THE INDUSTRIAL ECOLOGY CHALLENGE OF THE UNIVERSITY - PILOT EXPERIENCES AT THE NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Introduction

According to new policy and preventative targets in environmental regulation and research, actors in society are now asked to address ecological efficiency over the life-cycle of products.[2] [3] [4] This calls for new approaches and creates opportunities for technological and organisational innovation as well as the formation of new roles and rules for the actors. Innovation, communication and collaboration is needed both vertically along product chains and horizontally across product chains. The emerging concept of industrial ecology (IE) is one promising answer to such demands.[5] [6] [7] [8] The life-cycle approach demonstrates that environmental performance in a systems perspective is often closely connected to parameters in the product use phase and in the waste disposal phase. Such parameters need to be better understood and positively influenced by various incentives, such as the use of economic instruments and the building of extended producer responsibility (or product stewardship) infrastructures.

However, most important are the engineering design options to be developed by industrial companies in the overall production phase, from cradle to gate, focusing eco-efficient products and cleaner production manufacturing processes, as well as better use of waste energy and materials at the local industrial park or local community levels. Beyond products there is also a need for eco-efficient design and operation of critical infrastructures in society, particularly within energy, transportation, building and water and sanitation systems.[9]

The systems approach to such issues is indeed a challenging one. There is a need for defining and understanding the new context of industrial ecology from various standing points. The theoretical basis of the approach is not at all clear, the qualitative and quantitative methodologies for measuring and assessing eco-efficiency of complex product and infrastructure systems are not well developed, and the instruments and measures to stimulate innovation in line with long-term needs are also not well developed. There is a tremendous role for the university in this area.

Leading industrial companies have started developing and implementing strategic as well as operational efforts according to the industrial ecology concept. In fact, industry is often ahead of universities in this particular area. A close collaboration between university and industrial partners would be needed to advance the production of knowledge on theoretical, methodological and practical aspects of implementing industrial ecology in society. This challenge was taken by the Norwegian University of Science and Technology (NTNU), who are now in their second year of offering a graduate level course

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7 Graedel and Allenby: Industrial Ecology
8 Suren Erkman: History of Industrial Ecology
9 O'Connor ....: Industrial Ecology - A critical review

on industrial ecology as part of NTNU's Industrial Ecology Programme which is a strongly interdisciplinary initiative in close partnership with leading industrial and foreign research partners.[10]

Background and ideas when implementing IE in the university

In the industrialised world we have seen environmental consciousness growing in the society at large and more specifically in industry. Since the late sixties/early seventies, we have got environmental laws, governmental regulatory bodies and the development of non-governmental organisations being very active on the environmental area. We have got international treaties regulating the use and phase-out of environmentally dangerous chemicals. In some countries we have also seen regulations aiming at increased recycling of resources and for some categories of products, as well as law enforced regulations of emissions and energy consumption.

National environmental statistics indicate the importance of energy consumption from a resource point of view as well as from an environmental point of view. The greenhouse debate leads to increased focus on greenhouse gas emissions and increases the possibility of globally (UN) agreed limitations on national emissions of greenhouse gases. Obviously lost resources as an environmental burden and fossil energy consumption become the two main challenges in an IE perspective.

All these developments can be seen on the background of the UN report on sustainable development and the UN conference in Rio in 1992; a conference that also links poverty, population growth and global environmental degradation. Industry has responded to this development by increasingly being environmentally proactive. One consequence of this is that emissions and discharges from industrial processes in many cases have been reduced to levels where they do not make visible harm in the local environment.

Another consequence is that industry increasingly talks about being eco-efficient and includes into this not only its own processes, but also all other processes going into the making of products, supply of raw materials and energy and the use and reuse of end products. By moving from a more limited process oriented way of thinking into a systems oriented way of thinking, industry meets society, both as regulatory bodies and as consumers, with ideally the same interests, and that is to develop and make products that can be consumed with a minimum of environmental consequence, including degradation of non-renewable resources. This is - as we see it - what the concepts of industrial ecology, eco-efficiency, etc., is all about.

If we for a moment go back to the UN conference in Rio, we can easily define challenges outside the more limited circle of industrial production, consumption and re-use of material products. The matter of population growth, the ethical aspects of consumption, distribution of wealth, the balance between long term ecological demands and more short term economic interests of nations and companies, all are challenges that have to be dealt with partly at a level beyond the concept of IE. If we on the other side develop a better understanding of what the concept of IE means, we will also most probably better understand these more global and general challenges. In our IE effort at NTNU, we have not the intention to really include these wider aspects, at least during the first years of work. Our goal has been/is to develop a better understanding of what the more limited aspect of IE will mean for students, academia, regulatory bodies and industry, focusing ways to better understand and improve the eco-efficiency in industrial society with an emphasis to the design, production and function of products, services and infrastructure.

