power plant nearby, and in turn, buys the process steam needed. The chipped wood waste is still mainly used at the power plant in Säynätsalo, but leftovers – about one third of the wood fuel – are transported to Rauhalahti (one tenth of the wood fuel used in Rauhalahti). The owner of the power plant in Säynätsalo is the same as that of Rauhalahti. Because of this, efficiency improvements have been achieved. For example, the energy production is now controlled remotely from Rauhalahti power plant. This implies savings in service and control costs. The same personnel can be used to control the operations in Rauhalahti and in Säynätsalo.

Conclusion

The system in Jyväskylä similarly to that in Kalundborg or in the forest industry case has self organised or 'developed by itself '. The IE model has evolved from existing industrial structures and around the existing supply and demand factors. It will be very difficult to use this model in another system, because no intentional efforts or design principles to create the system as a whole exist. Therefore, it is also difficult to derive some management principles from the case that could be used as a general model for IE. Every region or industrial system will require its own case study, because the characteristics are system specific. It seems that eco-industrial park or local industrial ecosystem case studies are still mainly descriptive, i.e. presentations of the actors and the flows of matter and energy between them.

On the other hand, these studies are needed to illustrate the potential and the problems involved when trying to facilitate industrial ecology-type development in industrial structures. There are some points in the Jyväskylä system that show the problems in the Kalundborg case, e.g. the need to reduce the coal and oil input. Also the relatively advanced diversity and interdependency in Kalundborg, e.g. waste sludge use as fertlizer in fields or the use of waste heat in fish farms, would promote the Jyväskylä actors to look for more possibilities to use wastes. REF from households and the need to increase the use of forest residues as fuels are such issues. In the following chapters, my effort will be to consider the case studies in light of my basic research question and consider the barriers that a local industrial ecosystem project faces.

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PART THREE

Industrial Ecosystem

CHAPTER FOUR

Industrial Ecosystem – Considering four ecosystem principles in an industrial system

Introduction

In this chapter I will present what I have understood as an Industrial Ecosystem with the forest industry system and with the Jyväskylä city energy supply system. I will divide the presentation into three parts. In the first part the ecosystem material and energy flow model is considered as the goal of an industrial ecosystem project. This will be derived from the chapter on the forest industry system. In the second part the two cases are discussed with regard to the way in which their material and energy flows have achieved the conditions described in the first part. Here four principles are presented. I will argue that these serve to describe some of the elements that have been important for the development of industrial ecology in both of the case studies. The final part tries to sum up the principles, their use for describing the case studies and shortly discuss the problems in the argument.

Industrial Ecosystem Part One: The ecosystem material and energy flow model used in an industrial system

The chapter three on the Forest Industry Industrial Ecosystem focused on the flows of matter and energy in the two systems, the forest ecosystem and the industrial system of the forest industry. The flows of matter, nutrients, energy and carbon were considered in the systems. In light of industrial ecology philosophy the argument was formulated as: *To construct a forest industry industrial ecosystem, one should try and develop the flows of matter and energy in the industrial system in a way that these would be similar to the same flows in the forest ecosystem.* It was suggested that if this kind of development happens, it is likely to direct the industrial system to operate more in accordance in nature's ways and hence possibly reduce the burden that the industrial system causes on the natural environment.

Arguably, one can note that the forest industry industrial system in Finland has some important features in its material and energy flows, if we consider the effort to mimic the natural forest ecosystem. First, as nature does, also the forest industry system recycles matter. As in a natural forest ecosystem the reproduction capacity of the trees in the forests is secured, because the cuttings are lower than the annual growth. Second, the forest industry system is beginning to participate into the natural nutrient cycle of the forest ecosystem by returning some important nutrients into nature as fertilizer that is derived from waste ash of the industry energy production. Third, the forest industry uses renewable flows, e.g. waste fuels, in the energy production and is cascading energy (utilizing waste energy) in the co-production method of heat and power (CHP). Fourth, the industry has secured the forest ecosystem capacity to bind CO_2, because the annual cuttings are lower than the annual growth of the forests. In a similar way, without disturbances caused by man, a natural forest ecosystem is able to bind the amount of CO_2 that is released from its natural drain.

The Jyväskylä system would seem to fit into the ecosystem material flow model as well. In case of waste material utilization or recycling, the system actors are using waste fuels as resources in the energy supply system. The system uses peat, the use rate of which in Finland is less than the annual growth and hence its reproduction capacity is secured if the total peat covered land area in the country is considered. The energy supply system is cascading energy in the CHP method and thereby reducing the consumption of external imported non-renewable fossil fuels of coal and oil and the related emissions. The energy is utilized in several temperature and pressure levels.

The Jyväskylä system is contributing to the carbon binding capacity of ecosystems through the fact that the amount of fossil coal and oil that is used is reduced. The one feature of matter recycling, returning nutrients to nature, that was specific in the forest industry case study, is not special in the Jyväskylä case. We did not focus on the potential to return power plant waste ash embedded nutrients into the local ecosystem in the region. However, there are experiments on the way near the Rauhalahti plant to use the ash in land building or in gardening projects. The material flows here are still very small.

The goals of an industrial ecosystem

In this chapter, I will present my understanding of an Industrial Ecosystem in the two case studies. This will be done in three parts. To sum up the discussion above, the first part is presented in **table 1**. This is the material and energy flow model of an ecosystem as presented in chapter three with the forest ecosystem flows. The flows include matter, nutrients, energy and carbon. To follow the industrial ecosystem analogy, this model is used to construct an industrial ecosystem as was done with the forest industry industrial ecosystem. However, I feel that the four flows are among the most important ones regardless of what is the industrial sector or area of industrial activity in question. All industrial activity will need materials or nutrients from nature, will use energy and affect the carbon cycle. Hence, these flows are closely related to the most severe environmental problems of today.

The four goals of an industrial ecosystem that are derived from the way in which an ecosystem operates with its material and energy flows include the following:

1. The reproduction capacity of the ecosystem should be respected in the industrial system and matter should be recycled between the industrial actors.
2. An industrial ecosystem will recycle nutrients or return them into the ecosystem.
3. Renewable energy sources and cascading of waste energy flows constitute the basic condition of energy production and use.
4. The industrial ecosystem will try and secure the capacity of the ecosystems to bind CO_2.

Arguably, if these goals are achieved or considerable improvements toward their direction happen, an industrial system can reduce its burden on the natural environment. This seems to be the case with the forest industry system and in the Jyväskylä energy supply system. Both of the systems have reduced their use of imported non-renewable fossil raw materials of coal and oil as well as the related emissions. Wastes that are not utilized have been reduced.

Table 1 Industrial Ecosystem Part One. The goals of an industrial ecosystem. The ecosystem material and energy flow model used in an industrial system. The flows of matter, nutrients, energy and carbon are considered here. Carbon can ordinarily be seen as a part of material flows, but it is of that importance for energy, environmental impacts and climate change, that it is also considered separately.

Ecosystem	An Industrial Ecosystem
• *Matter*: Respecting reproduction, recycling of matter	• *Matter*: Respecting natural reproduction, recycling of matter
• *Nutrients:* Recycling of nutrients	• *Nutrients*: Recycling of nutrients, returning nutrients into the ecosystem cycle
• *Energy*: Using renewable energy, cascading energy in food chain	• *Energy:* Using renewable energy, cascading waste energy
• *Carbon*: Binding and releasing CO_2, overall balance	• *Carbon:* Securing the ecosystem capacity to bind the CO_2 released by industrial activity

Industrial Ecosystem Part Two: Four ecosystem principles in an industrial system

The potential in the ecosystem model

My reading of the literature in industrial ecology, where the natural ecosystem is compared to the material flows of an industrial system gave me the motivation for my research question. My effort has been to consider if the ecosystem material and energy flow model could provide the industrial ecology thesis with other important principles and concepts besides the basic condition of recycling or closed loops, which I will call as 'roundput'. This is because the reader of IE might associate the analogy to mean only this recycling of matter or the closed loop condition common for a mature ecosystem. In the following, I want to argue and emphasize that the ecosystem can provide us with a source for many other important features or models of a sustainable system in terms of the flows of matter and energy.

To my knowledge, for example Allenby and Cooper (1994) and Benyus (1997) have used a similar approach in that they compared a developing ecosystem to the current 'throughput' industrial systems, and a mature ecosystem ('Type III ecology'), with nearly complete cycling of matter, to a future visualized industrial ecosystem (see also Jelinski et al. 1992). The authors went through many features in ecological succession such as community energetics, community structure, life history, nutrient cycling, selection pressure and overall homeostasis and derived suggestions or research proposals for industrial systems and for industrial ecology from these (Allenby & Cooper 1994).

Above, the model of the material and energy flows in an ecosystem was presented as the direction towards which these same flows in an industrial system should be developed in order to construct an industrial ecosystem (**table 1**). Next, I have tried to reflect on the cases and consider what issues and factors have been important when the forest industry and the Jyväskylä industrial ecosystem have developed toward these kind of flows in their operation. For this purpose, I have used metaphors and concepts that arise from the sustainable system development of an ecosystem.

Therefore, the part two in the industrial ecosystem here includes the ecosystem principles of *roundput*, *diversity*, *interdependency* and *locality*. I will argue that diversity, interdependency and locality are important complements to the basic IE principle of roundput. **Table 2** sums up the four principles. The principles are intended for reaching the ecosystem material and energy flow model in **table 1.** The four ecosystem principles can be helpful when an industrial system tries to *adapt* to its natural environment. I will use the condition of adaptation as an optimal condition of a sustainable industrial ecosystem.

Roundput (waste utilization)

The very basis of the neologism of industrial ecology, since the *Scientific American* article by Frosch and Gallopoulos (*Strategies for Manufacturing*, 1989), has been to mimic the cyclical flow of material and cascading of energy, typical for a mature ecosystem, in an industrial system. With the term *'roundput'* we can present an opponent for the term 'throughput'. The throughput is a term describing the traditional linear industrial material and energy flow model starting from the source functions offered by the natural environment, continuing through process to process, and eventually ending up as wastes to be dumped into nature; from raw materials to products to wastes. There are lot of evidence from environmental studies showing how the industrial throughput consumes too much of natural resources and dumps too much emissions and wastes back into nature.

Industrial ecology is then considering the possibility in an 'industrial roundput'. With roundput we denote recycling of matter and cascading of energy between the actors and processes of a co-operative local/regional industrial ecosystem[14]. The four goals of industrial ecology in table 1 constitute my

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[14] William Ashworth (1995) has coined a term 'aroundput' when reflecting on the basic picture of the flow of materials in a forest ecosystem, the cyclical flow between organisms.

argument of roundput. In theory, with roundput or with recycling, the amount of virgin input from the environment to an industrial system can be reduced as these are substituted with waste flows. Because wastes are used as resources, the amount of wastes from the industrial system as a whole will be reduced. Wastes are also often less emission intensive fuels than fossil fuels.

Because of the modern use of the fossil fuel stocks for energy, the roundput condition has been made difficult to achieve in industrial systems. The unlimited utilization of the non-renewable stocks of coal and oil has made the unlimited growth of throughput possible. Recycling has remained a neglected option. Further, through the use of coal and oil the throughput happens as emissions amount. Recycling (or sequestering) of CO_2 is practically impossible, because of e.g. high costs.

Diversity (in the actors involved, in their material and energy flows)

The principle of roundput in itself, is not enough for reaching an industrial ecosystem. Also other features of the system development are important complements of this basic IE principle. As discussed above, I have tried to use the model of a sustainable ecosystem for identifying these other principles for an industrial ecosystem.

The condition of *diversity* could be seen as a desirable direction towards which to develop the industrial system in order to move toward an industrial ecosystem. In an ecosystem there are producers (plants), consumers (animals) and recyclers (decomposers, detritivores, fungi) present in a co-operative situation (see Ehrenfeld 2000, Ehrenfeld & Gertler 1997, Husar 1994, Frosch 1992). These constitute the recycling system. The sustainability of recycling arises from the ability of the ecosystem to adapt to endogenous or exogenous changes through diversity (Ring 1997). For example, when one species is not able to survive, the system as a whole is able to sustain itself. There are many actors involved that can fulfill the function, e.g. a recycling function, of the missing actor.

