8. INDUSTRIAL ECOLOGY IN TRANSITION COUNTRIES: HISTORICAL PRECEDENT AND FUTURE PROSPECTS

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Abstract: Industrial ecology uses the structure and processes of natural ecosystems as a model for organizing industrial activities, seeking to integrate wastes and by-products into the production process thus reducing the need for material extraction and waste disposal. In this paper we discuss the theory and practice of industrial ecology as developed in the former centrally planned economies, and make observations on the suitability of industrial ecology in current transition countries. We describe the Soviet concepts of "combined production" and "waste-free technology", and show that Soviet scientists were familiar with many fundamental elements of modern industrial ecology. Although the potential environmental benefits of industrial ecology were recognized by central planners, industrial ecology was pursued primarily as a means to increase production. We then discuss issues specific to the (re) implementation of industrial ecology in transition countries, such as appropriate policy instruments, the relation between economic growth and environmental impacts, the question of central planning versus spontaneous organization of industrial interactions, the valuation of resources and environmental externalities, and the underlying goals of industry and society in the context of changing material aspirations among the populations of transition countries.

Keywords: industrial ecology; transition countries; by-products; central planning; market economy; Soviet Union; environmental protection; production; consumption

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1. The Modern Concept of Industrial Ecology

Environmental security literature in recent years has recognized dual roles for industrial production in modern society, both as a source of material welfare as well as a cause of ecological stress. The concept of industrial ecology is increasingly noted for its potential to reconcile manufactured abundance with minimized environmental impact (Frosch and Gallopoulos, 1989; Graedel and Allenby, 2003).

1.1. WHAT IS INDUSTRIAL ECOLOGY?

Industrial ecology is an approach to organizing industrial systems that uses natural biological ecosystems as a model. The structure and processes of natural ecosystems, including the complex interactions of organisms with each other, are used as a basis for creating industrial networks. The traditional pattern of industrial production/consumption is a linear flow, where raw materials are extracted from nature, processed in factories and used by consumers, and then disposed as waste back to the environment (Figure 1a). Industrial ecology seeks to integrate wastes and by-products back into the production process, thus reducing the demand on nature for material extraction and waste dumping (Figure 1b). This approach closes material cycles and reduces the need for raw material input and pollution output.

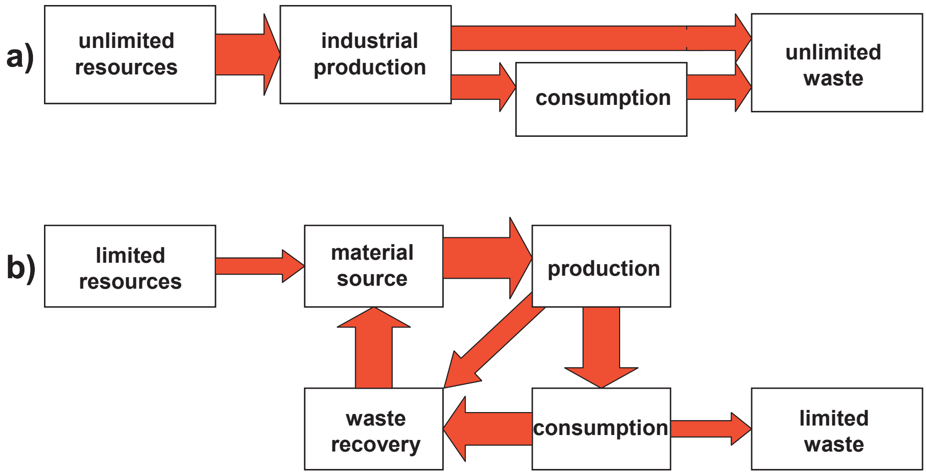

Figure 1. Material flows in (a) traditional linear industrial system and (b) industrial ecology system.

A key component of industrial ecology is the exchange of by-products or waste material among different firms for mutual economic and environmental benefit. In such a case, one enterprise gains by having ready access to a needed raw material, and the other benefits by either reducing waste disposal costs or increasing revenues. Ceteris paribus, the environmental impact is lower if the first enterprise extracted virgin material and the other released its waste into the environment. This integration and optimization of material and energy flows of industrial activities avoids the creation of pollutants rather than polluting first and then cleaning up.