When that is said, we also have to say that the students in our first year test program as soon as they got the chance tended to jump into these more wider aspect. Apart from the identified need of better understanding the implications of an IE-based strategy, we also had second main reason to enter into this educational effort. This is the need to recruit into both industry and other governmental or private organisations people with a more stringent understanding of what eco-efficiency and IE by the end of the day will mean in practice.

[10] NTNU's Industrial Ecology Programme is outlined on the Internet: www.smu.ntnu.no/IndEcol

Introducing Industrial Ecology at NTNU

Industrial ecology was introduced to NTNU by Norsk Hydro in 1993. Norsk Hydro as a company based on energy production and energy intensive products as nitrogen fertilisers, light metals and PVC, has since early 1990 had thoughts in line with the concept of IE on its agenda as well as research collaboration with MIT. NTNU and Norsk Hydro developed these ideas further, with strong input from international research partners, in particular with MIT. Through research seminars arranged in 1994 and 1996 by the Norwegian Academy of Technological Sciences (NTVA), 11 12 a process of forming a structured and interdisciplinary university programme on industrial ecology was facilitated. NTNU's Industrial Ecology Programme was launched during spring 1996 with strong support from the Rector of NTNU, with considerable financial support from the Norwegian Research Council, and by a close collaboration with 9 leading industrial companies in Norway. Norsk Hydro took the lead role among industrial partners, including offering an adjunct professor towards the university to chair a programme steering committee and a pilot course module towards students within the university.

Because of the conceptual stage of IE and the fact that the concept seems to be developing rapidly in industry, it was clear that the development of IE from a concept and into an academic activity with its own theories, methodologies and identity had to be very much based upon industrial experience, as a case-oriented approach, in interaction with university faculty. In this respect, the contributions from the industrial partners have been of vital importance to the programme. From the very start of this work some principally important decisions were taken:

Industrial companies were asked to participate actively in the development of the program, and particularly to give case-oriented input to teaching at NTNU.

To get an interdisciplinary approach from the start, an interdisciplinary steering committee for the IE program was established.

Because of the wide range of topics that need to be covered in the frame of IE, it was at an early stage decided to start out the first year pilot course module with a wide spectre of expertise as lecturers. The module was offered from the Dept. Machine Construction and Materials Technology.

It was decided to give ourselves/NTNU three years to reach a platform for a program in IE, open for any student in her/his last year of study before the Master thesis and for PhD students.

To get an activity started with the growth in faculty in mind, it was decided to start preparatory work to recruit PhD candidates on key issues of IE in place in parallel with the course module.

A program secretariat and co-ordinator was established as part of the Centre for Environment and Development at NTNU.

In addition to these decisions, and partly as motivated by the early work, some important new initiatives have been taken on the area during recent months. First, NTNU has recently launched its «Programme on interdisciplinary research», as a strategic measure to promote research collaboration between the disciplines of natural science and technology on the one side and the disciplines of social sciences, the humanities and medicine on the other. Within this programme the area of industrial ecology is now accepted as a priority field, within the framework of Sustainable production and consumption which is one out of four research directions for interdisciplinary attention. Second, industrial ecology is from January 1998 started as a strategic research field within the new national research programme Productivity 2005 (P2005), targeting production of knowledge for environmental life-cycle oriented implementation and improvements in Norwegian industry, particularly within the goods manufacturing industries. Third, there is now being carried out a project to propose the offering of a new

[11] NTVA 1994: «Product Design and Development for Sustainability». The Norwegian Academy of Technological Sciences, Report 5-1994, Trondheim, January 1994.

[12] NTVA 1996: «Industrial Ecology and Sustainable Product Design». The Norwegian Academy of Technological Sciences, Report 2-1996, Trondheim, January 1996.

comprehensive curriculum in industrial ecology, equivalent to a Masters programme in industrial ecology.

All these efforts clearly demonstrate that the IE initiative during few years has reached considerable momentum within the university, primarily due to the high interest and contributions made by key faculty combined with industrial partnership. It is our strong belief and intention to develop these actions in close collaboration with leading universities abroad. The implementation and development of industrial ecology both need to be based on an open and dynamic attitude, valuing the perspectives and experiences made in similar initiatives in other countries, so that there is a joint international effort to advance the theoretical and methodological basis of industrial ecology.

Purpose of this paper more specifically

In the autumn of 1996 we started the first year pilot course module with a limited participation of 15 students, recruited from different departments across the university. We are now in our second year of offering the IE course module, with some modifications in terms of content, number of students and general layout. The course module is now taken by some 40 students, and is part of the official curriculum at the university, open to Masters level students across disciplines as an elective module focusing interdisciplinary understanding of key industrial ecology challenges.