An ideal local industrial ecosystem would have diversity in the actors involved. Many different industrial as well as non-industrial actors should be encouraged to engage into an industrial ecosystem project. Large manufacturers, but also SMEs and public actors such as the local municipal organization as well as consumers should be present. The life cycle of a certain product may flow through, be affected by and affect all of these actors. Hence, to control and monitor the recycling efforts, as many actors as possible that are involved in the operation of various life cycles should be included into the planning and implementation of an IE project.

Diversity may be a required precondition for facilitating the emergence of a co-operative recycling system in that there is a need to secure the stability of the industrial ecosystem by including different firms, different areas of industrial activity and other societal actors into the system. Diversity in the actors involved can help to find uses for by-products and wastes and it may also secure the needed supply of these. When one actor departs, through diversity the system can adapt to this endogenous change and still find new suppliers of wastes or new customers for waste derived products, e.g. for waste heat, and the waste does not have to be dumped into the natural environment.

The diversity principle in terms of diversity in industrial material and energy flow inputs and outputs could also facilitate the emergence of an industrial ecosystem (to include also wastes e.g. as fuels). Then, the industrial system could include actors that can provide it with waste (fuels), not only actors that use virgin stocks for example. In an energy production system, the companies should look also outside of oil and coal sectors for their suppliers and find waste suppliers, e.g. saw-mills with saw mill wood wastes or households with REF (recycled fuels). In this way, the system could perhaps reduce the use of the non-renewable emission intensive fossil fuel inputs.

The modern tendency to rely on stock resources for energy and to proceed with the ideal of mass production reduces variety and diversity in industrial inputs and outputs (Ayres & Ayres 1996). This can be argued to have been one of the reasons for the tendency of not taking into consideration value creation for industrial wastes, because the stocks have been thought of as unlimited.

Interdependency (in co-operation)

The diversity in an ecosystem leads to interdependency in the relations of different organisms. Organisms need to fit in with their surroundings and cooperate with the other actors in the system. One must note that in an industrial context, diversity in the actors involved and diversity in terms of many different material and energy flows including different valuable waste flows does not result into an industrial ecosystem alone. Roundput will only take place through co-operation. This can be difficult when considering the ideal of a modern competitive organization.

The important point in the comparison of a natural ecosystem and an industrial system is that an ecosystem is more of a co-operation system than a competitive system, which in turn is the basic condition of modern market economy. Ehrenfeld (2000) reflects on this comparison as essential for industrial ecology and notes that *"Competition exists in natural systems, but in balance between competition and cooperation. Individual creatures in a given niche compete for scarce resources but never make war on the others in a winner-take-all strategy."* (p238) The modern ideal of an organization has been an independent organization that either controls its external environment, both social (e.g. competitors, suppliers, customers) as well as natural (unlimited use of the source as well as the sink functions provided by nature), or is otherwise superior, self-reliant and therefore independent from its environment (Boons & Baas 1997, see Pfeffer & Salanchik 1978, Piore & Sabel 1984, Alter & Hage 1993, Pizzocaro 1998).

Although examples of networking and co-operation are beginning to exist, important opportunities for systems integration remain to be neglected (Boons & Baas 1997, Ayres & Ayres 1996). Hence, the effort to create co-operation, interdependency or the development of complex symbiotant relationships with regard to the kind of waste utilization (roundput) that would fit the ideal of a local industrial ecosystem is in its early stages in modern industrial structures.

In other words, industrial ecology or an ideal industrial ecosystem is a form of inter-organizational phenomena (Boons & Baas 1997). An industrial ecosystem will be a collection of industrial and possibly non-industrial actors that co-operate in common material and energy flow management. For this I will use the term *interdependency*. Interdependency will describe the needed feature of the actors in the industrial ecosystem regarding their relations with the other actors in the system.

Locality (in material and energy flows)

The *locality* metaphor is in line with the industrial ecosystem analogy. Local natural ecosystems need to rely on and respect the renewal (cyclical) time of the local resources. They respect the local natural limiting factors and the local natural carrying capacity. In an ecosystem, the inputs of matter and energy are normally derived from within a close proximity to minimize the use of energy. The products are produced for the purposes of the local organisms. The carrying capacity of the local ecosystem is usually secured in the ecosystem operation if there will be no human-induced disturbances. An organism in an ecosystem needs to adapt and fit in with its local environmental conditions.

To take an example from the modern industrial use of energy, one can note that the way in which energy is used has made it difficult for a regional industrial system to learn to adapt itself to local environmental constraints. In a regional industrial system the local natural limiting factors have been neglected, because of substitution with imported stock resources or with human-manufactured capital (often manufactured by using fossil raw materials). For example, the use of imported coal instead the use of local waste derived fuels has been the dominant tendency in regional energy supply systems. If an industrial system will import coal and oil, it may fail to recognize that the local carrying capacity of the ecosystem cannot keep up with the growth of the industrial system, e.g. the capacity to reproduce resources (or tolerate the emissions). Further, the fossil fuel energy is the basis of transportation and has in this respect made growing distances between industrial actors possible, which will consume energy (see Ring 1997).

It would seem that if the main part of the resource basis of the industrial system will be in local renewables in accordance with the sustainable yield, the growth rate of the industrial system may better adapt to the local reproduction capacity of, e.g. forest or peat reserves. If the industrial system does not learn this, its resource basis will be used up. The use of wastes as fuels will reduce the pressure that is put on the use of renewables.

Some suggestions for industrial systems in order to develop them toward locality can be determined. An industrial ecosystem will reduce the use of imported resources for minimizing the required energy. It should try and use local resources, renewable natural resources in accordance with sustainable yield and renewable local waste flows. The products that are produced should be directed to local end-consumers. This is for reducing the energy consumed and reducing the amount of wide-spread consumption wastes. These occur far from the gradle of production and can be scattered over wide-spread geographical areas and therefore difficult to monitor and control (Anderberg 1998, Nakamura 1999). The aim of a local industrial ecosystem is to reduce the amount of the source as well as the sink functions of nature that it requires for its operation, i.e. to reduce the Ecological Footprint of the local economy (Wackernagel & Rees 1997). An optimal regional economy in terms of its footprint is one that is self-reliant in its material and energy flows and remains within the carrying capacity of the local natural ecosystem.

Table 2 Industrial Ecosystem Part Two. Four ecosystem principles in an industrial system for achieving the ecosystem material and energy flow model

Ecosystem	A Local Industrial Ecosystem
Roundput (waste utilization) Recycling of matter, including carbon and nutrients cascading of energy in food chains	*Roundput (waste utilization)* Recycling of matter, of nutrients cascading of energy binding of released CO_2
Diversity (in the organisms, actors involved) Producers (plants), consumers (animals), recyclers (decomposers, bacteria) are present in a balanced situation diversity of species and their genetic variance within each group also of importance	*Diversity (in the actors involved, in their material and energy flows)* Large manufacturers, many different companies, SMEs, end-consumers, public organizations involved, diversity in the industrial inputs and outputs
Interdependency (in co-operation) An organism adapts to its surroundings, co-operation instead of competition	*Interdependency (in co-operation)* Material and energy flow management in co-operation, from competition to co-operation
Locality (local material and energy flows) Using local resources, producing for local consumption, respecting the local carrying capacity	*Locality (local material and energy flows)* Using local resources, keeping the life cycle within the local system, producing for local end-consumers, reducing the Ecological Footprint of the local economy through self-reliance in the used material and energy flows

Four Ecosystem Principles in the case studies

Table 3 reflects the four ecosystem principles on the two case studies of the thesis, the Forest Industry Industrial Ecosystem and the Jyväskylä Industrial Ecosystem. My argument is that the principles show how these two systems have developed toward the ecosystem material and energy flow model that was presented as Part One of the Industrial Ecosystem in the beginning of the chapter.

Roundput (waste utilization)

The actors in the forest industry system utilize forest residues from cuttings, wood wastes from saw mills as well as wood wastes, waste liquors and waste chemicals of pulp mills. The cuttings of the forests are lower than the annual growth of the trees and in this respect the natural cycle or the natural roundput is maintained in the forests. The forest industry is beginning to return parts of the nutrients embedded in the energy production waste ash back to the forest ecosystem to serve as fertilizer. Paper mill waste heat is used in pulping and waste energy from the electricity production is used in the co-production method of heat and power in the industry power plants. The annual binding of CO_2 in the forests exceeds the amount of carbon released through industry cuttings.

In the Jyväskylä system the waste utilization is illustrated with the effort to benefit from saw mill wastes, plywood mill wastes, forest residues and at the experimental level from REF (recycled fuels) from households. Peat reserves are used as inputs in the energy supply system to reduce the use of non-renewable fuel inputs. Peat is arguably a renewable resource in Finland. Therefore, the cycle or roundput of nature is maintained if we consider all of the peat resources in the country, and the use of peat for energy is preferable to the use of imported non-renewable coal and oil. The CHP method is the basis of the Rauhalahti energy, electricity and heat production. Waste heat is used by the end-consumers in the city.

Diversity (in the actors involved)

A local forest industry industrial system, or a local forest industry integrate, is a community of companies, which some would argue has a common goal. Forestry companies, a saw mill, a pulp mill, a power plant and a paper mill constitute the system structure. Many different material and energy flows circulate in the system. Also the Jyväskylä energy supply system has a relatively diverse structure in the actors that are engaged into the operation of this recycling system. The system includes services, households and other buildings of the city as end-consumers and as potential waste suppliers for the fuel basis of the energy production. The industrial companies of the system include a power plant, which is a plant that serves the needs of the services and other buildings and those of the residential area, the households as well as industry. The system includes a paper mill, a plywood mill, saw mills and forestry companies. The Greenlandia horticultural center benefits from energy cascading in the system by receiving waste heat from the paper mill.

Interdependency (in co-operation)

Both of the systems demonstrate co-operation between the actors involved in common material and energy flow management, of which waste management is an important part. The CHP plants in the systems provide the other actors with heat and electricity and get wood wastes for fuels in return. Waste utilization has resulted in interdependent relations between the actors in the systems.

For example, in Jyväskylä the cascading of energy is possible, because the Rauhalahti power plant and the Kangas paper mill have started to co-operate. The paper mill needed to reduce its use of external oil and therefore was willing to look for alternatives. The waste energy of electricity production is now obtained from Rauhalahti to satisfy this need. The two actors have reached a mutually benefiting agreement here. The second main IE feature of the system, the utilization of the local waste material for fuels, has been enhanced because of the development of mutually benefiting co-operation as well. This shows in the relations between the Rauhalahti plant and the Säynätsalo actors, which co-operate through wood waste utilization. The owner of the power plant in Rauhalahti is now the same as that of the Säynätsalo local power plant. The change in ownership has made the co-operation between the actors easier, e.g. the control costs have been reduced (see chapter three on the Jyväskylä case).

Locality (in material and energy flows)

In the forest industry of Finland, there are 11 local forest industry systems, integrates, where the presented actors operate in close physical proximity by using each other's wastes. A typical integrate includes a saw mill, a pulp mill, a paper mill and a power plant all of which are located near the forest ecosystem from which round–wood is harvested for the system. The need for external inputs has been reduced, because local wastes and local renewable forest resources are used.