Industrial ecology is often expressed as a symbiosis where groups of Industries work collaboratively through exchanges to reduce total natural resource consumption while simultaneously increasing individual profitability. In practice, it is best implemented in “eco-industrial parks”, which build community networks of industries that interact by sharing utility inputs and making use of each other’s by-products. There are numerous successful examples of industrial ecology in Europe, North America, and elsewhere.

1.2. EXAMPLE OF MODERN INDUSTRIAL ECOLOGY: KALUNDBORG

The best known example of industrial ecology practice is in Kalundborg, Denmark, an industrial port city of 20,000 people. A cooperative network has developed between several industrial companies and the Municipality of Kalundborg. One company’s by-product becomes an important resource for other companies (Kalundborg Centre for Industrial Symbiosis, 2006). Resources exchanged by the firms include steam, heat, fly ash, gypsum, sulfur, and organic sludge that otherwise would have been unwanted waste (Figure 2).

Residual heat from the coal-fired Asnæs power station is recovered and used as district heating for the city of Kalundborg and as process steam for industrial production. The combination of heat and power production results in a 30% improvement of fuel utilization compared to separate production of heat and power. Approximately 4500 households in Kalundborg receive district heat from the power station. The Statoil oil refinery receives process steam and water from the power station. The steam covers about 15% of the refinery’s total consumption of steam. The refinery uses the steam for heating oil tanks, pipelines, etc. The Novozymes enzyme factory and the Novo Nordisk pharmaceutical factory use steam from the power station for the heating and sterilization of the processing plants. Some of the cooling water from the power station is used by a fish farm producing 200 t of trout and salmon per year. The fish have better growth conditions in the heated water.

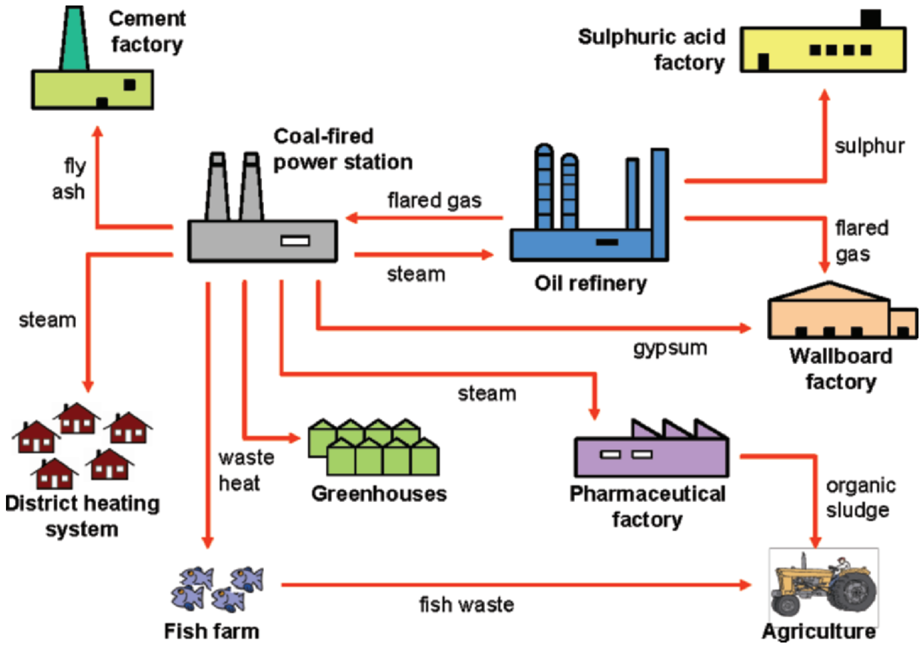

Figure 2. Material and energy exchanges in the eco-industrial park in Kalundborg, Denmark.

The desulfurization plant of the power station, which removes sulfur dioxide from the flue gas, produces about 200,000 t of gypsum per year. Desulfurization is a chemical process in which sulfur dioxide is removed while forming gypsum as a by-product. The gypsum is sold to BPB Gyproc, a company that manufactures plasterboard products for the construction industry. The gypsum from the power station significantly reduces the import of natural gypsum. Being more uniform and purer than natural gypsum, power station gypsum is therefore well suited for the plasterboard production. Gypsum recovered by the municipal recycling station of Kalundborg is also delivered to BPB Gyproc, thereby further reducing imports of natural gypsum and the amounts of solid waste for landfilling.