Our experiences so far and our suggestions for changes are the topic of this paper. We have also been active in forming possible PhD subjects. Presently we have four students with IE as part of their PhD theses, and we are in the process of getting six more. We are not discussing this part of our work any more here, but will limit ourselves to point out that the work with these theses will be an integral part of the future basis for under graduate education.

In this paper we have already pointed out the background for our ideas behind the content of this first year's module program. Then we shall briefly present the program as it was carried out. After the module had been finished and examinations were held, we have had an extensive evaluation of the module.[13] The main points will be presented below. Finally, we will point out our ideas about the changes introduced in the second year's module program.

In general we have reason to believe that our ideas about content, scope and workload have been in the right direction and dimension. Seen from the point of view of examinations for the 15 first IE students at NTNU, the results have been very good. We, therefore, believe that what is needed are changes and adjustments but not a major turnaround relative to contents and direction of the pilot course module program.

The first year IE pilot course module program

Introduction

The intention of this pilot course was specifically to get enlarged experience and to create a basis for educating students within the concept of industrial ecology, and more generally to get feed-back on how to further develop our programme at NTNU. By inviting lecturers from different universities, research foundations, companies, public authorities and internal departments, we both got input from different academic fields and from people with different reference points and thus valuable feed-back from a wide range of people to the programme. Industrial ecology as young academic field without any common accepted theory and methodology has to relate on practical experience from such people.

Establishing this pilot course required several strategic decisions, and thus, the following pages will be organised in a structural part and a thematic part. The seminar schedule is shown in Figure 1. In addition to the topics of the lectures shown below, every invited company was given the opportunity to give a lecture titled "Why is industrial ecology important for our company, and what have we done". We

[13] Kjetil Røine: Industrial Ecology Pilot Course Module: Internal Evaluation Report, SMU summer 1997.

also arranged several workshops supporting the topics of the seminars. The pilot course had a load of 3/16 of a full time year of study.

The structure of the pilot course

The pilot course model was based on seminars (50 % of total work load), unlike the traditional education model at NTNU, and on projectwork (50 %), between the seminars and lasting all through the pilot course. We chose to carry out an interactive pilot course using seminars consisting of lectures (1/3 of total seminar time), workshops (1/4), company presentations (1/6) and project (1/4). In this new module it was even more important to have the opportunity to discuss the topics, to achieve interaction and receive critical comments on the programme than in traditional courses. This was easier to do through seminars.

Seminars	Topics	Project between seminars
Seminar 1 *Introduction to the Course and Industrial Ecology* (1 day)	"Industrial Ecology at NTNU - why, who and how" "From SHE to Industrial Ecology - Experiences within Norsk Hydro" "Environmental Management in ABB"	Knowledge to the product system
Seminar 2 *LCA Theory, Databases and Industrial Case Demonstrations* (3 days)	"LCA Theory and Methodology" "LCA and System Boundaries" "Applications of LCA - a presentation of the UMIP-project" " Presentation of a company's LCA-tool and of operational use of LCA in industry - ABB" "The Valuation Methods used in LCA" "The Use of Databases in LCA"	and the role to play Critical passage of the presented
Seminar 3 *Industrial Ecology - The Fundament and Conceptual Clarification* (3 days)	"Ecology as Model for Industrial Ecology - Fundamentals and Characteristics in Natural Ecosystems" "Industrial Ecology - The Concept and Challenges" "From Environmental Technology and Cleaner Production to Industrial Ecology - Is there a Different Theoretical Basis and Engineering Practice?" "Irreversible Thermodynamics as Theoretical Basis for the Minimisation of Losses in Industrial Systems - Energy Conservation as Case" "Step towards an Industrial Anthropology : Approaching the Cultural Dimension of International Business"	LCA on the device Identify the most important industrial ecology
Seminar 4 *Industrial Ecology - Market, Consumers and Politics* (4 days)	"Involvement in Nature and the Environment in the Public and Industry" "Sustainable Economy" "Role of Financial Institutions as Premises Deliverer towards Sustainable Production" "How does the Introduction of Extended Producer Responsibility affect Production and Product Design" "Design for Environment- the Quality Function Deployment Principles" "The Role of the Government - its Instruments and its Challenges"	challenges in an environmental context Identify the most imporant industrial ecology
Seminar 5 *Sustainable Energy Production and Use* (1 day)	"The critical Subjects in the Energy Debate - an Overview" "The Creation of an Energy-optimised Building" " Statoil`s role as an Energy Company and work towards Renewable Energy Systems"	challenges in a market context Strategy for improving the
Seminar 6 *Life Cycle Cost and Product Design* (3 days)	" Cost-Modelling in a Life-Cycle Product Perspective" "Case of Light Metal Front Fenders" "Design for X" "Environmentally Friendly Product Design as seen from the Industrial Designer's Point of View"	product and the product system Project hand in
Seminar 7 *Presentation of Projectwork* (1 day)		

