Industrial Ecology:

An Agenda for the Long-term Evolution

of

the Industrial System

"Cahier de propositions"

of the Industrial Ecology Workshop

(First draft for discussion, based on contributions by

Suren Erkman, Colin Francis, Ramesh Ramaswamy)

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Institute for Communication and Analysis

of Science and Technology (ICAST),

P. O. Box 474, CH-1211 Geneva 12, Switzerland

Industrial ecology in a nutshell

There is today an increasing realisation that focussing on industrial processes within specific sectors of the economy does not address satisfactorily many of the environmental concerns that we currently face. And yet global environmental issues – such as climate change, ozone depletion, the loss of bio-diversity and habitat, or water scarcity and water pollution – can often be traced back to the enormous expansion on a global scale of the industrial system.

Moreover, approaches by governments in many countries to environment and development are even today frequently sectoral and compartmentalised. An excellent illustration of this is provided by the classical end-of-pipe strategy for environmental protection. Although it has proven to be quite useful for the treatment of pollution, the end-of-pipe approach does nothing to address the critical question of how to make more efficient use of limited resources in the context of a growing population with increasing economic aspirations.

Therefore, we see that the concept of industrial ecology has emerged at a time when traditional approaches are increasingly seen as being insufficient to solve current environmental problems or to respond to the question of sustainable development. However, before answering the question – "What is industrial ecology?" – let us describe briefly how the field evolved. The beginnings of industrial ecology are normally associated with the paper "Strategies for Manufacturing", or to give it the original title "Manufacturing – The Industrial Ecosystem View", written by Robert Frosch and Nicholas Gallopoulos for a special issue of Scientific American entitled "Managing Planet Earth" ([1], but see also [2]).

Although this article is undoubtedly the source of the current development of industrial ecology, the ideas were not strictly speaking new. One can point in particular to a study "L'écosystème Belgique. Essai d'écologie industrielle" carried out in the early 1980's by the Centre de recherche et d'information socio-politiques (CRISP) in Belgium. Another early examination of the area had been carried out in Japan in the 1970's with an Industry-Ecology Working Group set up by MITI (the Ministry of International Trade and Industry). We also find the concepts inherent to industrial ecology present in the work of a number of others – Ayres, Cloud, Commoner, Hall, Nemerow, and Odum to name but a few [3].

The year 1989, however, was a propitious moment for the article by Frosch & Gallopoulos to appear – the previous decade had seen the accident at the Union Carbide chemical plant in Bhopal (India) as well as the warehouse fire in Schweizerhalle (Switzerland) with the resulting pollution of the Rhine river. Ideas that the future of industrial economic development would be limited by the availability of resources or inputs had been replaced by the realisation that outputs posed a much greater problem. The report of the World Commission on Environment and Development, "Our Common Future", had been published in 1987 and everybody was thinking about sustainable development in the preparation for the 1992 Rio Earth Summit.

How does industrial ecology differ from the traditional approaches mentioned at the beginning? The basic premise of industrial ecology is that industrial activities should not be considered in isolation from the wider world but rather in terms of an *industrial ecosystem* functioning within the natural ecological system or Biosphere. The industrial system, in a similar way to a natural ecosystem, essentially consists of flows of materials, energy and information, and furthermore relies on resources and services provided by the Biosphere. It is important to stress at the outset that the word "industrial", in the context of industrial ecology, refers to all human activities occurring within the modern technological society. Thus tourism, housing, medical services, transportation and agriculture are all a part of the industrial system.

Industrial ecology starts out from the basis of "industrial metabolism". Industrial metabolism is an analytical approach – basically an application of materials-balance principles – that seeks to understand the circulation (and stocks) of materials and the flows of energy linked to human activity, starting with the initial extraction of materials and going through to their inevitable reintegration into the biogeochemical cycles [4]. Industrial ecology, on the other hand, goes further. Having sought firstly to understand how the industrial system works - how it is regulated and its interactions with the Biosphere – industrial ecology then uses what is known about natural ecosystems to determine how the industrial system can be restructured to make it compatible with the way natural ecosystems function [5].

Industrial ecology, therefore, combines a rigorous conceptual framework (that of scientific ecology) with a practical approach to sustainability. It represents one path to provide real solutions to the question – "How can the concept of sustainable development be made operational in an economically feasible way?"

All authors agree more or less that there are three key elements to the industrial ecology perspective:

a) It is a systemic, comprehensive, integrated view of all of the components of the industrial economy and their relationship with the Biosphere.

b) It emphasises the biophysical basis of human activities, i.e. the complex patterns of material and energy flows both within the industrial system and outside. This is in stark contrast to current approaches that mainly consider the economy in terms of abstract monetary units.

c) It considers technological dynamics, i.e. the long-term evolution of clusters of key technologies, as a crucial (although not exclusive) element to achieve a transition from the actual unsustainable industrial system to a viable *industrial ecosystem*.