In the Jyväskylä system the actors involved and nearly all the fuels that are utilized are located within the radius of approximately 80 kilometers. Peat is transported from 80 – 90 kilometers away. The Säynätsalo plywood mill is located 15 km away from the CHP plant of Rauhalahti. The discards of the plywood-mill are transported to the power plant. The saw mills that provide the system with waste wood are within the distance of approximately 30 to 50 km. The local wood waste use has helped in substituting the imported coal and oil inputs. The distance between Rauhalahti and Kangas Paper Mill is about four kilometers. The heat distribution to the local households usually covers maximum of 10-20 km. (see figure 2 in chapter four)

Table 3 The four ecosystem principles in the forest industry and the Jyväskylä case studies

The Forest Industry Industrial Ecosystem	The Jyväskylä Industrial Ecosystem
Roundput (waste utilization) The annual cuttings are lower than the annual growth of the forests Waste materials are recycled and used as fuels Nutrients from waste ash of the power plants are returned back to the ecosystem cycle Waste energy is used for heat in the co-production method of heat and electricity (CHP) The binding of CO_2 emissions in the forest ecosystem exceeds the amount of carbon released through cuttings (consequence from the first point)	*Roundput (waste utilization)* The annual use of peat is lower than the annual growth of peatlands in Finland Waste materials are used as fuels Waste energy is used for heat in the co-production method of heat and electricity (CHP)
Diversity (in the actors involved) The system includes forestry companies, a saw mill, a pulp mill, a paper mill and a power plant The inputs of the actors include renewables, waste materials, waste energy, non-renewables The outputs with value include normal products as well as wastes, e.g. heat and ash (fertilizer)	*Diversity (in the actors involved)* The system includes a power plant, a plywood-mill, saw mills, a paper mill, forest companies, a horticultural centre, households and services as end-consumers The inputs of the actors include renewables, waste materials, waste energy, non-renewables The outputs with value include normal products as well as wastes, e.g. heat
Interdependency (in co-operation) The many actors co-operate in waste utilization	*Interdependency (in co-operation)* The many actors co-operate in waste utilization
Locality (in the material flow supply and demand) Using local renewables in accordance with sustainable yield Using local wastes to substitute imported non-renewable fossil fuels Meeting the needs of local industrial consumers	*Locality (in the material flow supply and demand)* Using local renewables in accordance with sustainability (if integrated over all Finnish peatlands) Using local wastes to substitute imported non-renewable fossil fuels Meeting the needs of local end-consumers

Industrial Ecosystem Part Three: Four ecosystem principles for an adaptive industrial ecosystem

Sustainable development as adaptation

Industrial ecology seems to be one of the most rapidly developing concepts in the societal sustainable development discussion. The most well known environmental report during modern environmentalism, the Brundtland Report, defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). An ideal industrial ecosystem, as understood in this thesis, should then have as its ultimate aim the effort to develop industrial systems toward sustainable development meaning their use of material and energy flows. Through industrial ecology the resources that industry takes in from the environment are reduced and wastes and emission that the industrial activity generates to be dumped into nature are reduced. Industry should be able to operate in a way that the ability of the ecosystem to function is secured. In terms of sustainability the vision is, then, that this would also secure the existence of industrial activity. Industrial subsystems will always be dependent on the source and sink functions provided by the larger life support system (see Daly 1996).

Many agree that the work of Robert Ayres has provided some important preconditions for what is now developing as some would say 'the field of industrial ecology' (see Frosch 1992). Ayres defined the concept of 'industrial metabolism' to mean that all systems, whether an organism, an animal, an ecosystem or an industrial system are alike in that they take resources or food from the environment and eventually put back products or wastes (Ayres 1994, see Ayres 1989). What is important in the comparison of an ecosystem with an industrial system is that an ecosystem would seem to have some important characteristics that can be argued to make it more sustainable than industrial systems and economic systems. John Ehrenfeld (2000) has noted that " *Natural ecosystems, in my experience, offer the only wordly example available to humans of long-lived, robust, resilient living systems, the characteristics of which are all features of the radical idea of sustainability...*" (p237)[15]

Herein lies the most important argument for drawing from the ecosystem metaphor in the context of industrial environmental management. If we want to figure out ways to achieve sustainability in terms of the material and energy flows of industrial systems, we should consider the potential to learn from the ecosystem material and energy flow model. It will never be possible to construct an industrial system as a perfect industrial ecosystem. But the direction might offer some needed environmental improvements with regard to the way in which industrial systems use the source as well as the sink functions provided by nature (Frosch & Gallopoulos 1989, Allenby & Cooper 1994).

In an ecosystem species come and go, but the system as a whole seems to be able to adapt to endogenous and exogenous changes. Therefore, the ability of individual organisms as well as of the system as a whole to *adapt* to their surroundings can be argued to be the condition that leads to sustainability of a natural ecosystem. In modernity, the evolutionary theory has been often related to competition, the ability to 'outcompete' with one's local environment in a continuous struggle to survive (Clark 1991, see Simpson 1949). Clark (1991) argues that this can be misleading. This is because evolution is mainly based on fitting in with one's surroundings and adaptation into the ecological situation. An organism is able to adapt to the environmental constraints in the local envi-

[15] See also Bey (2000) who notes on natural ecosystems as " the only sustainable systems so far".

ronment and to the operation of its co-operation partners (Clark 1991, see Simpson 1949), which, then, is not simply competition with one's surroundings.

Adaptive industrial ecosystems

The four ecosystem principles of roundput, diversity, interdependency and locality are intended as a potential direction toward which an industrial system should strive at in order to reach an industrial ecosystem. In other words, it is argued here that with the principles an industrial system may be able to improve its environmental performance in terms of the material and energy flow model in table 1, and in this sense improve its sustainability. The ultimate goal of an industrial ecosystem would be and adaptive sustainable system. I will use the notion of adaptation as a goal of a successful industrial ecosystem by dividing it into two parts.

The first part means that an organization in the industrial ecosystem will adapt to the material and energy flows of its suppliers and of its customers. For constructing an industrial ecosystem an important point is that the industrial organization will adapt to the waste material and waste energy supply of its co-operation partners. An organization should be able to use these waste flows as inputs. Similarly, an organization should be able to create value for its waste products[16] and in this way satisfy the demand of its customers partly with waste derived products. Waste energy in the form of district heat is an example of this with the Jyväskylä energy supply system. In this first sense of adaptation, a relatively advanced adaptive system exists in the forest industry case and in the Jyväskylä energy supply system case study. The use of each other's wastes constitutes an important feature of the operation of the actors that are engaged into the two industrial systems.

The second part of the notion of adaptation in an industrial ecosystem can be a result of the first part. That is, if the company can utilize wastes it can better adapt its activity to the natural environment. This of course is the condition towards which all industrial environmental management projects should strive at. The company, and more importantly, the industrial system as a whole can retain its use of local renewable natural resources within the sustainable yield if substitutes are found in wastes. It can reduce the emissions that the use of non-renewable fossil fuels create by substituting the use of these with waste utilization. The amount of wastes can be reduced, when wastes are seen as products with value.

In this second sense of adaptation, again, the Jyväskylä industrial ecosystem and the forest industry system can be argued to be relatively advanced. The Jyväskylä Rauhalahti CHP plant uses local peat reserves for substituting imported coal and oil. As noted earlier, peat in Finland can be argued to be a slowly renewable resource and also in this sense preferable to coal and oil. In the case of the heavy industry system of a forest industry local integrate, one can note that totally in Finland the annual cuttings of the forests are lower than

[16] Linnanen (1998) has used the term circular value chain, when highlighting the need to see products with value also after their use.

the annual growth. The industry has adapted to its local natural resources and to their renewal rate.

Both of the systems have reduced the use of non-renewable fossil fuels considerably through waste utilization and this has made it easier for the natural environment to tolerate the outputs of the industrial activity, in other words, for the industrial systems to move toward adapting to the natural ecosystem. Fossil fuel generated emissions have been reduced and wastes have been reduced. In the forest industry the amount of CO_2 that the forest ecosystem binds exceeds the amount of carbon that is released through the forest industry cuttings. In terms of adaptation, the emissions here are 'adaptable to nature'.

Preventing problem displacement

My argument is that to consider the four ecosystem principles of roundput, diversity, interdependency and locality together in a systems approach and to relate them to the ultimate goal of adaptation is needed in order to avoid suboptimal solutions or problem displacement (see Jänicke & Weidner 1995, Ayres 1994). There exists relatively advanced local recycling systems that demonstrate interdependency and symbiotant relations, but still rely on imported fossil fuels as the main input. For example, the most often cited IE case study, the Kalundborg industrial district at Denmark (see Ehrenfeld & Gertler 1997, Gertler & Ehrenfeld 1996) is an advanced and diverse system when considering the waste utilization. Kalundborg has been an important eye-opener for the development of the industrial ecosystem thesis. However, the two key actors in the system are a coal-fired power plant and an oil refinery that use imported non-renewable fossil raw materials. Similar systems exist in other parts of the industrial world. There is a risk, that the environmental gains achieved through recycling in such systems will loose their significance. This is if the system will increase its growth rate over certain levels, because the basis of growth is in the emission intensive non-renewable fossil raw materials.

Further, if recycling is approached as recycling of some isolated product flow, say, of paper wastes, problem displacement may occur. Studies on the rapidly increasing paper recovery rates in Germany indicate that strong recovery rates may not be the best scenario for the environment (Korhonen 2000, Korhonen & Pento 1999, Pento 1998a, 1998b). When the effort is to recycle, the recovered paper must be made to fit the production life cycle. This means that the paper is de-inked. De-inking will create de-inking sludges. When there might not exist enough de-inking capacity, e.g. de-inking technology or de-inking plants or newspaper plants to process the rapidly increasing amounts of recovered mass, part of the paper may have to be incinerated. Incineration generates incineration ash.

At some point of recovery and recycling, the total amount of the generated waste can remain unchanged regardless of the high recovery rates. Waste paper at landfills will be reduced, but de-inking sludge and incineration ash increase. To avoid such a situation, the recycling or roundput goals should be considered with a systems perspective. The system diversity, i.e. the many actors involved and the different material flows that occur in various steps of the product's life cycle and in the related life cycles should be carefully considered.

Conclusion

The purpose of our's has been to reflect on an industrial ecosystem in visualized terms and to point out the successful features in the two case studies. I do not want to claim that the principles I have presented are in any way easy to achieve. They are not, consider the above paper flow example for instance. In case of diversity and interdependency, the problems in developing symbiotant co-operation relations have been discussed with the sections above. In addition, one could note that for an organization to engage into material flow based co-operation, barriers may occur resulting, for example from issues that relate to technological capacity. A company may have to diversify into unfamiliar areas of activity. It can be difficult for a company to build pipe lines or waste processing technology, which may be required in order to adapt to the waste supply of its co-operation partners.

Also information barriers must be taken into account. For example, the use of quantitative data to prepare an environmental report for a company is still only a developing field of study and practice. Co-operation partners will need information about the potential wastes that are offered as well as about the potential users of waste raw materials. The local arrangement of the material flows of the industrial system will be difficult if the region does not have vast renewable reserves, e.g. in peat lands and forests. Similarly, the local system may only include large manufacturers that are not prepared to engage in waste processing activities. The existence of recyclers is important for the industrial ecology cyclical flows. In the case studies of this thesis the CHP plants have served as producers of heat and electricity as well as recyclers to process and use the wastes of other actors in the systems.

Both of the cases have points, where environmental improvements are continuously needed. For example, the forest industry still uses imported fossil coal and oil to some extent. The use of peat by the Jyväskylä energy supply system is a problem, because peat is, at most, a very slowly renewable natural resource. When the model of the cases is reflected on other industrial systems, other barriers of the implementation of the presented ecosystem material and energy flow model or of the four ecosystem principles can occur. Every local system is a unique system and needs its own case study to identify the opportunities for industrial ecosystem development.

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CHAPTER FIVE

Some Barriers of a Local Industrial Ecosystem

Introduction

The book has focused on the concept of an industrial ecosystem and on the effort to draw from the ecosystem model of material and energy flows when understanding such as system. We have tried to identify some directions toward which an industrial ecosystem project could strive. I feel that in the context of the thesis, with the argued presentation and understanding of an industrial ecosystem concept (in chapter four), one has not been able to study how can we actually construct or design an industrial ecology system in practice. In other words, I have considered IE as a vision, as a goal on top, and some potential directions for IE-type system development. Two arguably advanced case studies and existing systems have been described for this. But I have not actually considered what is an 'industrial ecosystem project' or how can this project as a practical management program move toward the direction of, e.g. the four ecosystem principles of the last chapter. We have not discussed what kind of policy frameworks, implementation programmes, corporate environmental management systems, design principles, tools or information management systems should be included into an industrial ecosystem management agenda.

In other words, there are two aspects in IE. First, as in this thesis, it is a vision, a goal and a concept for describing and *understanding* an industrial system that is highly developed in its environmental performance; a desired outcome of industrial environmental management or the result of a successful application of environmental policy instruments. Or IE is the way to tell a story about system development of an industrial system that has emerged as relatively advanced in terms of sustainability. Second, IE can be understood as an environmental policy concept, a management concept or strategy, as a material flow management tool with which environmental policy and management goals could be achieved in practice.