Figur 1: The tematic content of the pilot course module and the project work between the seminars

The intention was to offer a highly multidisciplinary course with students participation from both technical and non-technical faculties, as well as with academic staff at NTNU and participants from the companies. By doing this we both achieved a rapid spread of knowledge to the academic staff and to the companies, and a more long-term effect on the students and their contribution to industrial activity/enterprise. This wide range of participants also invited to, and certainly resulted in, interesting discussions and input to our further work.

Only two non-technical students attended the first year pilot course. This lack of balance between engineering and social sciences among the students gave the discussions a very strong technological orientation. We found that this was a weakness with the program as it evolved. However, the participation from staff at NTNU and the companies really inspired the students.

As will be more thoroughly commented below, the students worked on a project all through the pilot course. We found this very important in order to relate the broad aspect of topics covered in the seminars to a practical and identifiable case study. The pilot course module was designed to give concentrated periods of input through the seminars, with supplementing project work focusing on the same topics as in the seminars. However, educating students in industrial ecology, with a high number of different lecturers, in an introductory course not going that deep into different fields, is a maturing process. In this context, it was very important to achieve an interacting and iterative process between the project work and the seminars. In addition, through the project work the communication between the students improved, by focusing on an interdisciplinary learning process.

The lectures

As can be seen from figure 1, the pilot course covered a wide range of topics and used a high number of external lecturers, and this resulted in some problems for the students to follow the governing idea of the pilot course. This, in addition to the fact that the students did have extraordinary fragmented and different background knowledge, was a huge challenge for us adjusting the "academic" level of the lectures in order to make sure that as many students as possible were able to satisfactory follow the pilot course.

Another challenge was concerning the invited lecturers, because they could not precisely know what was lectured before, where to start their lecture, and the competence of the students, although this was told in advance. It also became necessary to adjust seminar content to when guest speakers were available. For this reason the seminars to a certain but limited degree lost the stringency in content as originally planned.

The professor in charge of the course was from industry. His comments was related to this standing point and acted as, particularly according to the students, a valuable link between industry and academia. He also gave an introduction to each seminar in order to helping the students to get more concentrated grip on the topics and more easily to follow the governing idea of the pilot course.

Workshops

Although we encouraged the lecturers to focus on interaction with students in their speeches, we found it valuable to arrange workshops. The workshops should create activity and go more thoroughly into the topics of the lectures by inviting to interaction between participants and the lectures in a maturing process. We organised the workshops mainly after three different models:

- Pre-decided questions to the participants
- Questions from the participants based on the lecture
- Discussion based on an pre-read article.

All these models were two-pieced. The participants were first working in small groups, then a plenary discussion. For this section we also invited professors from NTNU to contribute in the discussions,

mainly because they were considered to be potentially interested in industrial ecology and this was a basis for further collaboration. In fact this has become the reality.

Company presentations

The intention with company presentations was to relate the theoretical and "high-flying" lectures to practical examples from industrial reality. This practical aspect is to a certain extend lacking in the traditional education at NTNU. There was a certain overlap between the different company presentations. When that is said, the students found it very interesting to meet the different companies, particularly to get insight into how companies are approaching the environmental issues, balancing the short-term economical demands from stock owners with environmental demands from nature. The companies had been chosen and invited to cover the different aspects of industry. The following companies were represented:

Statoil	as an energy producer.
Norsk Hydro and Norske Skog	as materials producers
Kværner and ABB	as producers of typical infrastructure and industrial equipment.
Siemens	as a producer of consumer products.
Storebrand	as a financial actor and insurance company

In addition the Director General of the Ministry of Environment gave a presentation on behalf of government and authorities, where he emphasised the need for interdisciplinary qualified analysts of complex energy and environmental issues.

However, each company felt a need to present themselves in terms of turnover, products, etc., and most of the companies had most of their experience on health, environment and safety related to their own processes, and not particularly in industrial ecology. Although these companies are assumed to be proactively ahead of the business development, they could obviously have paid more attention to being self-critic and humble about their own activities.