In short, industrial ecology aims to look at the industrial system as a whole. It does not just address issues of pollution and environment but considers as well the entire spectrum of issues that are involved in the management of commercial enterprises, ranging from technologies, process economics, inter-relationships of businesses and financing to overall government policy. As such, industrial ecology provides a conceptual framework and an important tool for the planning of economic development, particularly at the regional level [6]. Also, industrial ecology proposes ways for optimising the use of scarce resources as well as for protecting the environment. As a result, it is particularly relevant in the context of developing countries where growing populations with increasing economic aspirations must make the best use of limited resources [7].

Looking back on the first decade of industrial ecology we see how the field has matured and gained in recognition in business communities as well as in academic and government circles. We may point to the early article "Industrial Ecology: A New Environmental Agenda for Industry", written by Hardin Tibbs and published by the business consultants Arthur D. Little; or the publication in 1995 of the first textbook on Industrial Ecology by Graedel and Allenby (both at the time with AT&T). In 1997 we saw the launch of the Journal of Industrial Ecology by the MIT Press, and then in early 2001 an International Society for Industrial Ecology was created [8].

Now, as we approach the 10th anniversary of the Rio Earth Summit in 2002, this is a particularly appropriate moment to address the question of how industrial ecology can contribute to the future long-term evolution of the industrial system. In this *Cahier de Propositions* we put forward a series of proposals based on our recent thoughts.

Restructuring the Industrial System

The principal objective of industrial ecology is to reorganise the industrial system (including all aspects of human activity) so that it evolves towards a mode of operation that is *compatible with the Biosphere* and is *sustainable over the long-term*. The strategy for implementing industrial ecology is referred to as "eco-restructuring" and can be described in terms of four main elements:

1. *Optimising the use of resources:*

   Optimising the use of materials and energy in any industrial activity starts with an analysis of production processes in order to eliminate unnecessary losses. This is a step that is carried out by individual companies on their own activities and goes under the title of *pollution prevention* or *cleaner production*. While considerable efforts in this area have been undertaken during the past 10 – 15 years, there is still room for further improvement, particularly in the newly-industrialising countries that will represent the principal manufacturing base in the future.

Once we begin to consider the biological analogy underlying industrial ecology we realise that additional aspects of resource optimisation are not covered by the approaches mentioned above. In natural ecosystems certain species feed on the waste of other species and thereby contribute to the creation of a "food web". Industrial ecology therefore suggests the idea of an "industrial food chain" in which companies are linked in some form of network in order to exploit unutilised resources or by-products and thereby increase resource utilisation.

An important concept for favouring co-operation between companies in order to maximise resource use by mutually recovering the by-products that they generate was born in the early 1990's – the "eco-industrial park" (EIP). The EIP is proving to be an important tool within the industrial ecology approach and at present there are around 50 EIP projects underway, particularly in North America, Western Europe and Asia [9]. However, this idea can also be applied on a regional basis to create "eco-industrial networks".

What types of companies would benefit from being co-located in an EIP? Here once again, the biological analogy serves a useful purpose. In biology there exists the concept of biocoenosis, which refers to the characteristic patterns of association of certain species of organisms in ecosystems. And, just as in natural ecosystems, there are certain key species that can participate in an "industrial biocoenosis". For example, a power plant is an obvious focal point for an industrial biocoenosis, given the extent of material flows involved and the enormous quantity of energy wasted as heat.

Although some examples of partial and spontaneous industrial biocoenoses have been around for a long time, an important challenge for industrial ecology now is to focus efforts on developing these industrial complexes in a more explicit and systematic way [10]. This requires field studies to be carried out for different industrial sectors to map the flows of resources and identify how by-products can be employed by other industries in order to understand the "metabolism" of the industrial sectors.

2. *Closing material loops and minimising emissions:*

In natural ecosystems all materials flow cyclically in a form of "closed loop". For many nutrients this arises because bacteria, fungi and small invertebrates break down dead matter or waste products into simpler chemical compounds that can once again be used by plants. Companies that carry out this function in the industrial ecosystem are usually referred to as "recyclers". Unfortunately, while natural ecosystems are very effective at closing the materials loop, the industrial ecosystem is far from optimal. Only a small fraction of the waste is broken down into its *technological nutrients* to be returned to the system; the majority is "lost from the industrial system" through – (i) the creation of waste during the manufacturing of products, (ii) as waste that is formed by a product when it is considered to be of no further useful value, and (iii) in the form of products that are designed to be completely or partially dispersed during their use. At the present, the losses of materials due to consumption patterns [i.e. types (ii) and (iii) above] greatly exceed those during the manufacturing process.