In this final chapter I will try and consider the problems of industrial ecology and the understanding of the concept in the cases. A visualized industrial ecosystem will be presented based on the experience from the two studied systems. I will try and reflect on the need to integrate production and end-consumption systems. An integration of a forest industry system and an industrial system that includes the end-consumption within its system boundaries such as the one with Jyväskylä is constructed. Again, the key word here is 'understanding' and not management, strategy or design. As in the course of the book, I will mostly remain in what I meant above with the first shape that IE has taken in the literature. In terms of the second aspect, the industrial ecosystem design principles or a management strategy, the concept at this time with this amount of practical case studies, does not seem to provide any specific models or strategies that would extensively differ from the more 'traditional' corporate environmental management tools.

The second character of the concept still seems to be more of a collection of various approaches, techniques and tools instead of a distinctive management system of its own. This is not inherently bad. One should not just abandon older ideas when it seems that a new one is evolving. But the goal and the vision in IE certainly are new and the realization of the vision will also need new approaches and tools as well as combinations of the existing ones. Some argue that industrial ecology-type development is beyond the stage of 'normal science' and must begin with a fundamental paradigm shift, with a 'revolution' and change in the vocabulary with which we understand the world[17].

The visualized industrial system that will be reflected below is intended as a future research hypotheses. Of course, one such future research need would also be the effort to reflect more on the second shape of IE, on 'industrial ecosystem management'. One could consider how environmental policy, direct regulation, green taxes or corporate environmental management systems (EMS), tools such as life cycle assessment (LCA), material flow models (MFM) and environmental (or ecological) accounting (e.g. eco-balances) could facilitate development that is towards the IE vision. I will only consider some potential initiatives here, perhaps helpful in future study proposals, because the approach in the book has remained within the first character of IE.

As an introduction to the vision of a local industrial ecosystem, in which some integration points of production and consumption are considered, arguments that encourage such experiments are discussed in the first two sections. After the presentation of the system, proposals for management and policy in IE are considered. The final part of the chapter deals with barriers of IE-type system development considering the cases as well as industrial ecology in general. The last part includes a concluding discussion on the basic argument and approach in the thesis.

The case studies as an industrial system and an end-consumption system

The forest industry of Finland can be understood as a case of industrial ecology with a heavy industry system. A forest industry local integrate will be in continuous interaction with the forest ecosystem, because it uses lot of natural resource inputs in its production processes. Saw mills and pulp mills as well as the energy production of the industry receive the natural income from the forest in a form of wood inputs that serve as raw materials and as fuels. The system boundaries of a local forest industry system include mainly heavy industrial processes as actors. The system produces for the purposes of the industrial actors, although end-products such as paper are used in wide geographical areas.

It is possible to approach the Jyväskylä city energy supply system in chapter four as an industrial system that includes the end-consumption system within its system boundaries. The most important customers of the Rauhalahti and Säynätsalo power plants are households, service buildings, municipal department buildings and the light industry in the city. The development of the system to include the Kangas paper mill as a customer of the Rauhalahti plant

[17] Ehrenfeld 2000, see the discussion in the last part of this chapter.

has been important for the industrial ecology of the system. The amount of waste heat that is utilized for industrial use has been increased.

Many authors have called for an integration of the management of consumption systems into environmental management programs, because these often drive waste and emissions generation, and in the end, the natural resource intake into industrial systems for producing for consumer needs[18]. The importance of the role of consumers, households, services and transportation shows in the case of energy use. For example, in EU countries the amount of all primary energy use when allocated to end-users was approximately 62 % for residential, service and transport use and only approximately 38 % for industrial use (Lehtilä et al. 1997). Further, to substitute the consumer wastes that end up at landfills by burning these as REF (recycled fuels) and using the generated energy is preferable in light of global warming. Methane (CH_4), which arises from the decay of products and wastes at landfills, is more harmful than CO_2 (methane is about 20 more potent greenhouse gas than CO_2).

The way in which the material flows of societal development have evolved during the last two decades encourages the need to integrate production and consumption systems into a one industrial ecosystem. The so called 'production emissions' and wastes or point source emissions that occur on site have been reduced in many industrialized countries, e.g. due to environmental policy or legislation. However, the latter steps of the life cycle are continuing to cause problems for the policy maker. Some use the notion of 'problem displacement' (Jänicke & Weidner 1995). Here, it has been observed that consumption emissions and wastes amount (Nakamura 1999, Anderberg 1998). These are wastes that 'become wastes' only after their use, e.g. used paper. Therefore, these appear in wide geographical areas and are scattered. Because of small isolated streams, the management or monitoring of such wastes can be difficult.

From product-based to regionally based management systems

The philosophy in this thesis has been that the industrial ecology, industrial ecosystem and industrial metabolism analogies or the metaphor of a natural ecosystem are helpful for understanding the system structure of industrial and societal material and energy flows. As Ayres (1994) notes all systems, whether an organism, an animal, an ecosystem or an industrial system are alike in that they take in resources from their environment and put back products or wastes. The concepts of an ecosystem may help in terms of presentation, when considering the material flows of an industrial/societal system.

With regard to the material and energy flows, the sustainability of an ecosystem is based on diversity and adaptive interdependency between plants

[18] see Burström 1999a,b, Anderberg 1998, Rejeski 1997, Brunner et al. 1994, Bacchini et al. 1993.

(producers), animals (consumers) and decomposers or bacteria (recyclers)[19]. The matter, nutrients and embedded energy circulate between these actors, while the system runs entirely on (infinite) solar energy. One of the important differences between an ecosystem and an industrial system from the viewpoint of industrial ecology is that the flow from producers to recyclers is practically non-existent in an industrial system while its is an important flow in a local ecosystem. Further, a local ecosystem produces from local inputs and for the requirements of local consumers and minimizes the use of energy. An industrial ecosystem project, then, would strive toward physically integrating production, consumption and recycling to reduce the use of energy and to create a local recycling network to minimize the waste and emission output from the system as a whole. The flow from consumers and from producers to recyclers and back will be increased in this locally based system.

Two general strategies for industrial ecosystem management have been determined (Boons & Baas 1997, Lowe 1997). First, the design for environment (DfE) or life cycle assessment (LCA) and life cycle management plan, design or trace the potential environmental impacts throughout the product's life cycle; from raw material extraction through production and use to end disposal. Second, the geographical approach, the regional/local industrial ecosystem or the eco-industrial park thesis, such as that applied in the Jyväskylä case, tries to integrate industrial actors into a common local recycling system, an industrial ecosystem. As in a local ecosystem, cyclical flows of matter and energy cascades are developed between the firms.

As noted above, the life cycle of a product may often cross spatial boundaries and therefore the LCA focus will be of importance. However, to minimize the use of energy and to be able to manage as much as is possible of the life cycle, extraction/harvesting, production and consumption processes should be integrated into an industrial ecosystem, where the actors are located in close physical proximity to each other. The product-based tools such as LCA can serve as an information management tool in this process to provide the actors with information on the material and energy flows that are potential inputs for their processes.

A local industrial ecosystem extends the recycling philosophy beyond the recycling of an isolated product flow, say, of paper, and tries to minimize the environmental impacts of the system as a whole, in this case of a forest industry system of which the paper flow is one part. The questions that are to be looked at in the system include, in addition to paper recovery, for example the use of incineration ash from industry energy plants (from burning of recovered paper) for fertilizer in the forest ecosystem or the use of waste heat from paper mills for heating the pulp mills etc. The traditional LCA of paper would close the cycle by studying the use of the recovered mass in pulping and would not consider the use of waste heat or utilizing wastes for fertilizer.

The product-based or the life cycle approach may at times seem to be in conflict with the aims in the geographical systems approach of a local industrial ecosystem (see Boons & Baas 1997, Lowe 1997, Ehrenfeld & Gertler 1997). In

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[19] Husar 1994

general terms, some understand the basic aim of the LCA to reduce the environmental impacts, e.g. wastes, of a given product throughout its life. But the goal of the regional industrial ecosystem thesis is to reduce the environmental burden from a system of companies and other societal actors as a whole. In this approach, the system and its many different material and energy flows and the many different actors involved is more important of a focus point than an individual waste flow or an individual actor in the system. A situation may occur in which a certain firm will want to reduce its wastes, e.g. because of environmental legislation or perceived risks of waste management costs. This particular waste flow might be important when trying to create an industrial ecosystem, which will rely on the existence of wastes and then tries to substitute the virgin inputs to the system as a whole with these. It can be difficult to convince all of the actors in a local industrial system that the benefit of the system is the most important goal.

Integration of production and consumption

Below I will consider the possibilities to use the experiences gathered in the case studies for physically combining a local forest industry system with an end-consumption system such as the one in Jyväskylä. This will be done by reflecting on a material flow management scenario, in which local wastes from industry and partly from end-consumption are used in production to meet the needs of both production processes and end-consumption of a local area. The scenario is visualized and intended as a future possibility.

A local industrial ecosystem in **figure 1** includes production and end-consumption systems. The argument that is on the basis of the figure is that, because there are 11 local forest industry integrates in Finland that arguably have some important features of IE and which are based on co-production of heat and power (CHP)[20], one should reflect on the possibility to combine these with a local city energy supply system. All of the major residential concentrations in Finland are based on CHP for their energy supply and many of these are located near a forest industry integrate.

In figure one, the CHP plant of a local forest industry system provides the forest industry actors with heat (waste energy in CHP) and electricity. The local city will benefit from the waste energy of the electricity production as district heat. The households, services and other buildings are connected to heating pipelines. Local renewable natural resources as well as local renewable waste flows are used as fuel inputs in the CHP plant. The renewable natural resources are used in accordance with sustainability. These as well as the local waste fuels are less emission intensive than imported non-renewable coal and oil inputs.

[20] The figure 11 is approximate in that in Finland there exists lot of forest industry or forest industry related industrial activity. Therefore, the figure can be different, e.g. if smaller or more simpler structures are taken into account there are more integrates etc.

The system and the CHP plant will use wood wastes from saw mills, pulp mills, wastes from paper mills, forest residues from cuttings and wood wastes from furniture mills as fuels. In addition, black liquor from pulp mills serves as fuel. The CHP plant can receive REF from households or from municipal departments in the city or wastes from agricultural farms located near the city to be used as fuels in the plant. Parts of the nutrients embedded in the waste ash of the power plant will be returned to nature as fertilizer. In this system also the raw materials for pulp production are derived partly from the saw mill wastes. Pulp mills will get part of their heat from waste energy of paper mills. Pulping waste chemicals are re-used in pulp processes to minimize the need for external chemical inputs that are costly. This reduces also the harmful waste chemical flows to environment.

Arguably, the vision in figure 1 has some important features of the industrial ecology philosophy. It is also integrating extraction/harvesting, production and end consumption actors into close physical proximity and minimizing the use of energy or the export of isolated product wastes. First, the local forest ecosystem is the source of raw materials for the system and currently in Finland it is used in accordance with sustainable yield. Arguably, this is the case with local peat harvesting for the fuel input of the CHP plant in the system as well (see the Jyväskylä chapter discussion on peat as a slowly renewable resource). Second, in case of production, the CHP method and the waste utilization (with the technique of fluidized bed burning) in it help to keep the fuel basis of the system local, i.e. the substitution of imported fuels with local waste energy and waste derived fuels such as forestry an saw mill wastes. In addition, the local ecosystem can absorb the amount of CO_2 emissions that exceeds or is equal with the amount of carbon released through extraction and harvesting the ecosystem resources (because cuttings respect the reproduction rate).

Third, when considering end-consumption, it can be argued that it is possible to connect also these actors into the co-operation effort in waste utilization, into close physical proximity of the other actors, i.e. of extraction and production processes. Such a scenario could be achieved if the cities in Finland increase the amount of district heat (waste energy) that they will buy from the local forest industry systems. It is possible to enhance the role of consumption in the presented hypotheses through substituting the imported fossil fuels with REF from households in the input basis of energy production.