The thematic issues in the pilot course

The seminar plan consisted of seven seminars within the following topics:

1. Introduction to the Course and Industrial Ecology
2. Life Cycle Assessment - Theory, Databases and Industrial Case Demonstrations
3. Industrial Ecology – the Fundament and Conceptual Clarification
4. Industrial Ecology – Market, Consumers and Politics
5. Sustainable Energy Production and Use
6. Life Cycle Cost and Product Design
7. Presentation of Projectwork

Industrial ecology has emerged as a consequence and a response to the notion of sustainable development. With this starting point it is obviously easy to embrace too many topics. On the other hand, the system-oriented basis of industrial ecology, and the «new» principles of industrial ecology, invited us to be broad-mined. The balance between the conceptual and principal topics on the one hand, and the practical implementation and methodology on the other hand was difficult to find.

Being interdisciplinary is inherently difficult. One challenge in the designing of the program was to combine quantitative and qualitative aspects, visualised by the co-ordinate axis in Figure 2 below. Since we wanted to attract students from completely different faculties it was of considerable importance to

compose the program to make as many students as possible comfortable with the learning process. Even within the technical departments the background knowledge is quite different and this may be a source of complication and frustration. We ended up with a programme both embracing quantitatively methodology and tools like LCA and LCC, and more qualitatively and descriptive methodologies like Quality Function Deployment and Design for X.

On the other hand we offered lectures which can be classified along an ordinat-axis as shown in Figure 2. The distinction is drawn between i) the fundamental, conceptual, principal introductionary and system-oriented lectures, like "Ecology as model for industrial ecology" and "Irreversible thermodynamics" and ii) the more practical lectures telling about the implementation of the industrial ecology principles.

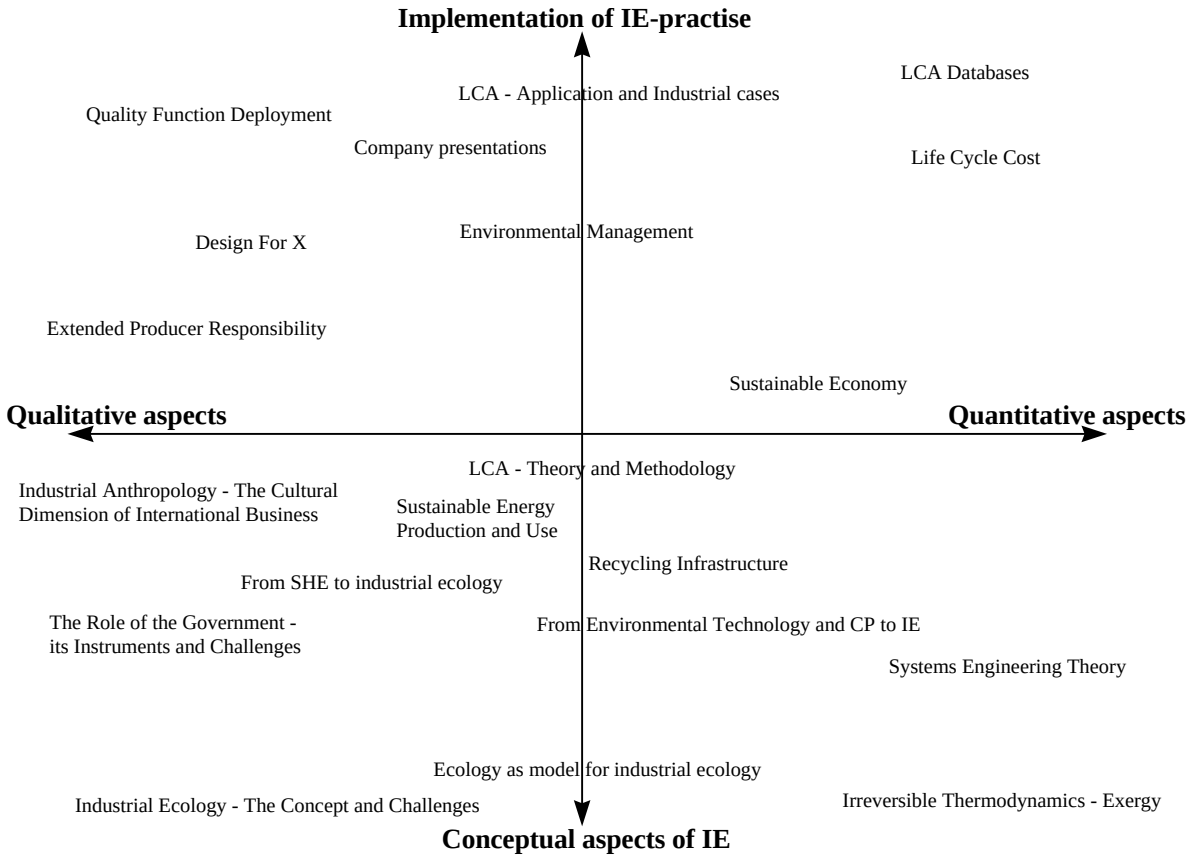

Figure 2: The different topics in the pilot course related to each other

A third dimension in composing the seminar schedule was the relation between technological and non-technological topics. As can be seen from the figure above, the qualitative aspects are very well represented, and many of these have a profile of social science. We found, however, that most difficulties occurred when conceptual natural science, like irreversible thermodynamics, was lectured, and this problem will increase by an increasing number of non-technological students. As mentioned previously, teaching an interdisciplinary course with discursive topics and lecturers, is difficult both for the students and for the organisers.