Closing material loops within the industrial ecosystem, therefore, means addressing the complete lifecycle of the product. One aspect is to make the recycling industry more effective, both with respect to technological solutions as well as logistics. As we shall discuss below, however, energy is required to close the material loop in a natural or an industrial ecosystem. As long as we continue to use fossil fuels as our source of energy in the industrial ecosystem, recycling will also contribute to the creation of waste from the combustion process. The energy associated with recovery of a material must therefore be considered when deciding on a strategy for closing the loop. In the case of the recovery of aluminium from scrap, for example, the energy requirement for recycling is much lower than that for extraction and purification of aluminium from bauxite. The environmental impact due to recycling is only one-tenth of that to produce virgin aluminium.

Although it is possible to envisage closing material loops for (i) and (ii) above, there are some materials that are designed to be completely or partially dispersed during their use. Some examples are pharmaceuticals, fertilisers, pesticides, detergents, solvents, etc. Such materials clearly cannot be recycled after use and will always represent a loss of resources. Minimising dissipation of this type of product is a difficult challenge and may be addressed (in some cases) by rethinking the service demanded.

One area where open material flows can no longer be accepted is when such materials are toxic/hazardous and in particular when they are persistent and bio-accumulate. Whether the material is lost due to inefficient recycling or through dissipative use, sustainability arguments imply that its future use must be seriously questioned and alternative solutions provided.

3. *Dematerialising activities:*

An important objective of Industrial Ecology is not only to create cyclic flows of materials but to *minimise the total flow of matter and energy* used to provide equivalent services. Technical progress often makes it possible to obtain more service from a smaller amount of matter, such as by producing lighter objects or by replacing one material by another (e.g. a few kilograms of optical fibre allows for more telecommunications throughput than one ton of copper cable). However, *dematerialisation* is not as simple as it may seem – less massive products may have shorter life spans and will therefore ultimately consume more resources and generate more waste. Furthermore, dematerialisation does not apply only to consumer goods, but also to the heavy infrastructure of the industrial system, such as in buildings, roads, transportation networks, etc. [11].

At the present time two strategies are being debated – *relative dematerialisation* so as to obtain more services and goods from a given quantity of matter, and *absolute dematerialisation*, which strives to reduce the total flow of matter circulating within the industrial system. In addition, there has been a recent surge of interest in dematerialisation in the context of the so-called "new economy", or "internet-based economy", and there have been many claims that the emerging information technologies will contribute to the dematerialisation of the economy. However, this is far from proven, and at this stage we must acknowledge our ignorance about the real impact of new information technologies on resource consumption [12].

Probably one of the best ways to dematerialise the economy is to emphasise the service rendered, i.e. to market the *use of the product* rather than the product itself. For many years our economic system has been organised to maximise production. Within the context of industrial ecology, the objective is to prioritise use in order to evolve towards a genuine service-oriented society. This involves strategies such as durability (extending the useful life of a product), renting rather than owning, and selling use rather than the actual product [13].

4. *Reducing and eliminating the dependence on non-renewable sources of energy*:

   Although we can strive to close material loops in our industrial ecosystem, this is not possible for energy. What is more, energy is required to carry out the recovery of materials in order to close the loop! Therefore, energy becomes an extremely important factor in the eco-restructuring of the industrial system. One positive approach is to increase energy efficiency through developments such as co-generation and energy cascading.

   However, fossil fuels (coal, oil or natural gas) are a crucial factor in powering the engines of industrial economies. Combustion of fossil fuels is fundamentally dissipative and lies at the root of many environmental problems, including the enhanced greenhouse effect, smog, oil spills, acid rain, etc. An even more important contribution to eco-restructuring, therefore, must involve a change in the way that we obtain energy so as to make it more compatible with the goals of industrial ecology. In a first phase we can try to make fossil fuel consumption less harmful – for example by recovering carbon dioxide gas or by *decarbonising* the energy supply via a change from coal and oil to natural gas (and eventually perhaps hydrogen) [14]. However, it is clear that this is only a temporary solution and the move from fossil fuels to alternative renewable energies must be introduced quickly.