The power station removes fly ash from the smoke to reduce emissions to the atmosphere, thus producing about 30,000 t of fly ash per year. The ash is used in the cement industry as a cement-blending agent. The largest ash customer is Aalborg Portland. Ash deriving from the firing of orimulsion, a bitumen-based fuel, is recycled in a plant in Great Britain. Nickel and vanadium are reclaimed from this ash.

Enzyme production at the Novozymes enzyme factory is based on fermentation of raw materials such as potato flour and cornstarch. The fermentation process generates as by-products about 150,000 m^3 of solid biomass and about 90,000 m^3 of liquid biomass per year, containing nitrogen, phosphorus, and lime. After inactivation and hygienization, local farmers use the material as fertilizer in the fields, thereby reducing their need for commercial fertilizers.

The insulin production at the Novo Nordisk pharmaceutical factory produces yeast as a residual product, which is converted into yeast slurry that is used as feed for pigs. Sugar water and lactic acid bacteria are added to the yeast, making the product more attractive to pigs. The yeast slurry replaces ~20% of the soy proteins in traditional feed mixes. Over 800,000 pigs are fed per year on this product.

The desulfurization plant at the oil refinery reduces the sulfur contents of the refinery gas leading to significantly reduced SO_2 emissions. The by-product is used in the production of ~20,000 t of liquid fertilizer roughly corresponding to the annual Danish consumption. In addition, sludge from the municipal water treatment plant in Kalundborg is utilized at Bioteknisk Jordrens Soilrem as a nutrient in bioremediation processes.

The exchange of resources between industrial companies in Kalundborg provides a number of advantages. Through recycling, the by-product of one company becomes an important resource for another company. This leads to improved economy and reduced consumption of resources, e.g., water, coal, oil, gypsum, fertilizer, etc. The overall environmental strain is reduced, including discharges of wastewater, CO_2, and SO_2. The utilization of energy resources is improved through the use of residual heat and waste gases.

2. Theory of Industrial Ecology in Centrally Planned Countries

While generally considered to be a modern, state-of-the-art concept originally popularized in a 1989 article (Frosch and Gallopoulos, 1989), the fundamental approach of industrial ecology has existed for many decades in countries with both market economies (Erkman, 1997; Desrochers, 2005) and centrally planned economies (Sathre and Grdzelishvili, 2006). In this section we discuss the theoretical development of industrial ecology in the former centrally planned states, drawing information from original documents in Russian as well as international scientific literature.

2.1. REVIEW OF PREVIOUS LITERATURE

Several authors have noted the parallels between particular aspects of industrial ecology and the structure of industry in centrally planned economies. Erkman (2002), in an overview of the recent history of industrial ecology, acknowledged that examples of industrial ecology-like thinking existed in the former

Soviet Union, particularly in the areas of resource and waste optimization, but did not describe or document this in detail. Hewes (2005), in a study of the social relations and initiatives required for the successful development of eco-industrial parks, described examples of industrial symbiosis that existed in Soviet Ukraine, as well as efforts underway to reestablish those links within the current market economy. Gille (2000) described the establishment, implementation, and partial abandonment of elaborate mechanisms to reuse waste materials in Hungary, beginning in the 1950s and continuing to the market economy transition in the 1990s. This study shed light on the motivations, policies, and "pathologies" of industrial ecology in a centrally planned economy. Desrochers and Ikeda (2003) contrasted this Hungarian experience to historical efforts towards waste reuse in market economies, arguing that the most accurate means to determine the "least wasteful" uses for materials is through market prices that provide an index of scarcity for alternative materials and products. Sathre and Grdzelishvili (2006) provided a comprehensive overview of the theory and practice of industrial symbiosis in the former Soviet Union, upon which much of the historical information in the present paper is based.

2.2. COMBINED PRODUCTION

Soviet leaders asserted that large-scale industry would best create the material basis of a communist society (Blackwell, 1994). To increase industrial productivity, they promoted a form of industrial ecology termed "combined production" (*kombinirovanaia produksia*). A year before the Bolshevik revolution, Lenin outlined the economic benefits of combined production, a practice that he described as:

> the grouping in a single enterprise of different sectors of industry, which represents either consecutive steps in the processing of raw materials (for example, the smelting of iron ore into pig iron, the conversion of pig iron into steel, and the further manufacture of different products from steel), or cooperation between industrial sectors (for example, the utilization of waste materials or byproducts, the production of packing materials, etc.). (Lenin, 1916, p. 312)