However, the governing idea of this course was based on the more limited scope of IE as a concept that covers development, manufacturing, use and re-use of products and/or resources with a minimum of environmental consequences and degradations of non-renewable resources. This understanding includes the importance of the consumer, market, and the non-technical disciplines. As indicated in Figure 3, we wanted to cover all the different phases in a life-cycle process, discussing different actors and driving forces.

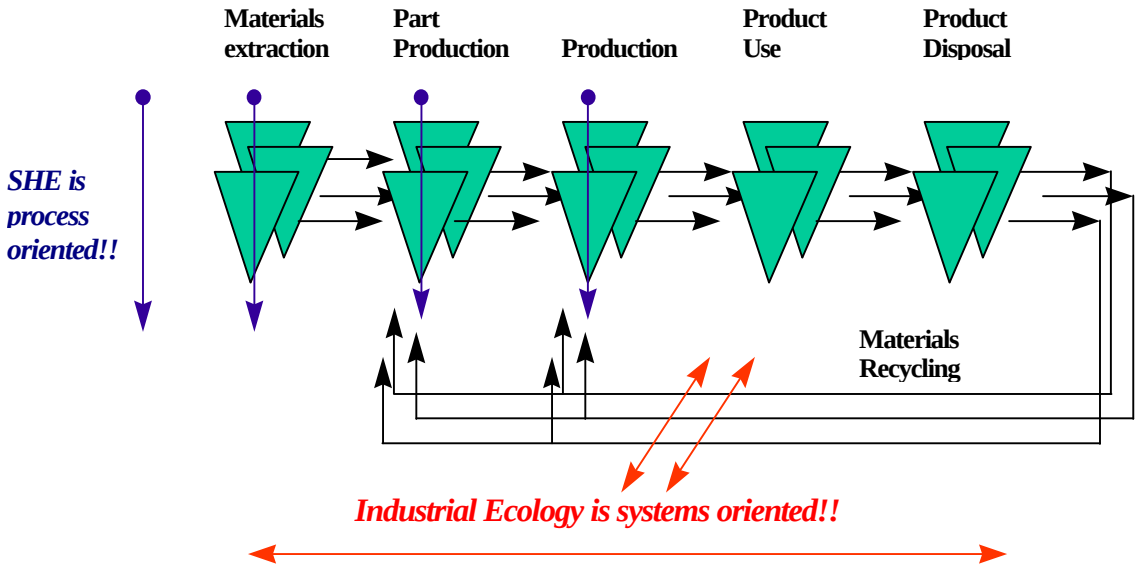

Figure 3: The life cycle perspective of the industrial system

Going more deeply into the pilot course, the introduction seminar were supposed to give an overview of industrial ecology, as seen from Norsk Hydro. We were advised by ABB to present environmental management at an early stage, because this is the organisational grip for handling the environmental challenges, and has to be fundamental to every activity.

Since we kicked off both the project work and the seminars simultaneously, and since LCA was significant in the project work this was the topic of the next 3 day seminar. This massive introduction of a new topic was for some of the students more confusing than inspiring. And what about industrial ecology? The students complained that they did not have the framework or vocabulary to hook all the new knowledge at. Introducing a new subject at the university demands clarifying what is the new content of this compared to previous subjects. Is the concept of industrial ecology a new way of telling the same old environmental story or does it really contribute with a new way of thinking? Discussions about this and about the close and fundamental relations to the ecological and thermodynamic field was the subject of the next three-day seminar. The students found this seminar really clarifying, and in addition to the topics of the lectures, the balance and shifts between workshops, company presentations, project work and lectures at this seminar were successful.

The industrial society is truly interrelated with several actors, changing agents and driving forces. To get an overview of the relations between these aspects was important in this pilot course. This emphasised the need for non-technological contributions, which the students found really promising. These aspects were tried taken care of in a four-day seminar focusing economics, politics, the user phase, consumer behaviour, in fact typical non-technological issues and principles.

The combustion of non-renewable energy resources is a major contributor to the environmental load in industrial society (Ehrenfeld, Dahle). We found it reasonable to offer one seminar focusing on this, inviting the Norwegian energy company Statoil and chair of Nordic World Watch Institute Øystein Dahle to lecture such issues.