These four elements allow us to propose concrete steps to bring about a long-term evolution of the industrial system. It is of great importance today to address these questions, and in particular for developing countries. A great deal of manufacturing for the global market is increasingly occurring in developing countries and it is now a crucial time to influence their choice of industrial development path. For example, the analysis of resource flows at an early stage of development can lead to a resource-based development plan for a region or country that will create an industrial system that uses its resources more effectively. In addition, the increasing use of industrial estates as an economic development tool in many Asian countries provides an excellent opportunity to introduce the concept of eco-industrial parks (EIP) that can respond to the requirements of resource optimisation, material loop closing and energy efficiency.

Approach & Strategy

Two important questions are – (i) how to introduce decision-makers to the ideas behind eco-restructuring, and (ii) how to help small and medium size industries in particular to take advantage of the possibilities provided by industrial ecology. This requires teams of technical experts who can also address the broader implications of industrial ecology. To some extent, drawing once again on the biological analogy, it requires a *community of experts who can work in an interdependent manner on the industrial ecosystem*. The need for experts to work in applied industrial ecology has resulted in ICAST creating this year a programme in applied industrial ecology, called *Industrial Ecology Praxis*.

Bringing about the evolution of the industrial system cannot occur within a vacuum and one can point to 5 areas where support is needed to advance the industrial ecology agenda – research, education, communication, the policy and legal framework, and the financial and business sector

We can highlight a number of research areas for study in industrial ecology that are likely to have significant impacts for eco-restructuring. However, it is important to point out here that industrial ecology remains a marginal subject for study at the university level at the present. It is important for the field that this situation change and that industrial ecology becomes a credible subject for study. One of the priority areas for research in industrial ecology is in the validity of the industrial ecology metaphor itself [15]. If we are going to be inspired by natural ecosystems for the reorganisation of the industrial ecosystem we need to be sure that we are basing our ideas on a realistic view of natural ecosystems and the Biosphere in general. In addition, we should not forget that we already have many years of experience of how our industrial ecosystem is interacting with natural ecosystems, in general in a negative sense, and ensure that we learn from these interactions as well.

Industrial ecology also requires us to be pro-active towards the industrial system – i.e. it is not merely a waste management approach. Optimising resource utilisation, closing loops and dematerialisation all require research on the material processing function within the industrial system – starting from the creation of new materials (*e.g.* through Green Chemistry) through the design of new products (*e.g.* Design for Environment) to better technologies for material recovery – in order to put in place a more effective industrial system. Research into how energy is going to be provided and used to power this industrial system is equally of tremendous importance and is often overlooked within the industrial ecology agenda. Finally, we should not try to "reinvent the wheel" and there is a need for research into how existing tools contribute to the goals of industrial ecology.

In order to convince the different sectors of society of the usefulness of the industrial ecology approach, and create a political and legal climate that will allow the process to advance, research is needed to identify existing cases where industrial ecology is being practised, and to understand how they function and the benefits they have brought. It is also true to say that the end-of-pipe strategy has left long-lasting effects on society, in particular with respect to policies and legislation, and research is needed to see how existing policies and regulations need to be modified and new policies and legislation put in place to allow an industrial ecology approach to be used effectively.

Of course, an evolution of the industrial system requires an "industrial ecology-literate" society that understands what industrial ecology is trying to achieve and can contribute to its progress. This requires two fundamental changes in the education system. Firstly, students at school need to be reintroduced to the natural world in which they live through an understanding of scientific ecology concepts. Secondly, students at the university level need to be made aware that a reductionist approach to science and engineering is not going to be very helpful when it comes to an industrial ecosystem approach. There is a need for people working in industry who are at home with a systems approach and in dealing with complex systems. We can go back to the Frosch and Gallopoulos article for a succinct description of the problem:

However, we should add other areas – for example economics, business administration and political science – to this list since the understanding that there is a material basis for all human activities (and not just a monetary basis) needs to be instilled in our current society.

> *"The concepts of industrial ecology and system optimization must be taught more widely. Current engineering and technological education either omit these concepts entirely or teach them in such a limited way that they have little impact on the approaches taken to the environmental problems associated with manufacturing."*

Furthermore, it is through communication that we can contribute to informing society at large about the ideas behind industrial ecology and eco-restructuring. The acceptance by all sectors of society is critical if these ideas are to contribute to a sustainable form of development. For the past 6 years the Industrial Ecology *chantier* has been successfully communicating the ideas of industrial ecology throughout the world. Through workshops and conferences - such as Kalundborg (Denmark) in June 1996, Ahmedabad (India) in February 1999, Troyes (France) in September 1999, Algiers (Algeria) in November 2000, and the most recent in Manila (Philippines) in April 2001 – the concept of industrial ecology has gradually spread within different sectors of the society (industry, business, government, academia, and NGO's). Quite an extensive network has now been created and for example, following the Manila workshop, an IE-Asia Network has been officially created in the Asian region through which people can exchange their experiences.