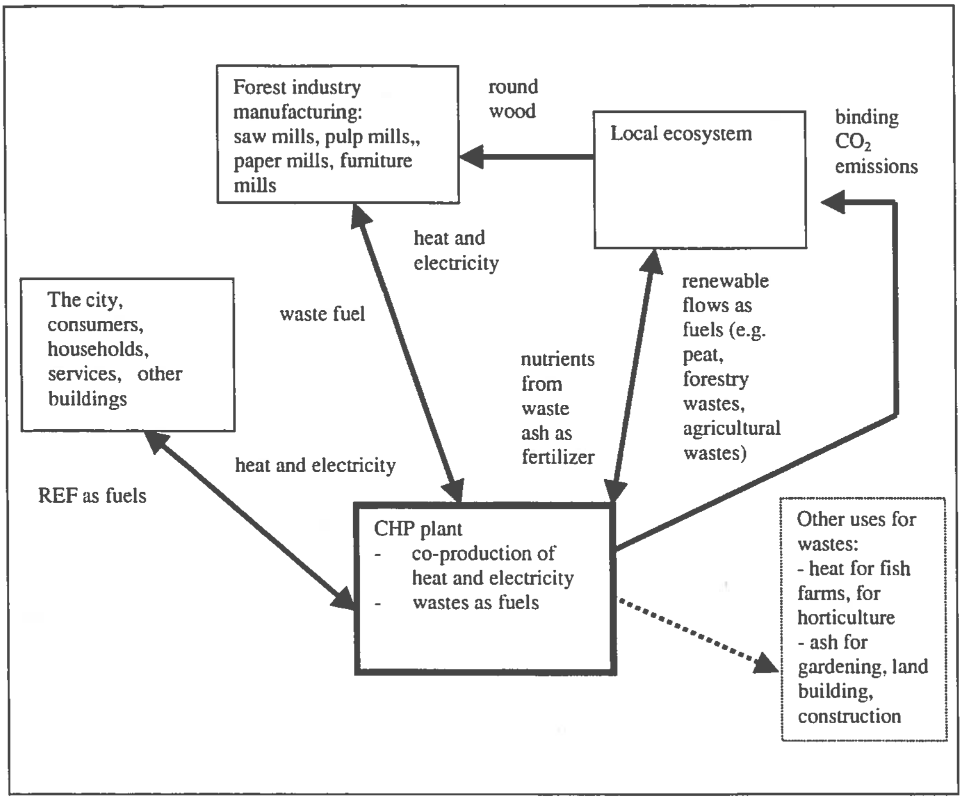

Figure 1 CHP-based energy production integrating production and consumption systems into a local industrial ecosystem

Importance of situational factors

The key feature in the vision of the system in figure 1 will be the connection of the city energy supply system to the energy production of a heavy industry system, in this case the forest industry system. The key activity here is the forest industry CHP energy plant. If this integration will be achieved, through the CHP energy production, significant parts of the extraction steps, as well as production and consumption steps of the life cycle of heat and electricity could be co-located into the local system.

Although the described system might only be possible in the context of the two case studies in the thesis, that is a city energy supply system and a local forest industry system and its CHP plant , conducted within the Finnish energy and forest sectors[21], the model might provide some directions toward which to develop regional material and energy flow management in other regions. Energy, heat and electricity are needed practically everywhere and forest, pulp and paper sectors are also important focus areas for environmental manage-

[21] See the chapters two and three for the cases, see Korhonen et al. 1999, Korhonen et al. 2001.

ment in global scale. The EU average with regard to the share of co-generation of the total national electricity generation is little under 10 % at the moment and the objectives are likely to rise considerably in the near future. The success of industrial ecology, however, will be tested through case studies, where the regional system in question is considered in terms of its specific situational characteristics and factors that affect the operation of the system.

Support systems for regional industrial ecology

A physical anchor tenant of a local industrial ecosystem

The literature in IE, particularly on regional IE or eco-industrial parks, seems to agree that there is a need to identify a certain key organization, an important company or a key actor in the region around which an industrial ecosystem, a recycling network of industrial actors, could emerge. Such a key activity has been called as a 'symbiosis institute' (Baas 1998), a 'support system' (Baas 1998, Boons & Baas 1997), an 'anchor tenant' (Lowe 1997, Chertow 1998, Cote & Cohen-Rosenthal 1998, Korhonen et al. 1999), an ' initiator' (Brand & de Bruijn 1999), 'a process unit' (Wallner 1999) or a 'separate co-ordinating unit' (Linnanen 1998).

I will argue that the CHP plants in the cases have served as such an 'anchor tenants' of a regional industrial ecosystem. That is, to serve as the driver of some of the main physical material and energy flows of the regional energy supply system. The power plant facilitates the use of waste material and waste energy as input resources and as valuable output products in the local recycling system. The CHP plants in the case studies use diverse fuels as input including wastes and therefore help in drawing the actors together into a recycling network. The plant produces for many actors as well. It provides them with electricity, heat and steam. Other possible uses of heat or wastes with a power plant, e.g. for heating fish farms like in Kalundborg or the use of ash for fertilizer are listed in figure 1.

Some additional factors that are important in a CHP plant's potential to be the anchor tenant can be identified. In Jyväskylä the power plant is to a large extent publicly owned. There exists no such competitive pressure than if the company in question would be a private organization and involved in normal market-type situations, which many still see as the main barriers of environmental innovations in firms. Environment can be regarded as an external burden. A public organization may also facilitate the co-operation between local firms. These could otherwise be reluctant to engage in interaction, because of e.g. competition or lack of trust.

Arguably, a co-production plant is relatively reliable. If the production is disturbed, heat and steam can be produced with oil boilers and the system can be repaired within hours to recover into normal production routine. A CHP plant can stay in operation for decades and serve as a long term 'support system' for a local industrial ecosystem. However, the long age of CHP plants may be negative from the environmental perspective, because it might prevent the adaptation of new and possibly 'greener' technology in the plant. The environmental benefits of the CHP method include the fact that it can be organized in a one big plant. The flue gas emissions can be dealt with at one place cost-effectively.

An institutional anchor tenant

Despite we would have a potential industrial ecosystem anchor tenant in a power company, the question still begs, how can existing industrial systems be redirected towards industrial ecology? How can we plan, manage or design an industrial ecosystem, i.e. how can we develop IE in terms of its second shape as was discussed earlier in this chapter? There have been no intentional efforts to deliberately create an industrial ecosystem in the two systems of the case studies, nor in the case of Kalundborg. For example, in the 1960s when the Jyväskylä system started to evolve, there were no official environmental policy programmes (in today's sense of the term) nor a ministry of environment in Finland. The forest industry system and the Jyväskylä system have self-organized, because of situational factors and local conditions. The price of round-wood has been an important stimuli for the forest industry, the reduction of fuel and operating costs that for Jyväskylä.

I argued in the case studies that points such as these are mainly descriptive or mere presentations of an existing situation. IE study is simply telling a story about a development of a system after this development has occurred. Again, as argued in the introduction of this chapter with the interpretation of the first shape of IE, the concept is a goal on top and a vision toward which policy and environmental management should strive. Based on current amount of case study experience, the actual suggestions or principles for the strategy on how the policy and management efforts should be organized and implemented in practice, i.e. the second character of industrial ecology, remain in their initial stages at most.

With the existence of a CHP plant or the feed backs in prices of wood one can try and partly explain environmentally friendly development of an industrial system. But this does not mean that one is able to actually use the experiences as evidence of a successful management strategy for an industrial ecosystem, because such an intentional strategy does not exist in the systems of the two case studies. In other words, to build or plant an anchor tenant such as a CHP plant into a local industrial system may not result in any environmental improvements nor in industrial ecology-type system development. For example, there might not exist enough wastes that can be used as fuels in the system and the company will require imported fossil fuels as inputs, which can create an emission intensive system etc.

The co-production plant as an anchor tenant drives the main physical material and energy flows of the local industrial system and could in theory be the focus point around which the control mechanisms and management of these flows are arranged. To manage an industrial ecosystem, one needs this kind of a physical anchor tenant, but it seems that also 'an institutional anchor tenant' to provide the actors in the system with institutional support is needed (Burström & Korhonen 2001).

A public municipal organization in the local area might be a potential organization to fulfill parts of this function. First, as with a publicly owned power company, this public body could facilitate the private industrial actors to co-operate. Second, the municipality provides the system with political support and a decision-making forum. Third, the municipality may serve as a platform in which data on regional flows of matter and energy can be collected and processed. A private organization is unlikely to have the motivation to monitor material flows of a region, because it is mainly concerned about its own economic results. Fourth, in its everyday duties the municipality distributes information and monitors different regional actors and co-operates with them in various regional development projects and could then be the right forum for information management and education for industrial ecology.

Fifth, the municipality may be able to construct or provide infrastructure support for an industrial ecosystem. It is in charge of spatial planning and building of physical infrastructure. Finally, the municipality organization is the only large actor in a region that simultaneously has to deal with the economic, social and nowadays also ecological well-being of the region, because, for instance, of legislative duties. Again, a private company is usually concerned on its profit maximization and hence is unlikely to fully consider these 'three pillars of sustainability' in the regional context. It is also possible for a municipality to enhance industrial ecology-type activities with economic and legislative incentives, because it has a certain amount of public authority in the region.

The anchor tenant concept seems to be important for the development of regional industrial ecology. It will be easier to build on existing local strengths in environmental management rather than trying to 'create an industrial ecosystem from scratch' (Chertov 1998). A CHP energy plant serves as a starting point for case studies for developing this path for both regional energy supply systems for cities and residential areas, as well as for heat and electricity production for industrial processes. Therefore, the idea of an anchor tenant (or the effort to identify such an actor in a system of firms) can be understood as one management proposal that the case studies would support. In light of the two forms of IE the anchor tenant concept is a proposal for what was interpreted as the second shape of the concept above in the introduction.

Regional Environmental Management Systems

This chapter has emphasized local or regional industrial ecology development through co-operation between producers and end-consumers as well as through co-operation between private industrial companies and public organizations. In the previous section on an anchor tenant the need for some kind of management or design principles, that is, the need to consider the second shape of IE was expressed. One should also note that it is important to include the societal drivers of the material and energy flows, the values, the decision making processes of the actors involved into an IE study. Furthermore, the issues related to management and organization of environmental efforts should be included into the material flow framework of IE.

One possible path along these lines could be developed with a discussion on regional environmental management. Welford and Gouldson (1993) have reflected on an idea of a Regional Environmental Management System (REMS). In REMS the familiar model from literature on business environmental strategy, an environmental management system (EMS), that has been develop based on quality management systems, is formulated into regional context. The aim in REMS is to extend the EMS-type process beyond the boundaries of a single organization toward a co-operative regional system. This philosophy is related to that in the local industrial ecology approach. As discussed in chapter four, IE is a form of an inter-organizational phenomena or is similar to studies that have been conducted in the field of organizational sociology, where the dependency of a firm on its surroundings is the focus[22] .

In REMS the hypotheses is to include many different firms, public organizations, local research institutions, the university and environmental and citizen groups of a certain region into a regional environmental management effort. From these actors a management group could be constructed. In the process of REMS an initial environmental review for the region is prepared. Also a general regional environmental policy is formulated. The implementation program for the objectives of the policy includes more detailed and possibly quantified goals and action proposals as well as the definition of responsibilities. As in quality management, the aim of continuous improvement requires that the success of the program will be assessed or an audit is carried out. The system will be repeated with feed-back from this first round.

REMS offers a potential management and organisatory structure for industrial ecology. The REMS-type goal definition, the formulation of the action proposals and the assessment of the results could be quantified in terms of the material and energy flows of the industrial ecology system. For example, the objective of an energy supply system would be to reduce the use of imported non-renewables by a certain amount by a defined time, e.g. during the year 2001. The action proposal could be that the local actors invest in a CHP plant. More specifically, an action proposal includes an effort to substitute the non-renewables with wood waste flows from the local saw mill or with recycled fuels from the municipal department buildings and from households. In the auditing phase one concentrates on the success of the implementation of waste utilization goals. The feed backs should be used when the REMS and IE efforts are further developed to respond to the aim of continuous improvement.

Energy policy and environmental policy

The energy policy of the country in question is crucial for the progress of co-production of heat and electricity and therefore for the development of a kind of a local industrial ecosystem that was described in the case studies or in the

[22] Boons & Baas 1997, see chapter four.

vision in figure 1. We can identify two main policy directions, which can support the utilization of CHP (Korhonen et al. 2001, see Grohnheit 1999).

First, requirements for centralized heat planning can facilitate the combination of the production of heat and electricity. Experiences from Denmark support this argument. (Grohnheit 1999). With these arrangements cogeneration plants have the potential to supply heat for district heating networks, which are owned and operated by municipal or local energy utilities. Second, another direction in policy is to liberalize electricity production and the access to national electricity grid. Here fair competition conditions for local CHP operators in small district heating networks or in industry are quaranteed. In such a situation, the CHP plants could, for instance, sell surplus power over the national grid and buy back-up power when needed.