What could be the best order of the seminars, both thematically and pedagogically? In the planning of the program we found that the concept of IE should evolve and be clarified through the seminars and workshops. At the start-up of the program we therefore gave only a few hours introduction to ideas and content. As will be seen later, the students complained about this, even if their understanding at the end was very good. We also found it wise to introduce LCA at an early stage because this is an extremely important tool within industrial ecology, and because the projectwork was dependent on knowledge to LCA.

Projectwork

The design of the project work was given a lot of consideration and also discussed with professors from other universities. We wanted that the project work should cover i) the aspect of energy consumption, ii) life cycle analysis of the product involved iii) the market side of the product (How the market will react from an environmental point of view) and iv) the possibility of making product changes.

From the discussions around the idea of case- and project work, we got some very strong signals telling that the pilot course should definitely put emphasis in project work since theoretical and methodological content in industrial ecology is not well defined and appropriate for use on practical problems. Thus, the project should be as specific as possible, and because of this, the idea of including the market side of the life cycle was not really "accepted" from the more engineering side of our advisers, because this would result in a project not specific and concrete enough.

In conclusion to both our own ideas and the advices given, we ended up with the following case for project work: From Siemens we got design and function of an energy saving device that can be plugged on to an electric convection panel oven. The idea is that the device can be programmed to set the oven into "on" or "off" over the day and over the week. With most Norwegian homes and offices being heated by electricity, the device represents an economic interesting product for many homes and offices. The task was to consider this device in an industrial ecological context.

To cover the LCA-part, the project was defined with a functional unit as follows:

> "A living room with a defined size, two persons using it and with a defined comfort temperature when people are present".

Figure 1shows the proceedings of the project work and the seminars.

To cover the different aspects of a complete IE system, including market, regulatory bodies and production, the students were divided into five groups with the following different roles to "play" :

- The role of producer
- The role of the user
- The role of supplier
- The role of NGOs
- The role of authorities.

As seen in Figure 1, the first part of the project work was to criticise the presentation and assessments of a presented LCA on the device. This part was common for all the groups, different from the next part where the different groups were left free to define their system boundaries based on their particular role. Would they for instance choose only electricity or also alternative energy forms? Would they choose to compare with alternative uses of electricity for instance compare heat pumps with the given product system, panel oven and saving device? Would they include the production of electricity or limit themselves to the supply of electricity as such? The intention was that the students should choose and argue based on their role and the industrial ecological principles.

Literature

There is a rapidly growing literature on IE aspacts, but it was difficult to compile a reader being appropriate to a strongly interdisciplinary course. We simplified that by using as main references :

1. Graedel, T.E. and B.R. Allenby (1995) *Industrial Ecology*, Prentice Hall, Engelwood Cliffs, NJ
2. Hauschild,M and H. Wenzel (1997) *Environmental Assessment of Products_Volume 2 - Scientific Background*, Chapman & Hall, London.

Both books were supported by selected articles and lecture notes produced by some of the lectures, now available on Internet.

Points from the evaluation

Through interviews with the students, comments from lecturers and faculties that followed the pilot course module, in addition to our own observation, we have made some conclusions about the programme.

In general the students were very satisfied with this pilot course which offered something unique in their graduate education so far. The fact that the pilot course was indeed interdisciplinary, holistic, system- and future-oriented, creative, invited to discussion and offered an impressing list of national and international recognised lecturers, inspired the students. They also argue that the pilot course, and particular the seminars, was intensive, demanding and extensive. Similar arguments are pointed out by the participants from the companies, lecturers and others. As already discussed, we do not think that the program needs dramatic changes. But we have concluded on some changes:

The structure of the pilot course

Although it was not the intention, the students found the lectures too much based on one-way communication. Besides the fact that several different lectures resulted in lack of continuity, the main reason for this seems to be lack of knowledge because of the broad aspect of topics lectured. To compensate for this, trying to help build a broad understanding of IE through the program, we will introduce the coming seminar with a one hour presentation at the end of the previous seminar. We will refer to the same basic list of literature and also refer to that in the introduction to each seminar. This seems to be even more important since we are now extending the number of participants to 45 students.

The long lasting maturing process made us aware of the fact that the students were not prepared for the presentations from the companies until later in the course. At that time they have more experience and knowledge in the industrial ecological thinking, and thus both the companies and the students will obtain more from this interaction. By gathering all the company presentations in a one day seminar we hope to get a more focused presentation. This one day seminar will then act as a starting point for project collaboration between students and companies at a diploma and PhD level.