There is a specific need for information targeted at policy makers and local authorities on industrial metabolism and resource flows in order to help them to contribute to sustainable development through local Agenda 21 projects. Many industrialists, particularly in developing countries, realise that industrial ecology can be very important for the future of their enterprise, by helping them to use resources more effectively (which can also have the effect of making their business more profitable). They need information beyond that available during a general presentation of industrial ecology. There is therefore a great need for technical training workshops to provide them with the necessary tools to address the 4 elements of eco-restructuring described previously.

As we have already mentioned, policies relating to environment and development must evolve in parallel with the evolution of the industrial system. Industrial ecology, and the concepts behind it, can provide a useful basis for rethinking how we address environment and development in policy making and in creating the corresponding legal framework. Finally financing of industrial investment is based frequently today on very short periods of time for return on investment. This may be a major hurdle for industrial ecology, since it is a concept that is based mainly on long-term development rather than short-term profit.

In conclusion, industrial ecology gives us a valuable methodology to initiate change through eco-restructuring of the industrial system. However, we should not believe that industrial ecology can bring us to a sustainable form of development by itself. If *authentic development* can be thought of in terms of six factors – economic, environmental, social, political, cultural, and ethical [16] – then industrial ecology clearly sets out to address directly only the first two dimensions. This is a strength because in this way it does not "try to do everything", which would lay it open to the type of criticism that is often levelled at sustainable development itself. Nevertheless, this means that efforts to restructure the industrial system through an industrial ecology approach must be considered in the context of an overall sustainable development approach in which the critical importance of the social, political, cultural and ethical dimensions is fully recognised.

Proposals for an Industrial Ecology Agenda.

❅ Implementation Mechanisms -

- ⇨ The implementation of an Industrial Ecology approach requires our industrial activities to be modified significantly – or ***eco-restructured***. The strategy contains 4 principal elements:

  1. Optimising resource use.

     Whether we consider limits to growth as being on the input- or output- side the industrial ecosystem must optimise its use of resources if it is going to increase its capacity to support human development on a global basis.

  2. Closing material loops and minimising emissions (in particular of toxic materials).

     Losses of materials due to human consumption patterns are often greater today than those occurring during the actual manufacturing steps. New products must be designed to minimise material dispersion, both during their manufacture and in terms of the service provided, and in particular where materials are potentially harmful. Recovery of materials at the end of a product's useful life must allow them to be re-utilised in high-value applications.

  3. Dematerialising activities.

     Minimising the total amount of resources required to achieve equivalent services is an important objective within Industrial Ecology. We have to distinguish here between relative dematerialisation – obtaining more services from a given quantity of matter – and absolute dematerialisation – reducing the resource requirements for the industrial system as a whole.

  4. Reducing and eliminating dependence on non-renewable sources of energy.

     Currently industrial development is based almost exclusively on non-renewable fossil fuels (coal, oil and natural gas). These materials provide us with the energy that we need but their use is totally dissipative. The products of combustion give rise to all-to-familiar problems such as acid rain or the enhanced greenhouse effect. Therefore, we must move quickly to reduce and eliminate our requirement for fossil fuels by improving energy efficiency and adopting alternative renewable energies.

- ⇨ Industrial ecology concepts and principles must be incorporated into development planning, particularly in the context of developing countries where resources may be scarce.

  One of the aims of a resource-based development plan for a developing country is to ensure that the total flow of resources (and in particular scarce or hazardous materials) is optimised. Optimisation might be achieved through the selection of industries or by encouraging the closing of material loops.

- ⇨ In order to begin implementing Industrial Ecology it is necessary to integrate the usually narrow expertise of technical specialists into teams of experts who can address the broader systemic perspective of Industrial Ecology.

  Different species within an ecosystem carry out different functions that together allow the system to increase its capacity to support life. In the same way, the industrial ecosystem requires different actors who can contribute their particular expertise to implementing Industrial Ecology within the industrial sphere of human activities. The recent creation of a network of such experts (IE-Praxis) is a first step in this direction.

❋ Research -

⇨ The establishment of Industrial Ecology as a credible subject for study within the academic framework is of great importance for the future of the field.

For Industrial Ecology to develop as an accepted field of study, there is a need for research in Industrial Ecology to be recognised through the granting of Ph.D.s, the availability of tenured university positions, and an access to research funding.

⇨ A priority area for research in Industrial Ecology is to investigate in more depth the validity of the Industrial Ecology metaphor.