Influenced by the directives of Lenin, Efimov and Zhukova (1969) categorized three forms of combined production in Soviet industry. They spoke first of combination through coordination of different processes of output, in which all or many of the industrial actors needed to produce a certain product are geographically proximate. An example of this is the Magnitogorsk Iron and Steel Works at which all stages of metallurgical production are located, from extraction of ores to production of rolled metal, as well as production of coke and other required inputs. Secondly, they noted combination through the complex utilization of raw materials, in which multiple finished or intermediate products are obtained from a given raw material. For example, coal, oil, or complex metal ores are subjected to various thermal and chemical processes to make usable all the elements of the input resource. Lastly, they recognized combination through the utilization of waste, which is similar to the complex utilization mentioned above, but focused on by-products of industrial processing of other principle materials. An example is the further use of wood processing residues that result from the manufacture of sawn lumber. Efimov (1968) described the advantages of combined production thus:

> Combination of production ensures the fullest possible use of raw materials and the waste left over after their primary processing, reduces investments, and raises production efficiency indices. It reduces expenses on shipments of raw materials and half-finished products, accelerates production processes, ensures utilisation of wastes, gives rise to absolutely new products and materials (synthetics, plastics, etc.) into existence, makes mining operations cheaper because it allows utilisation of poorer types of raw materials, permits fuller use of the raw materials already brought to the surface, and reduces the range of employment of organic raw materials and, consequently, the amounts spent to obtain them. (Efimov, 1968, p. 201)

Note that the benefits listed are those that increase production or decrease costs, and environmental benefits were not explicitly considered.

2.3. WASTE-FREE TECHNOLOGY

As environmental awareness began to grow in the 1970s, the Georgian scientist Davitaya (1977) perceived the analogy relating industrial systems to natural systems as a model for a desirable transition to cleaner production:

> Nature operates without any waste products. What is rejected by some organisms provides food for others. The organisation of industry on this principle—with the waste products of some branches of industry providing raw material for others—means in effect using natural processes as a model, for in them the resolution of all arising contradictions is the motive force of progress. (Davitaya, 1977, p. 102)

In Soviet theory, environmental problems had a social basis and were engendered by specific social conditions (Granov, 1980). The causes and solutions of environmental degradation depend on the social forces that prevail in society and on the interests that those forces pursue. Problems result because technology in the Western world is owned by a specific social class who use it to extract profits and enrich itself rather than benefiting society as a whole. Communism alone, according to this theory, is free of private ownership and other selfish interests and is therefore capable of finding the optimal solution to meeting the aspirations of all social strata. It was recognized, however, that:

> [u]nder socialism the urgent problems of environmental protection do arise in the course of scientific and technological progress. This happens, particularly due to the fact that the socialist countries have not yet developed the new productive forces to the desired extent, which would make the environmental pollution minimal, above all, by creating a closed-cycle, no-waste production process. (Granov, 1980, p. 93–94)

Thus closing material loops came to be seen as an ultimate solution to environmental problems, to be achieved through continued economic and technological development. This affirmation of the validity of the environmental Kuznets curve[1] allowed the continued pursuit of increased industrial production while accommodating growing concern for environmental issues. The specific approach used by Soviet scientists and engineers was termed "waste-free technology". This concept, introduced in the 1980s, shared much in common with the earlier ideas of combined production, though it placed emphasis not only on raising the indices of resource utilization but also on lowering indices of waste emission:

> Soviet policy encourages the wide use of waste-free technological processes and the introduction of effective methods for complex use of raw materials and waste. Specialists emphasise the modern scientific technological potential to transition from extensive methods of utilization of natural resources to intensive, resource-saving technologies. This transition is important because reduced waste ad waste-free technologies successfully solve problems of environmental degradation and pollution. Thus, criteria for the selection of new technologies will be not only the economic effect, but will take into account all socio-economic consequences of the incomplete use of resources. (Turkebaev and Sadikov, 1988, p. 18)

Towards this goal of industrial production with reduced environmental impact, the development of complex industrial ecosystems and the importance of a diversity of actors were acknowledged by Soviet scientists who stated that:

[1]The environmental Kuznets curve, an inverted U-shaped relationship between income and pollution, suggests that environmental degradation increases during initial stages of economic growth but then declines with further economic development.