The students found the seminar form very promising compared to classes of one to three hours, but seminars of three days were too much both for organisers and students. We will therefore base the programme on two-days' seminars. The main negative consequence using seminar form is that the students have to prioritise our course instead of other courses. At some seminars we experienced this as a problem, resulting in low attendance.

There is no doubt that the workshops had a positive effect on the learning process, resulting in discussions and useful practise. Particularly the workshops where the students should define their own questions to the lecturer, or critically discuss a pre-read article, were profitable. The alternation between lectures and workshops, which the seminar form invites to, is valuable.

The thematic issues in the pilot course

As mentioned above, offering an interdisciplinary course is far more demanding than a monodisciplinary course, particularly when students with different academic background are participating. We experienced that we have to be very conscious about emphasising the frame and the preconditions for the students, to set the different lectures in a correct and an industrial ecological context. For instance, we will use more time and effort at the beginning of the course to introduce and discuss the concept of IE. What are the new elements that industrial ecology brings to the discussion? How does industrial ecology relate to other terms? With the complex world with several actors, driving forces and means in mind, it seems to be very important in the beginning of the course to create a common vocabulary in order to be sure of that as many students as possible have a more coherent perception on what is said.

A reasonable alteration between conceptual and practical lectures on the one hand, and the quantitative and qualitative on the other, as illustrated in Figure 3, is very important. Some students did not for instance find it valuable to learn methodology like LCA. They argue that this course should be overall

and holistic, not concerning about this detailed matters. In this course we certainly experienced the difficult trade-offs between broad and/or depth approaches to the topics. The overall goal in the pilot course was to obtain a systemic and overall view of industrial ecology and the system it has to be regarded within. Is this pedagogically better done by showing simple empirical cases and through these offer the students practical and substantial information? Or is it better to lecture in general terms? As shown in Figure 3, we chose to combine these aspects by giving on the one hand practical project work, company presentations and workshops, and on the other hand more systemic perspicuous lectures.

However, in this context, the thematic content and the order of the seminars may be discussed. As opposed to regular monodisciplinary courses we can not in the same way base our course on a common fundament of knowledge. This calls for a more separate evaluation of the content of this course. When that is said, we are now working for establishing a multi-departmental study-programme, and the topics covered in this course can be more thoroughly covered in other courses.

As mentioned above the students complained about lack of understanding in the beginning. This calls for more general and perspective giving lectures in the beginning, and more emphasis on for instance ecology. General lectures concerning development trends, technological innovation seems valuable.

The life cycle perspective was partly taken care of in the presentation of LCA. However, it seemed to be need for more focus on material flows, industrial metabolism, material loops and recycling infrastructure and strategies in society.

We experienced that the majority of the students had no or very little understanding of the fundamentals of economic theory. Since that is essential to the understanding of some of the regulatory forces that can influence IE, we will expand the program on this point. To do that, we will invite faculty from the university to develop a two-days' seminar.

We also want to put more emphasise on the social science aspect of industrial ecology, for instance on decision making in political processes and on the psychological aspect (behaviour of consumer, why we buy what we do).

The reality was that some students complained about lack of overall understanding. With mainly technological students, being used to well-defined curriculum, this pilot course represented a new way of learning, due to some incoherence between the lectures and the defined literature.

The project work

The experience with the project case was in general good. It is a simple case, easy to understand, but also complex enough to open up for a broad discussion of energy generation, energy application and energy consumption as a function of pricing, living comfort and even consumer's understanding of how to use technical devices. It also allows for LCAs and design evaluations. However, the project work focused less on materials and material flows in a life cycle perspective, and therefore lost this aspect in a not advisable way.

We observed that an expansion of the functional unit to include the whole house would support a wider discussion. We also see that we have to put more emphasis on the material flow and design of the technical device to avoid getting into an energy discussion only.

Finally, as we observed the work load on the students, we realised that we overloaded relative to the expected amount of time used. Even if the students accepted, we do think that we should open up for a more limited program for those who want that. In the year 1997/98 we will therefore run the course as two modules:

1. Module 1 is the theoretical part taken by all the students.
2. Module 2 is program 1 plus project work.

We have not found reason to change the basic reference to literature, but since we will have some more involvement from social science and econometrics, and also experience a constant flow of new literature, we have to expect additions and changes. We will organise a compendium with significant article, mainly written by the lecturers.

CONCLUSION

The overall conclusion is that an interdisciplinary course module on IE is very much appreciated by students in the university, as well as industrial companies and environmental authorities. We will need to test this course during at least 2 or 3 years until a well functioning programme is developed. Such a programme should include conceptual approaches to the IE thinking, theory and methodology, but should be strongly focused towards cases and real practise and trade-offs between different priorities. Finally, there is need for high attention to workshops and reflective discussion processes in order to help students developing a mature understanding of this complex area.

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