Requirements to reduce CO_2 emissions and the use of fossil fuels to mitigate the greenhouse effect, both in global and national scale, will obviously contribute into the motivation to develop policies that enable cleaner production strategies such as CHP. Practical policy instruments to guide the energy companies towards improved energy efficiency, and CHP, can be, e.g. voluntary agreements on improvements, taxation of fuel use or emissions, cap and trade policies, or regulations and licensing. (Korhonen et al. 2001)

The approach to the taxation of fossil fuels that has been taken in the northern countries of Sweden, Denmark and Finland, can be argued to have been successful in facilitating the type of activity and arrangements that would follow some of the aims in IE[23]. With taxes, the industry has been encouraged to develop toward natural cycles, the reproduction capacity of ecosystems, i.e. to reduce the non-renewables that are used and use wastes as well as renewable natural resources. Fossil fuel taxes also enhance the regional arrangement of industrial activity, because transportation is based on fossil oil. The road transportation fuels already have high taxes in the Nordic and EU countries. This is mainly due to fiscal reasons.

Barriers of industrial ecology

In this part I will try and discuss some of the barriers of a local industrial ecosystem project. First, some difficulties that are related to the application of the CHP method are considered. In the latter part of this section some more general problems in IE are listed.

When reflecting on the possibility to apply the CHP method, which has been one of the key features of the industrial ecosystems of this thesis, various situational factors and difficulties that differ from one system to the next must be considered (see also Grohnheit 1999, Verbruggen 1996, Gustavsson 1994). Obviously, the application of the method will require that there will be demand for its products. One natural precondition of CHP and district heating systems is that there exists climatic conditions in which heat is needed. Such conditions

[23] see Ring 1997

exist in Central European countries, in Eastern Europe and North America. The heat can be transferred only over approximately 10-20 kilometers. Therefore, in order to construct a district heating system there will have to be a locally concentrated demand for heat.

A required demand for heat exists in areas that include office buildings, commercial buildings, blocks of flats and raw-houses. Here it is economical to build district heating networks, where the heat energy transferred through pipelines can be used for heating of room space, hot water and for cooling of room space. It is often uneconomical to build district heating pipeline networks on areas of single family houses. However, the technology of relatively small CHP units for serving, e.g. a small number of houses, is developing. There is demand for CHP also in industrial systems as the case studies illustrate. For example, wood processing, chemical and food industries will require heat. The demand with the industrial actors extends throughout the year, while in district heating systems it is biggest during the cold part of the year.

CHP is relatively capital-intensive and it has long pay-back times. The development of the method implies that there will be a long-term plan. This can be seen as a preventive factor, e.g. in the industry, if short-term profits are emphasized. The Jyväskylä power company is publicly owned. It has been able to invest in CHP and wait for the gradually appearing paybacks. CHP might also face other economic barriers. Investment in CHP means that power purchased and heat produced otherwise are substituted with on-site fuels. If the price of electricity is low due to inexpensive hydropower or due to subsidized production of condensing power plants through subsidized coal for example, CHP might not be economic (Gustavson 1994). In addition, many institutional barriers may exist. Such include situations, where the licensing and regulatory activities are planned from the viewpoint of large electricity companies. They might have a monopoly over a certain area of the country and can set such terms for the electricity grid connections for a CHP company that will make it very difficult to implement CHP. (Korhonen & Savolainen 2001)

Below, as a conclusion of this section, I have listed some barriers that a local industrial ecosystem project may confront. I have understood these on the basis of the case studies in chapters two and three and from the literature on the other existing IE case studies. The problems have been discussed also in previous chapters and the following list will only include some general issues.

1. *The local conditions*

- The lack of renewable natural resources. In Finland there exists vast forest and peat reserves, specially when compared to the amount of inhabitants or the population density. This has been very important for achieving an industrial system that relies on local resources and can do this by respecting the sustainable yield. Renewable waste flows, however, exist everywhere, and it is important to consider the potential to use these as inputs in production.
- The lack of actors that are able to co-operate. There might not exist suitable wastes that local firms are able to utilize with their technological capacity. The 'right' kind of diversity in the actors involved is not easy to

find. The CHP plant is still a relatively rare actor in modern energy supply systems and, therefore, the kind of development that has occurred in Jyväskylä for example, will be difficult in systems that do not have the required technology.

2. *Information barriers*

- A modern firm might not be aware of the possibilities in environmental management or industrial ecology. This argument is supported by the low number of CHP-based energy systems in the EU or in the industrialized world. Conditions exist in many countries and regions, where CHP might bring economic and environmental benefits in the production of heat and electricity. But a large scale application of the method is yet to occur, despite the fact that it has been in use for decades in Denmark, The Netherlands and Finland.
- The tools that provide the co-operation partners or potential users of wastes with information, particularly quantitative information regarding the material flows need to be developed. An environmental report of a company and a possible eco-balance or an environmental accounting system that will be presented in the report are opportunities here.

3. *Economic barriers*[24]

- Environmental investments are in many cases new investments and can create costs, because of e.g. lack of experience or because the technology required is expensive. Environmental programs require new skills and can take large proportions of the working time of the company engineers.

4. *Policy and regulatory barriers*

- Environmental legislation is still a relatively new and evolving policy form and can vary from country to country. Regulation may favor some actors when some feel neglected. Environmental policy should consider also economic and social issues to secure the sustainability of a potential industrial ecosystem in the long term. Leaving economic factors outside the scope of goal definition when formulating an environmental policy program can lead into the failure of the program. For example, industry may not be able or willing to implement the reguired actions, because of costs that have not been taken into account in the planning of policy.

Discussion – Extending Industrial Ecology

Ecosystem as a source for a metaphor

My study question was to consider, whether the ecosystem material and energy flow model has other beneficial principles or metaphors for industrial ecology

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[24] see Esty and Porter 1998.

besides the basic roundput or closed loops. I have tried to use the ecosystem model for discussing the idea of an industrial system, which is a local system where the actors involved co-operate and reduce the environmental burden of the system as a whole. This system would operate in a way that can be argued to be similar with the ecosystem model.

I have then argued that the ecosystem material and energy flow model *can provide* other important principles for industrial ecology besides the common IE analogy of recycling of matter and cascading of energy, which in this thesis has been called as roundput. Therefore, it is suggested here that the argument in the thesis could be interpreted as 'extended industrial ecology'. In addition to roundput, the industrial ecosystem model that was presented in chapter four includes the ecosystem principles of diversity, interdependency and locality.

The ecosystem offers a potential source of a model for industrial systems, a model that can be understood as a sustainable system (Ehrenfeld 2000). The modern industrial system is not sustainable in its resource use or in its waste and emission generation according to evidence from the environmental studies during the last three or four decades. The numerous reports and documents that describe the problems in the natural environment caused by society will not be discussed here. Ehrenfeld (2000) notes that these errors of modernity, i.e. the environmental consequences of societal development, can be interpreted as unintended consequences of modernity to follow Giddens (1990). The problems in the natural world are something that have not been deliberately created. They result from our inability to predict future or generate knowledge about the function of the ecosystem.

The most intensively debated environmental question of today, the climate change, is an example of a dialogue in which experts continuously present many different views, even views that are strictly in conflict with each other. What is important to take into account, is that the knowledge about the operation of nature will always be based on some level of uncertainty. This implies that we should acknowledge how severe the environmental problems are since the human societal system will be dependent on the functions provided by its life support system (see Costanza 1999).

Our knowledge in general will always be based on the interpretation of the world around us. This interpretation carries with itself a dimension of uncertainty. Despite our understanding of the ecosystem functions is incomplete and uncertain, it is arguable, that the system can still provide the societal systems (economic or industrial) with potential sources of a metaphor (or a source for a model) for sustainable system development. Sustainability is very difficult to measure and impossible to predict. One is able to tell whether a system *has been* sustainable, not whether it *will be* sustainable. Industrial structures have not demonstrated their sustainability and they have not been around too long either. Ecosystems have, and according to what is commonly understood as a sustainable material and energy flow based system, they are sustainable.

Ehrenfeld continues (2000, 1997) that the observations of the problematic environmental dimension or consequence of modernity could in theory result in an analogous process of change as what has been discussed within Thomas Kuhn's (1962) sense of a paradigm shift. In Kuhn a new scientific theory replaces the old one as the occasional revolutions, where scientists turn from one great theory of the world to another, occur. Societal action and the everyday of various institutions, actors or organizations, will follow the underlying social paradigm, which is unlikely to change unless it clearly fails to achieve its goals. This paradigm, analogously to Kuhn's sense of a scientific paradigm, can be understood to describe and guide societal development as a 'dominant social paradigm' (DSP) (Ehrenfeld 1997). *"A paradigm is a framing set of concepts, beliefs, and standard practices that guide human action."*(Ehrenfeld 1997) or *"...a paradigm is or contains a set of structures on top of which social action is created..."* (Ehrenfeld 2000) .

Then, the evidence in environmental studies seem to indicate that the current environmental policy or environmental management domains do not secure the path to sustainability, or in the sense of the discussion above, are not within a sustainability paradigm. This observation could also be understood as a potential stimuli, or a starting point for new ways of relating to our interaction with nature. In sense of a paradigm shift, an acknowledgement of failure could lead into an interruption in the dominating paradigm and therefore also to a possible path to move toward more sustainable societal and industrial development within a new paradigm. In the process of reconsidering our basic ideas and worldviews, it can be important to draw from systems or frameworks that are outside the old paradigm. I understand that authors such as Ehrenfeld or the work of Herman Daly or Murray Bookchin that try to emphasize the need to integrate ecology into industrial design, management, into economics or into general societal development and cultural philosophy, are suggesting that the model of a sustainable system development of an ecosystem could be approached as a potential new paradigm for sustainability of societies and industrial systems.

Stages in paradigmatic shift for sustainability

Ehrenfeld argues for connectedness, cooperation and community when drawing from the ecosystem characteristics. He suggests that industrial ecology will be important, but not enough if only approached within the technical domain of the concept; if only the analysis and design of physical material and energy flows related to products and processes are studied. This is interpreted as the 'second stage in a paradigm shift'; industrial ecology as normal science. This shape of IE is positive, analytic and descriptive. Most environmental management systems or policy frameworks and corporate tools and practices for sustainability lie within this stage. Material flow models (MFM) or substance flow analysis (SFA) are examples of these.

The second stage in the paradigm shift does not occur without the first stage. The 'first stage' in the required shift toward a visualized sustainability paradigm is the acknowledgement of the ecosystem as a source for reconsidering and reconstructing the underlying ideas and world views of modernity . This stage is then normative, metaphoric and paradigmatic, an underlying vocabulary for understanding the world (see Ehrenfeld 2000, 1997). This stage has not been thoroughly adopted within the corporate environmental management or industrial environmental management communities. The discussion has mainly been kept alive by philosophers, sociologists and by studies on the culture of modernity.

For illustrating the complementary relation with these two stages in the paradigm shift, consider the notions of competition and cooperation below. Although highly simplified here, I hope that these serve to demonstrate some of the fundamental differences between an industrial system that functions within the dominant western social paradigm and a sustainable ecological system.

Sufficient metrics and tools within the second stage in the paradigm shift ('industrial ecology as normal science') are not enought as such. With these it is possible to understand and quantify an industrial system in terms of its physical flows of matter and energy. But the industrial ecosystem project can still fail. This is the outcome if the actors involved are not orientated towards co-operation. The first stage in the paradigm shift that would have to occur to enable the success of the second stage would mean that the dominant modernity ideal for competition over co-operation has to be reconsidered. In terms of the ecosystem analogy of an industrial system, one must note that instead of merely outcompeting with each other in a win-loose situation, organisms adapt to each other's operation through cooperation (see chapter 4). In an ecosystem, cooperation and adaptation are more important for sustainability than is competition. The modern ideal of a firm[25] , in turn, is a firm which controls its environment instead of seeking as its ultimate aim symbiotant relations with other organizations in the region or in the system of which the firm is a part of (see chapter 4). Then a material flow analysis or sufficient physical infrastructure including techniques for waste processing are not enough as such for an industrial ecosystem. The actors involved should be willing to co-operate with each other.