What can scientific ecology tell us about the design and management of the industrial system and its interaction with the Biosphere?

⇨ Basic research on the implementation of an Industrial Ecology approach is required from a technology perspective.

Industrial Ecology is anything but waste management! The approach needs research into the material processing function of the industrial ecosystem – starting from the creation of materials (e.g. Green Chemistry) through the design of products (e.g. Design for Environment) and their manufacture to the technology for material recovery and closing of material loops.

⇨ Basic studies of how current policies and regulations may be hindering the development of Industrial Ecology need to be carried out.

The end-of-pipe approach has left a legacy of end-of-pipe thinking. Policies and regulations have therefore been created to optimise environmental protection based on this line of attack. Industrial Ecology demands a radical rethinking of regulations and policies that may be counter-productive within this new perspective.

⇨ There is an urgent need for research to be carried out in order to identify cases where Industrial Ecology is already being practised, and to monitor and assess the results.

If the utility of Industrial Ecology is to be demonstrated, then it is necessary to provide other examples than Kalundborg, with its industrial symbiosis.

⇨ The link between Industrial Ecology and existing tools – such as cleaner production, eco-efficiency, environmental management systems – that are used by business as part of their sustainable development strategy, needs to be explored.

Industrial Ecology is a logical evolution of the current business trend rather than a "New Industrial Revolution" and it is important to investigate how to use existing tools at the level of a system.

❅ Education -

⇨ A basic introduction to the concept of Industrial Ecology should be included at a university level for all students of economics, business administration and political science.

*If we are to overcome the widely-held belief, particular in the business sector, that "matter does not really matter" then the idea that **there is a material basis for all human activities** needs to be generally understood and appreciated.*

⇨ Industrial Ecology must be introduced as a required subject for all science and engineering students at the university level.

The ideas encompassed in Industrial Ecology are essential if science and engineering students are going to contribute to their future professions in industry with anything other than an "end-of-pipe" mentality.

- There should be an initiation to scientific ecology as a core subject within the secondary level of the school system.

  It is as important to understand how the world we live in functions as to know a language or mathematics!

- Industrial Ecology needs to be promoted as well through Further Education courses.

  In order to reach those who are already in their active professional lives, an introduction to the ideas of Industrial Ecology is important. IE cannot merely be for the "next generation".

Communication -

- Industrial Ecology needs to be promoted as an extremely important approach towards making sustainable development operational.

  The awareness raising (capacity-building) efforts of the IE Chantier during the past 6 years need to be continued on a regular basis with targeted sectors of society in all regions of the world. Partners need to be identified to work with the FPH on such future activities.

- Information for policy-makers and administrators on the importance of the industrial metabolism of their area (country, region, town etc.) should be provided through publications that are specifically targeted to this group.

  If one wants to be serious about sustainable development and Agenda 21, the systematic preparation of local and regional resource flows cannot be avoided. These can only be drawn up with the active support of the relevant authorities.

- Training workshops must be created and actively supported to help the economic sector to put the Industrial Ecology approach into practice.

  Frequently, industrialists intuitively see the value of an Industrial Ecology approach to their business. This is particularly true for small enterprises in both developing and industrialised countries. However, they need the tools to make it occur.

Policy Framework -

- Individual countries need to re-evaluate their current environmental and industrial policies and laws so as to take into account an Industrial Ecology approach to development.

  Environmental policies derived from the command-and-control concept and an end-of-pipe approach to environmental management may introduce constraints on how materials can flow through the industrial ecosystem and prevent the closing of loops. On the other hand, new policies and laws are required that can promote an Industrial Ecology or systems-based approach while guaranteeing to society that it is not exposed to a greater environmental and health risk.

- ⇨ Industrial development at a local, regional or national level must incorporate a systemic approach, such as Industrial Ecology, if it is to be effective.

  Economic development policy needs to be based on an accurate knowledge of the resource flows within an area so that spatial planning, choice of industries and residential and commercial activities are organised so as to use the available resources in the most efficient manner possible.

- ⇨ Government responsibility for the environment needs to be re-evaluated as a function of the new needs provided by a systemic Industrial Ecology approach.

  Services that deal with "protection of the environment" have grown up within a 1970's vision of the industrial sector and the Biosphere as being separate entities. Frequently, laws and responsibilities are compartmentalised to address pollution of the air, water and soil. A systemic approach requires industry to be considered as part of the global ecosystem and environmental protection to be viewed in terms of resource optimisation and ecosystem support.

❅ Financing -

- ⇨ Financing of industrial activities must be evaluated within a longer-term perspective if an Industrial Ecology approach is to be fostered.