> [t]he principle of waste-free technology cannot always be introduced in an individual enterprise, but is definitely applicable in a big industrial economic system, e.g., a territorial industrial complex with multi-sectoral structural management. Here, based on deep inter-sectoral cooperation, cyclical use of raw materials and wastes in different industries could develop. This kind of resource use offers tight interweaving of the flows of initial resources and waste materials between regional sectors of industrial and agro-industrial complexes. The ideal symbiosis of industry in the near future should be a cycle where there is no beginning and no end. (Turkebaev and Sadikov, 1988, p. 18–19)

Such progressive thought and eloquent expression would not be out of place in a journal article or conference proceedings written today by modern practitioners of industrial ecology.

3. Practice of Industrial Ecology in Centrally Planned Countries

In this section we briefly illustrate the implementation of industrial ecology techniques in command economies by presenting examples of combined production and waste-free technology in several sectors: a metallurgical facility in Ukraine, the forest products sector in Latvia, and heat cascading in many areas of the former Soviet Union. We then discuss the motivations and limitations of industrial ecology as practiced in centrally planned economies.

3.1. EXAMPLES OF CENTRALLY PLANNED INDUSTRIAL ECOLOGY

3.1.1. Metallurgy

The Nikopol manganese ferroalloy facility in Ukraine was a large electro-metallurgical production complex that included smelting, sintering, and electrode manufacturing operations, plus electricity production, transport operations, and ancillary workshops (Zubanov and Velichko, 1988). The complex produced about 1.5 million tons of slag annually, which had been simply dumped into slag piles covering previously fertile agricultural soil. This was representative of other ferrous metallurgy facilities throughout the USSR, where in total more than 75 million tons of slag was produced annually during iron and steel manufacture. A project entitled “Waste” (*Otkhody*) was implemented at the complex during the 1980s, with the stated goals of efficiently using waste materials from production, and reducing air pollution problems.

Usage of four types of waste materials – gas, dust, sludge, and slag – was pursued (see Figure 3). Blast furnace gas generated during the ferroalloy production was collected. After appropriate cleaning, the gas was used as industrial process fuel and for the heating of domestic buildings. Other by-products suitable for reprocessing were dust and sludge from the dry and wet cleaning of blast furnace gas. Sludge from the sintering plant was pelletized and returned as raw material for ferroalloy production. Some sludge was used in concrete building materials, and future plans were developed for using the sludge as an additive in the production of manganese-rich fertilizer. Scientists found that the crystallized slag had qualities of high wear resistance, heat resistance, mechanical strength, thermal stability, and dielectric character, and so was suitable for various uses. They determined four main directions for reprocessing the slag. Some was crushed and used as gravel for road construction and building foundations, ballast for railways, and aggregate for concrete. Some slag was crushed and separated, yielding a metal concentrate that included about 60% manganese. It was used in the production of ferroalloy, and also was sold as raw material containing manganese. Molten slag granulated by contact with water was used as an additive for reinforced and mass concrete constructions, for cinder blocks used as thermal insulation, and for backfilling. Lastly, "slagstone" was produced by the casting or moulding of molten slag. The key to this method was the regulation of the crystallization of slag. Slagstone products included fire blocks, refractory linings, pipes, and panels.