As an example, consider the two case studies. I want to argue that the traditional definition of industrial ecology as a material flow management concept for closed loops, or recycling is not enough to describe why the systems in the cases are advanced in sustainability. Both the Jyväskylä case and the forest industry case are roundput systems in that material cycles and energy cascades have been employed. The cases, then, fulfill this basic condition of industrial ecology. But the ecosystem principle of diversity and particularly the principle of interdependency, in addition to being material flow management concepts, carry with themselves also some other important characteristics that can be understood with the ecological metaphor. These characteristics are not typical within what might be called as the dominant social paradigm or the dominant industrial and neoclassical construction of the sustainability concept.

The interdependency principle has been important for both of the systems. It is highly unlikely that such advanced roundput and waste utilization would have been possible without the emergence of symbiotant relations between the companies within the two systems. Co-operation relations relate to issues such as culture or trust or the attitudes of the actors in the systems. These issues go beyond physical or quantitative description and calculation of the flows of

[25] see Boons & Baas 1997

matter and energy, beyond roundput. It seems then that the two systems have had important characteristics in their development from both stages of the sustainability paradigm shift. They demonstrate the first stage by engaging into cooperation and community philosophy and the second stage by technically arranging the flows of matter and energy according to roundput.

But the systems, of course, are not sustainable or perfect in any way, nor is it necessary to claim that they are. But I feel that the complementary relation between the four principles carries with itself some evidence that industrial systems such as the systems in the cases may not evolve toward sustainability if only the technical, analytical or the design sense of environmental management tools are considered. It would seem that industrial ecology must move beyond the stage of 'normal science', beyond the second stage in the needed paradigm shift. The second stage does not happen without the first. In other words, industrial ecology as a vision, as a paradigm as a new understanding of a sustainable system must become first. Ehrenfeld seems to suggest that only after this we can experiment with tools that would be to the vision. There are numerous reports that show that the current tools lack this paradigmatic foundation, note the expressions like problem displacement, i.e. transferring the environmental bad from one part of the product system to another or from one media to another etc.[26] As a source for a new vision and a new metaphor for the first stage in the paradigm shift, we need models and analogies that originate outside our dominant world views.

An ecosystem seems to offer such a model, as it is the only observed living system in terms of the material and energy flows that has proven its sustainability over long term. I understand that this is not only an ethical or a moral call. One can show with quantitative and physical measures that a perfect industrial ecosystem is the goal that we should pursue, despite this will never be fully achieved. Type III ecology of a mature ecosystem with complete cyclic flows of matter, is more sustainable than the current industrial systems.

There are increasing amount of studies, also within economics, that more carefully use the knowledge derived from ecology. The work by Herman Daly (1996), for example, can be regarded as such. Daly has initiated perhaps an analogous discussion on the economic paradigm as has been considered with IE. He draws a picture of the world of modernity as 'full'. The human economic system is a subsystem of the larger ecosystem and dependent on it. This metaphor argues that the basic problems arise, because we are growing and the ecosystem is not. The limiting factors of economic development are then increasingly often found in natural resources or in the ecosystem's capacity to tolerate wastes and emissions (in Daly 'natural capital'). Daly's work would encourage to reconsider the dominant economic paradigm, in which the economic system is outside the ecosystem as an isolated system. The circular flow of goods between firms and households must be understood in relation with its physical support systems.

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[26] see Jänicke 1990, Jänicke & Weidner 1995, Ayres 1994.

Beyond the roundput principle

The argument above and in the chapter four has been that something more than pure material flow studies are needed to construct a sustainable industrial system. Also, the cases would indicate that roundput is not enough by itself. Further, it is safe to argue that roundput is actually not that different from the existing thinking or models within the technical domain of environmental management and policy. It is familiar to everyone who is familiar with thermodynamics or entropy. In principle, we know that 'it is good to recycle'. But do we now that it is important to try and understand an industrial ecosystem as a metaphor, where roundput can benefit from further learning from the ecosystem model, both in terms of the material and energy flows as well as in terms of the more 'softer' issues such as community, connectedness or cooperation? These paradigms are complementary to the basic technical concept of closed loops or energy cascades.

I would suggest that the principles of diversity, interdependency and locality might not be acknowledged if not using the ecosystem as a source for a metaphor. In this sense the understanding of an industrial ecosystem in the book with the four ecosystem principles is moving beyond the second stage in the paradigm shift discussed above and hence towards the underlying first stage. This understanding has benefited from using the ecosystem metaphor. I have argued that this kind of an approach can help to identify issues that are important for industrial ecosystem development. These issues might not have been identified if remaining within the dominant understanding of the concept of IE, which arguably is still mainly within the technical or analytic analysis of industrial material flows, within IE as normal science.

The argument for the four ecosystem principles, however, must be made with caution. I am not making, nor I think anyone should make, some universal claims for IE management. The cases are rare and the concept is still only evolving. The different situational factors in different systems more or less determine the success of industrial ecology-type efforts. But, one might gain by taking the combination of the principles as a working hypotheses for different case studies. For example, roundput might not be enough if it is not arranged locally, because emissions from transportation can displace the problem from waste at landfills to emissions into air etc. Further, to arrange roundput locally, one requires interdependency between the local actors.

On the other hand, it can be argued that the notions of interdependency or locality for instance, have already been discussed in various studies within environmental policy, economics or management. Why do we need another field of science, the ecosystem model, for considering these? However, it can be useful to construct a systems approach. Ecology can be a source for such an approach. The principles need to be studied together with others derived from an ecosystem, which provides one with some fundaments of a systems theory. The principles can be used for comparing the industrial system and the ecosystem. One can have principles that help to organize the study and gather information and data under these that are on top.

The principles can then be reconsidered or further developed. For example, if we start with the principle of diversity, the resulting study may show, that in a particular industrial system diversity has actually prevented the IE or roundput-type efforts. Such an outcome may occur, because the presence of many different actors (diversity) can result in many different and possibly conflicting interests that make the co-operation in waste utilization impossible. Then, an IE direction would be to limit diversity in order to develop material cycles and energy cascades through co-operation in which the interests can co-exist. Again, these examples are highly simplified, but hopefully illustrate my point that an approach, where the principles are considered together is needed.

It is also clear that the four principles of roundput, diversity, interdependency and locality are not in any sense absolute. As noted above, our knowledge from the ecosystem operation will always be based on uncertainty. In addition, the author has not a background in studies of biology or in ecology. In the thesis it has only been possible to discuss the ecosystem material and energy flow model in general sense, to try and illustrate some starting points for a construction of an industrial ecosystem, namely a vision for the system and a goal on top. The application of the ecosystem analogy is still in its early stages and emerging. Studies on this application are important, because environmental research, whether in policy, economics or management, should always focus on the actual physical flows of matter and energy that constitute the basis of our interaction with the larger life support system.

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Tiivistelmä

Teollinen Ekosysteemi
– Ekosysteemin materiaali- ja energiavirtamallin soveltaminen teollisessa systeemissä

Teollisen ekologian (TE) käsite pyrkii vähentämään teollisuuden ympäristökuormitusta soveltamalla luonnon ekosysteemin materiaali- ja energiavirtamallia teolliseen toimintaan. Ekosysteemissä kasvit, eläimet ja hajottajat hyödyntävät toistensa jätemateriaalivirtoja sekä rakennusaineena että energian lähteenä. Systeemin ainoa ulkoinen panos on (ääretön) aurinkoenergia.

Teollisessa systeemissä yritykset ottavat luonnosta raaka-aineita ja käyttävät luonnon energian lähteitä. Nämä muuttuvat tuotannon kautta tuotteiksi, päästöiksi ja jätteiksi. Systeemi perustuu uusiutumattomiin päästöintensiivisiin energian lähteisiin.

Teollisessa ekosysteemissä (TE) sovelletaan ekosysteemin materiaali- ja energiavirtamallia paikalliseen teolliseen systeemiin. Ekosysteemin analogia toteutuu kun yritysten toiminta järjestyy kuten organismien toiminta ekosysteemissä. Yritykset hyödyntävät toistensa jätemateriaali ja jäte-energiavirtoja yhteistyöllä paikallisessa järjestelmässä. TE poikkeaa tavanomaisesta yhden tuotteen tai jätevirran kierrätyksestä keskittyen monien eri jätemateriaali- ja energiavirtojen hyödyntämiseen paikallisella yhteistyöllä monien eri yritysten välillä. Jäte korvaa systeemin luonnonvarojen käytön ja näin myös jäte- ja päästömäärät systeemistä kokonaisuutena vähenevät.

Tässä tutkimuksessa ekosysteemin materiaali- ja energiavirrat jaetaan neljään ryhmään. Teolliseen systeemiin sovelletaan ekosysteemin materiaalin, ravinteiden, energian ja hiilen virtojen mallia. Mallin avulla rakennetaan *Suomen metsäteollisuuden teollinen ekosysteemi* sekä *Jyväskylän teollinen ekosysteemi,* joka perustuu Jyväskylän alueen energiajärjestelmään. Tutkimuksessa teollisen ekosysteemin käsitteeseen sisältyy neljä ekosysteemin periaatetta: *kierto, diversiteetti, riippuvuus* ja *paikallisuus.*

Avainsanat: teollinen ekologia, ekosysteemi, teollinen ekosysteemi, materia, ravinteet, energia, hiili, Suomen metsäteollisuuden teollinen ekosysteemi, Jyväskylän teollinen ekosysteemi, neljä ekosysteemin periaatetta

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Appendix

Research proposals for industrial ecology

Introduction

Industrial ecology as a field and industrial ecosystem as an approach are new areas of study building on ecology, economics, business studies and engineering etc. I feel that the research in the practical part of industrial ecology has been evolving around studies in which the existing concepts, approaches, tools and techniques are presented and new combinations and applications of these are discussed. As argued in the last section of the thesis, the main contribution of industrial ecology may come in the conceptual context. The sustainability agenda can gain from IE as the concept and the ecological metaphor in it may help to identify some of the basic aims and visions of sustainability for corporate environmental management.

It seems that one of the major areas of critique toward IE include the discussion that deals with the fact that the concept is just another metaphor and despite the vision is good, it does not help much if it cannot be achieved in practice. I do not agree with this. We have more than enough evidence that shows the problems in the goal definition and in the underlying visions that are taken as the starting points in various sustainable development programs. It seems that environmental management and policy agendas can at times be very fragmented and focus on specific aspects of the systems in question, e.g. on a product, on a process or on a certain activity and hence lack systems perspective.

It will be important to better define the optimal conditions of industrial and product systems in terms of their material and energy flows. This is needed, despite the fact that a vision of a perfect industrial or production-consumption ecosystem will never be achieved. We need a goal on top or a map with which to start the planning and the formulation of design, management and policy. With the vision and the goal, the implementation and the tools for it such as material flow models or life cycle assessment may have a better chance of contributing to sustainability.

I think the existing IE literature has 'proven' that the ecosystem can be a beneficial source for a metaphor, for a vision, for a model and a conceptual basis. But the effort to include the ecological metaphor into economics and into business studies will be a difficult task. The debate in ecological economics on the definition of natural capital, its valuation or for example on the role of natural capital in a production function (Daly 1996, Costanza et al. 1997) is an example of the obstacles involved when the integration of ecology and economics is considered[27]. However, through industrial ecology this discussion could perhaps gain and also find a practical example for its philosophy, a field for reflecting the theory on case studies in corporate environmental management. The concept of IE, in turn, could benefit by finding some basis in economics.

In this chapter I will try and consider some initial questions and research proposals that could perhaps be further studied in industrial ecology and in the local industrial ecosystem approach. One such question will be the above men-

[27] Discussion on ecological economics in Finland was initiated by the works of Pulliainen. See Pulliainen 1972, 1979.

tioned theory building in economics and in business studies. The following proposals are more oriented towards practical issues involved in a potential industrial ecosystem or eco-industrial park project. One could of course present many different questions for future work and I have only discussed some areas that I feel are related to the issues that arise from the two systems in the case studies. Some of the questions below have already been presented in various parts of the thesis. I felt that it might be useful to gather them together into an appendix to serve the purpose of an initial research plan.