The current requirement for industrial activities to be highly profitable over the shortest of time-scales, i.e. "increased shareholder value", is anathema to an Industrial Ecology approach that requires a longer-term vision. Balancing the desire for quick returns with long-term sustainability is a major challenge that the business and finance sectors must address.

References

[1] Robert A. Frosch and Nicholas E. Gallopoulos, *Strategies for Manufacturing*, Scientific American, Vol. 261, No. 3, September 1989, pp. 94-102.

[2] Robert A. Frosch and Nicholas E. Gallopoulos, *Towards an Industrial Ecology*. In: A.D. Bradshaw et al. (eds.): The Treatment and Handling of Wastes, Chapman & Hall, London, 1992, pp. 269-292.

[3] For details on the historical background of industrial ecology, see:

Suren Erkman, *Industrial Ecology: A Historical View*, Journal of Cleaner Production, Vol. 5, N° 1-2, 1997, pp. 1-10.

[4] On industrial metabolism, see:

Robert U. Ayres and Udo E. Simonis (eds.), *Industrial Metabolism: Restructuring for Sustainable Development*, Tokyo, New York, United Nations University Press, 1994.

Peter Baccini and Paul Brunner, *Metabolism of the Anthroposphere*, Springer Verlag, Berlin, 1991.

Albert Adriaanse et alia, *Resource Flows: The Material Basis of Industrial Economies*, Washington, DC, World Resources Institute, 1997.

Emily Matthews et alia, *The Weight of Nations. Material Outflows from Industrial Economies*, Washington, DC, World Resources Institute, 2000.

Main web resource on industrial metabolism: http://www.conaccount.net

[5] On the concept of industrial ecology, see:

Braden R. Allenby and William E. Cooper, *Understanding Industrial Ecology from a Biological Systems Perspective*, Total Quality Environmental Management, Vol. 3, No. 3, Spring 1994, pp. 343-354.

Thomas E. Graedel, *On the Concept of Industrial Ecology*, Palo Alto, CA, Annual Review of Energy and the Environment, Vol. 21, 1996, pp. 69-98.

Braden R. Allenby, *Earth Systems Engineering: The Role of Industrial Ecology in an Engineered World*, Journal of Industrial Ecology, Vol. 2, N° 3, 1998, pp. 73-93.

Robert U. Ayres and Leslie W. Ayres, *Industrial Ecology: Towards Closing the Materials Cycle*, Cheltenham, UK, Edward Elgar, 1996.

Proceedings of the *Helsinki Symposium on Industrial Ecology and Material Flows* (August 2000) – available on the web: http://www.jyu.fi/helsie

[6] On industrial ecology as a tool for regional planning, see:

William Stigliani and Stefan Anderberg, *Industrial Metabolism at the Regional Level: The Rhine Basin*, In: Industrial Metabolism: Restructuring for Sustainable Development, edited by R. U. Ayres and U. E. Simonis. Tokyo, United Nations University Press, 1994.

Peter Baccini und Hans-Peter Bader, *Regionaler Stoffhaushalt*, Heidelberg/Berlin, 1996

Annica Lindqvist-Östblom, *Flow-oriented studies for environmental management by local authorities – experiences from a regional substance flow analysis*, Thesis N° 825, May 2000. [Linköping University, Environmental Technique & Management, Department of Physics and Measurement Technology, Sweden]

Fredrik Burström, *Environment and Municipalities - Towards a Theory on Municipal Environmental Management*, Royal Institute of Technology, Division of Industrial Ecology, Stockholm, September 2000.

[7] Suren Erkman and Ramesh Ramaswamy, *Industrial Ecology as a Tool for Development Planning: Case Studies in India*, New Delhi, Sterling Publishers, 2001 (forthcoming).

[8] Hardin Tibbs, *Industrial Ecology: A New Environmental Agenda for Industry*, Arthur D. Little Inc., 1991.

Thomas E. Graedel & Braden R. Allenby, *Industrial Ecology*, Prentice Hall, Englewood Cliffs, 1995.

Journal of Industrial Ecology (MIT Press): http://mitpress.mit.edu/JIE

International Society for Industrial Ecology: http://www.yale.edu/is4ie

[9] On eco-industrial parks and eco-industrial networks, see:

Raymond P. Côté & al., *Designing and Operating Industrial Parks as Ecosystems*, Report of the project "The Industrial Park as an Ecosystem", Dalhousie University, School for Resource and Environmental Studies, August 1994.
See the web sites: http://www.mgmt.dal.ca/sres/research/Ecogroup.htm
http://www.dal.ca/eco-burnside

Ernest A. Lowe, Stephen A. Moran, and Douglas B. Holmes, *Fieldbook for the Development of Eco-Industrial Parks*, Report prepared for the Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency, Washington, D.C., 1996. [Prepared by Indigo Development: http://www.indigodev.com]

Ed Cohen-Rosenthal & al., *Designing Eco-industrial Parks. The North American Experience*, In: *Proceedings of the 1st European Conference on Industrial Ecology*, Barcelona (Spain), February 1997, pp. 35-48.