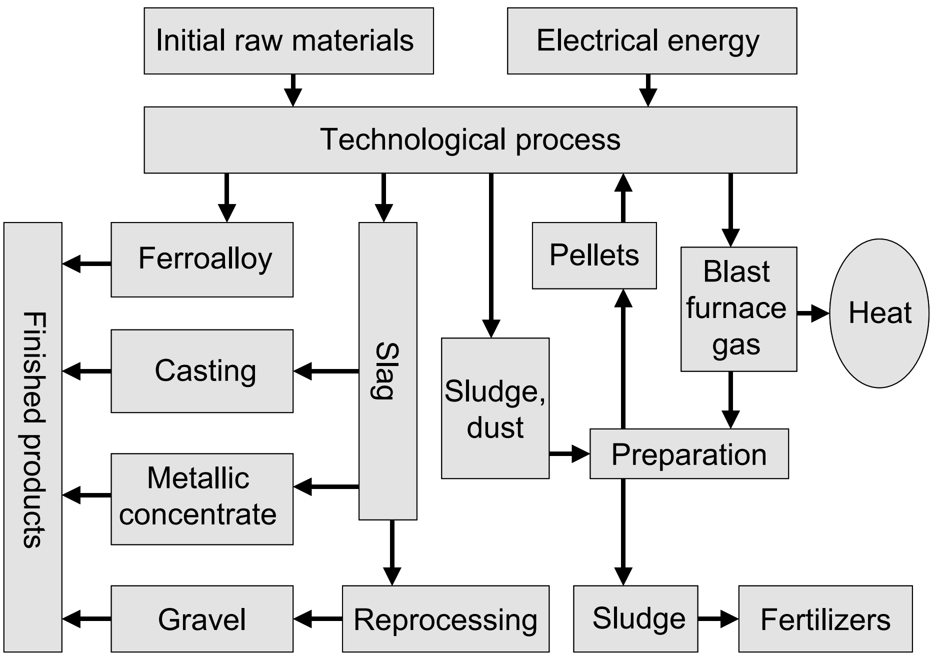

Figure 3. Schematic diagram of utilization of by-products from the Nikopol metallurgical complex in Ukraine. (Translated and redrawn from Zubanov and Velichko (1988)).

3.1.2. Forest Products

Vikulina (1983) described efforts in Soviet Latvia to increase the overall efficiency of forestry and wood processing industries. Part of this initiative involved the recovery and utilization of by-products of forestry activities. In particular, logging residues including branches, needles, and treetops, which had previously been left in the forest after the harvesting of commercial stemwood, were recovered. The potential resource available was on the order of 20 million tons annually. Uses for the logging residues included cellulose fibre for paper, vitamin flour (a feed supplement for cattle made from needle-bearing conifer twigs), and pharmaceuticals including chlorophyll carotene paste and petroleum ether.

One problem encountered was that the various components of the logging residues were mixed, reducing its suitability for specialized applications. Manual separation was slow and inefficient. Based on technology used in seed-cleaning machines in the agricultural sector, Soviet technicians developed a cyclone separator to divide the various fractions of logging residues for different uses. The lightest fractions such as needles, leaves, and twigs were used for vitamin flour and pharmaceuticals. The heavier fractions could be used for cellulose pulp production or as biofuel. Research continued on development of machinery to separate this fraction into high value pulping chips and lower value biofuel. A reported advantage of the increased efficiency of forest product use was the potential reduction in the total forest harvest needed.

3.1.3. Heat cascading

Cascading of heat resources was widely implemented in the Soviet Union in the forms of combined heat and electricity generation, and the recovery of heat from industrial processes. As early as the 1920s, power plants in Ukraine not only produced electricity but also provided hot water to heat greenhouses, fish farms, and other adjacent enterprises (Hewes, 2005). By 1975, about 29% of all electricity generated in the Soviet Union came from combined heat and power plants, operating at overall conversion efficiency of up to 70%, compared with 40% efficiency of steam plants supplying only electricity (Dienes and Shabad, 1979). The comparatively high usage rate has been partially attributed to differences in property rights between the Soviet Union and some Western countries, leading to differences in transaction costs and treatment of externalities that favor utilization of district heating, and combined heat and power (Mcintyre and Thornton, 1978).

The recovery of industrial process heat, particularly in the metallurgical sector, was widespread. The production of 1 t of ferrous metal, for example, required the heating of 100 t of water that could then be used for secondary purposes. Additional waste heat was found in slag and blast furnace gas. It is reported that 55% of recoverable heat in the metallurgical sector was utilized as a secondary resource (Efimov, 1968).

3.2. MOTIVATION FOR IMPLEMENTING INDUSTRIAL ECOLOGY

Notwithstanding the progressive theories developed by scientists in the Soviet Union and other socialist states, and despite the growing awareness of the severity of environmental problems, in practice the primary raison d'être of industrial ecology in centrally planned economies continued to increase production. Faced with growing societal demand for increased material welfare but with limited means to satisfy all demands, industrial symbiosis was part of an attempt by central planners to get by "on the cheap" (CIA, 1989, p. iii). In the Five Year Plan of economic and social development for the period of 1986–1990, Soviet Communist Party officials declared that:

> [r]esource conservation should be transformed into the main means of satisfying the growing demand in the national economy. Satisfaction of 75–80% of the growing demand for heating, energy and materials should be covered by using the resources more economically…[through]…complex use of natural and material resources, maximal reduction of losses and non-rational consumption, and wider integration of bio-resources and secondary resources into the economic circulation. (KPCC, 1986, p. 274)