Potential research questions for industrial ecology

Comparing case studies on local industrial ecosystems

For me, the concept of an eco-industrial park or a local industrial ecosystem is the easiest way to understand the ecosystem analogy in industrial context. This thesis has approached the industrial ecology analogy in local/regional industrial systems such as the Jyväskylä IE in chapter three. A model of a local industrial ecosystem provides an opportunity to derive goals and conditions of success for the sustainability of an industrial system. I think that much can be gained simply by understanding what is the goal of an industrial ecosystem project, what is an optimal local industrial ecology-type system and how it is possible to gain by applying the systems perspective. One needs to identify the main material and energy flows of a region as well as the main actors and processes that drive these flows and are affected by them. By constructing such a system picture of the main flows and their relations it might be possible to identify some areas of improvement, opportunities to use waste material and residual energy through co-operation and the potential to substitute imported fossil fuels with local renewables etc.

The next step could then be the more systematic data gathering and quantification[28]. The results of an industrial ecosystem project can be compared with a similar project in another regional industrial system. Here a suitable concept can be found in Ecological Footprint (Wackernagel & Rees), which can be understood as a measure of the amount of virgin resources that a regional economy obtains and the amount of the waste assimilation capacity of the ecosystem that the regional economy uses. There are only few Kalundborg-type case studies on IE at the moment but there are many fruitful local industrial systems in which the possibilities for moving toward 'multi-dimensional' waste material and waste energy networks can be studied. Energy, heat and electricity production and use as well as forest, pulp and paper sectors are areas with which some elements of IE could be considered practically everywhere.

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[28] For discussion on regional material and energy flows see Brunner et al. 1994.

Integrating production and consumption

As discussed in chapter five, one of the main critical arguments toward industrial ecology is that it can be mainly concerned on industrial production, when the integration of consumption systems is vital for the sustainability of societal systems in general. It is true that the aim of IE should be toward a local industrial-consumption ecosystem in which as much of the life cycle of a product as possible is included into the system. The environmental burden from this system as a whole is the main focus point. I have tried to identify some areas for future research in this question with the forest industry and energy systems in chapter five and will not discuss this further here.

Networking

Industrial ecology is an inter-organisational phenomena (Boons & Baas 1997). Again, this might be easiest to understand in the context of a local industrial ecosystem, which is a collection of interdependent firms. The particular focus in the industrial ecosystem analogy is on the utilisation of waste material and energy flows between the companies in the system. Then, the contribution to the networking literature could arise through the idea of a recycling network, a system of firms that relies on physical material and energy flow interdependencies.

Networking, and for example network learning, are hence important study areas for industrial ecosystem management[29]. There are many forms of interdependency that need to be taken into account when the aim is to reduce the societal material and energy flows that have harmful impacts on nature. Networks and co-operation between large manufacturers, between large firms and small firms, private actors and local public bodies such as the municipal organisation, between producers and the end-consumption systems need to be studied to move toward a holistic systems perspective on material and energy flows. The specific flows that affect these different actors need to be identified as well as the different interests that each of the actors have with regard to the recycling effort of the system.

Municipal Environmental Management

When trying to facilitate the emergence of a recycling network, a local industrial ecosystem, the boundaries between private and public actors need to be crossed. I have shortly tried to consider the role of a local municipal organisation in a potential industrial ecosystem in chapter five. The argument was that the private actors might often be reluctant to engage into co-operation with each other, e.g. because of lack of trust or competitive attitudes etc. In this sense, the municipality is understood as a possible impartial or neutral actor, a facilitator of the recycling system. In addition, the fact that some municipal or-

[29] For discussion on networking, inter-organisational relations and the environment of a firm see Boons & Baas 1997, Pizzocaro 1998, Ulhoi 1998, Kassinis 2000, Sinding 2000.

ganisations are using the model of an environmental management system (EMS) of a firm in their environmental work shows that private and public organisations are beginning to act together and develop management strategies by comparing each other's environmental issues (on municipal environmental management see Burström 2000).

SMEs in industrial ecosystems

In 1996, approximately 90% of European businesses were classified as SMEs (small and medium-sized enterprises) (CCEM 1997, cited in Hillary 2000). It can then be argued that if we consider SMEs as a sector their operation can be a very significant part of all industrial pollution (Hillary 1995). The industrial ecology philosophy for holistic systems approaches implies that an industrial ecosystem is not limited to large manufacturers. Also small firms are needed in order to complete the material cycles and the energy cascades and to focus on the environmental burden of the industrial system as a whole. However, it will be very difficult to construct some general environmental management principles for SMEs or to generalise about their environmental impacts, resource use and waste generation, because firms in the SME sector as a whole are heterogeneous (Hillary 2000).

In conceptual terms, perhaps the ecosystem analogy of decomposers, bacteria and fungi, the recyclers of the system could help in identifying some potential contributions of small firms to industrial ecosystems. In an ecosystem these small actors are vital for the success of the recycling network between organisms. In an industrial setting the role of recyclers is small when compared to the flows from producers and consumers to bacteria and fungi in an ecosystem. The industrial ecology agenda can still be focused mainly on large manufacturers, which obviously may face increasing societal environmental pressures.

Large manufacturers can mobilize large material and energy flows as their inputs in production processes and continuously generate environmentally harmful flows of waste and emission outputs. It would seem, then, that they also have opportunities to minimise costs, e.g. raw material and energy costs or costs that result from environmental legislation if they are able to successfully adapt an environmental strategy. Therefore, the potential to gain in economic terms through environmental work is beginning to be acknowledged within big industrial companies.

In general sense, SMEs do not face such societal pressures for environmental management as do large companies. A single SME does not use large material flows nor produce large waste streams. SMEs have resource constraints, e.g. financial, that may make it difficult for them to engage into the new 'unknown area' of business strategy of corporate environmental management. In other words, the win-win rhetoric is easier to understand in case of a big industrial producer than in case of an SME that does not have such societal pressures to engage in environmental management and hence also has more difficulty in identifying the economic gains of environmental work.

If SMEs operate as participants in a successful industrial ecosystem, the barriers that they face in environmental management could be reduced. In such a scenario, the large manufacturers provide the small firms with co-operation benefits and SMEs in turn contribute, for instance, by serving as users or recyclers of some otherwise unused waste streams of the big companies in the network. There is a need to conduct case studies on the potential in SME participation in industrial ecosystem projects and on co-operation and networking efforts that SMEs and large firms and public municipal organisations can jointly establish in regional environmental management[30].

Anchor tenant approach

In chapter five the anchor tenant approach for an industrial ecosystem was presented (see Chertov 1998, Baas 1998, Lowe 1997). On the basis of the two case studies in the thesis it seems that, as a co-production plant (of heat and power) in an energy system, a certain key organisation in a local industrial system around which to gradually build the material and energy flow network is important for the development of IE as a concept and for its practical implementation. Again, forest industry sectors and heat and power production are examples of areas of industrial activity in which certain influential firms in terms of material and energy flows exist. Such organisations can use a diverse input basis including many different kind of fuels and hence could perhaps process the wastes of other actors in the local industrial system (see the cases in chapters two and three and chapter five).

Regional Environmental Management Systems

In the last chapter the model of a Regional Environmental Management System (REMS) by Welford and Gouldson (1993) was shortly discussed. REMS could serve as a potential starting point for developing network management approaches or regional industrial ecosystem management. The important point is that in REMS the co-operation ideal includes firms but also local public actors such as the municipal organisation, local research institutions and citizen or environmental groups.

Material flow models

Material Flow Models (MFM) measure the flow of matter and energy within the anthroposphere and between the anthroposphere and the biosphere and aim to trace and reduce the flows that are harmful to nature. Specific flows of materials or substances (material/substance flow analysis), flows related to products (life cycle assessment, LCA), to a single company (eco-balances), to a region (regional metabolism) or the inputs required to produce a given service (material intensity per unit of service, MIPS) can be studied (see Vellinga et al. 1998). With material flow models it is possible to provide information for policy decision making and for corporate environmental management.

[30] For discussion on SMEs and industrial ecology see Andersen 1997.

Information on the flows of matter and energy is of course vital for the industrial ecosystem approach[31]. The industrial ecology analogy is in a sense a goal on top for material and energy flow management. Arguably, this has not been fully recognized in material flow studies. MFMs can remain somewhat fragmented, focusing only on isolated product or waste streams. The specific information is important, but would seem to be more useful if it can be included into an industrial ecosystem project in which the effort is to move toward a holistic systems approach. It can be argued that the IE-type goal definition or the construction of a picture of a desired material flow system on the other hand and quantitative material flow studies providing the IE project with more detailed information on the other are each other's complements; both are needed for enhancing industrial ecology-type system development.

Policy implications

Industrial ecology and the industrial ecosystem approach could be considered in the planning of international, national and regional policy as potential conditions toward which the industry should develop, or as noted above, as the goals on top. In literature on environmental policy, there has been lot of debates on the need for strict regulation or command and control mechanisms, top-down management conducted by the authorities. The discussion will not be reflected here in any detail. It seems clear that depending on various national and local situational factors, different combinations of approaches and instruments rather than remaining within only one set of environmental policy instruments are needed for environmental protection. The policy should maintain its ability for changes for adapting to the local ecological, economic and social factors.

The aim of environmental and other related policies, e.g. energy policy, should be to try and provide the conditions for firms to engage in industrial ecology-type co-operation. The policy maker considers direct regulation on the use of natural resources, green taxes or emission trading (on economic instruments for environmental policy see Määttä 1997, 1999, 2000). These approaches can encourage the utilisation of wastes and hence possibly the emergence of industrial ecology-type networks. Voluntary agreements between industry and the government are another potential path for environmental policy and management. Furthermore, approaches such as extended producer responsibility and take-back regulation are themes that are already considered in national environmental policy planning[32]. These concepts adapt a philosophy in which the firms or the manufacturers are understood as being responsible also for the very last steps of the product's life cycle. This can contribute to the development of material cycles and energy cascades and hence eventually enhance the emergence of (local) industrial networks of waste utilisation.

[31] For discussion on IE tools, e.g. material flow tools see van Berkel et. al 1997, van Berkel & Lafleur 1997.
[32] For discussion on policy needs for industrial ecology see for example Ehrenfeld 1997, Lifset 1992, Lindhqvist 1992.

For the evaluation and assessment of specific policy efforts the preparation of material flow scenarios can be useful. One could study the environmental outcomes of policy, e.g. the success of certain recycling initiatives in reducing the amount of wastes. As argued earlier, if the recycling efforts are considered from a systems perspective, one can at times identify problem displacement. Therefore, the IE-type systems approach could contribute to the planning of environmental policy. With large material flow scenarios, it might be possible to predict also the economic and employment implications of industrial ecology or recycling. Changes in material flows or large recycling programs can create changes in national or regional imports and exports, in technical capacity requirements and generate employment opportunities. The challenge for eco-industrial park or local industrial ecosystem case studies will be to prepare quantified comparative case studies between different regional systems and their IE agendas, which include ecological but also economic and social dimensions of the system operation.

Discussion

The kind of study proposals one will construct for the industrial ecology concept will depend on the way in which the analogy is understood. If it is understood as a metaphoric goal on top, a map or a vision of a sustainable local industrial system with a network of material cycles and energy cascades, the other more 'traditional' policy or corporate environmental management approaches, techniques and tools can then be placed under the concept. In a sense, these could be presented as future study questions for the implementation of the metaphor.

However, as discussed in chapter five, it seems that we are not there yet. In other words, before developing the industrial ecology toolbox and its implementation more fully it is important to know what the tools are for. The definition of a successful industrial ecosystem, I feel, would provide the policy maker and corporate managers with a goal, a desired outcome (of environmental management) toward which to strive. This definition and the integration of ecology and the ecosystem material and energy flow model into economics and business studies will require lot of conceptual work. On the other hand, the practical experiences must be gathered simultaneously with the conceptual development. Our knowledge on the operation of the ecosystem and on the actual impacts on it from industrial systems will always be incomplete.

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Burström, F. & Korhonen, J. 2001. Municipalities and industrial ecology: reconsidering municipal environmental management. Paper accepted for publication in the Journal of Sustainable Development. (Accepted April 6, 2000). The article has also appeared in Burström, F. 2000. Environment and municipalities – towards a theory on municipal environmental management. Royal Institute of Technology. Division of Industrial Ecology. Printed by KTH/Högskoletryckeriet, Stockholm, Sweden 2000. pp255-267.

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