Web site of the "*Eco-Industrial Development Program*", Cornell Centre for the Environment: http://www.cfe.cornell.edu/wei

President's Council on Sustainable Development (PCSD): *Eco-Industrial Park Workshop* (October, 1996, Cape Charles, Virginia), February 1997. Proceedings: http://www.whitehouse.gov/PCSD/Publications/Eco_Workshop.html

Erich J. Schwartz, *Industrial Recycling-Network. A Model to Integrate Ecological Aspects in a Production Economy*, Monograph, Institute of Innovation Management, Karl-Franzens-University, Graz, Austria, April 1995, 24 pages.

[10] Nelson L. Nemerow, *Zero Pollution for Industry. Waste Minimization Through Industrial Complexes*, New York, John Wiley & Sons, 1995.

[11] On dematerialisation, see:

Robert Herman, Siamak A. Ardekani, and Jesse H. Ausubel, *Dematerialization*, In: Jesse H. Ausubel and Hedy E. Sladovich (eds.):Technology and Environment, Washington, D.C., National Academy Press, 1989, pp. 50-69.

Oliviero Bernardini and Riccardo Galli, *Dematerialization: Long-Term Trends in the Intensity of use of Materials and Energy*, Futures, May 1993, pp. 431-448.

Cutler J. Cleveland and Matthias Ruth, *Indicators of Dematerialization and the Materials Intensity of Use*, Journal of Industrial Ecology, Vol. 2, N° 3, 1998, pp. 15-50.

Ernst von Weizsäcker, Amory B. Lovins, L. Hunter Lovins, *Factor Four. Doubling Wealth, Halving Resource Use*, London, Earthscan Publications Ltd, 1997.

Friedrich Schmidt-Bleek, *Wieviel Umwelt braucht der Mensch? Das Maß für ökologisches Wirtschaften*, Berlin, Birkhäuser, 1994.

Mathis Wackernagel & William Rees, *Our Ecological Footprint. Reducing Human Impact on the Earth*, Philadelphia, PA, New Society Publishers, 1996.

[12] On material flows and the Internet economy, see:

Peter Huber and Mark P. Mills, *Dig more coal – the PCs are coming*, Forbes, 31 May 1999. [http://forbes.com/forbes/99/0531/6311070a.htm]

Ryan Kim, *E-biz's hard drive. Online delivery trucks add to San Franciso street congestion,* San Francisco Examiner, June 21, 2000, p.1.

See also the web page of the "Network for Energy, Environment, Efficiency, and the Information Economy" (Berkeley): http://n4e.lbl.gov/

Gerhard Knolmayer and Ted Scheidegger*, "Bring the Fiber to the Power" Nebeneffekte der New Economy*, Neue Zürcher Zeitung, Freitag, 20. April 2001, Seite 78. [http://archiv.nzz.ch/books/nzzmonat/0/$7C1OA$T.html]

[13] Walter R. Stahel and Tim Jackson, *Optimal Utilisation and Durability - Towards a New Definition of the Service Economy*, In: T. Jackson (ed.): Clean Production Strategies, Boca Raton, FL: Lewis Publishers, 1993, pp. 261-291.

[14] On decarbonisation, see:

Nebojsa Nakicenovic, *Freeing Energy from Carbon*, In: Jesse H. Ausubel and H. Dale Langford (eds.): Technological Trajectories and the Human Environment. Washington, D.C., National Academy Press, 1997, pp. 74-88.

Robert Socolow (ed.), *Fuels, Decarbonisation and Carbon Sequestration: Report of a Workshop*. Princeton, NJ, The Center for Energy and Environmental Studies, Princeton University, PU/CEES Report N° 302, September 1997.
[Available on the web: http://www.princeton.edu:80/~ceesdoe/]

[15] For a general overview of industrial ecology, see:

Suren Erkman, *Vers une écologie industrielle*, Paris, Editions Charles Léopold Mayer, 1998. [Available from: http://www.icast.org]

[16] Denis Goulet, *Authentic Development: Is it Sustainable?*, Thaddeus C. Trzyna (ed.): A Sustainable World, ICEPP, Sacramento, 1995.