It thus appears that industrial ecology was viewed by Soviet leaders as a panacea to satisfy the growing material demands of society, becoming the last in a series of proposed technological panaceas that included electrification, mechanization, chemicalization, automation, and cybernetics (Hutchings, 1976). In Soviet thinking,

> [t]echnological progress offers a possibility of making a more effective use of economic resources and of obtaining a bigger economic effect with relatively low expenditure. This creates an opportunity for substantially increasing the rates of growth of the output of consumer goods… (Efimov, 1968, p. 15)

Thus Soviet industrial symbiosis was Jevons' "rebound effect" by design – increasing the efficiency of production with the specific intent of raising total production and consumption. This illustrates the contradiction of the approach to industrial ecology as implemented in the centrally planned economies, reflecting the fundamental goals of industry and of the society it served. As the core objective was to increase material consumption (i.e., physical growth) the marginally increasing the technical efficiency of industrial processes could not eliminate environmental problems, but at best postpone them.

4. Implementation of Industrial Ecology in Transition Economies

Can the transition countries take advantage of the legacy of centrally planned industrial ecology, as they shift from a state-planned organizational structure to an industrial system planned and implemented by private firms within a policy context defined by government? In this section we seek to understand the conditions necessary for the success of industrial ecology activities, the potential obstacles to the realization of industrial production with reduced environmental impact, and how industrial ecology might be fomented in transition countries to contribute to the development of sustainable industry. The transition countries are diverse both in terms of their varied industrial and environmental experiences during the centrally planned era, as well as their more recent developmental pathways towards a market economy. Here we do not focus on this diversity, but instead highlight general themes that may be common to many of the transition countries, acknowledging that not all observations will apply to every country.

4.1. POLICY AND ECONOMIC FRAMEWORKS

4.1.1. Policy instruments to encourage industrial ecology

As discussed above, the actual environmental performance of centrally planned industry was less than optimal, in spite of progressive theoretical considerations. Furthermore, the complex intersectoral linkages mandated by central planners were dissolved by the collapse of the command economies, resulting in industrial disruption (Oldfield, 2000). Today, significant improvements in the environmental performance in transition economies can result from improved resource management and technological modernization linked to new organizational arrangements. An appropriate environmental policy framework, if enforced rigorously, can encourage investment and operational decisions to incorporate environmental consideration (OECD, 2000). Much attention is currently focused on the management and policy aspects of industrial ecology, seeking to develop appropriate interorganizational and intraorganizational structures (Korhonen et al., 2004). In transition countries, such structures fulfill the roles that were previously played by central planners and state enterprises.

A policy framework to promote industrial ecology can include various types of instruments including regulatory, economic, and information sharing (OECD, 1999). Regulatory or legal instruments including environmental standards should encourage continual improvement rather than formalistic compliance. Current environmental legislation in most transition countries provides incentives for end-of-pipe techniques, rather than process changes and intersectoral integration that characterize industrial ecology. One example of legislation that favors industrial symbiosis is umbrella licensing, which implies licensing a group of firms instead of a single firm (Eilering and Vermeulen, 2004). The umbrella license establishes a ceiling for the various forms of environmental burdens such as emissions to air or water, within a geographic area covered by the license. Within the area, the licensed firms agree amongst themselves, the most efficient way to collectively obey the limits, which may involve exchanging or selling emission rights between the firms covered by the umbrella license.

Economic instruments applied by governments can also play important roles as incentives or as deterrents (OECD, 1999). The phasing out of subsidies that encourage the inefficient use of energy, water, and raw materials can lead to both environmental and economic benefits. Measures to create incentives for enterprises to adopt industrial ecology, e.g., research and development schemes and soft loans, could be used.

An open flow of information on the causes and potential solutions to environmental degradation can facilitate the implementation of industrial ecology (OECD, 1999). Efforts to improve communication within the industrial sector can increase the local knowledge of opportunities for effectively closing material cycles. Raising public awareness of environmental issues in general, and impacts caused by industry in particular, can stimulate the implementation of cleaner production techniques. This is especially relevant in the context of consumer decisions informed by a government-administered environmental labeling system for consumer products (Banerjee and Solomon, 2003).

4.1.2. Economic requirements in transition countries

The successful implementation of industrial ecology is more likely under conditions of a stable economy, reliable cooperation between companies, predictable supply of industrial inputs, and uniform and transparent environmental regulations (OECD, 1999). Industry in transition countries is undergoing a shift from centrally planned interaction to self-organization of industrial actors. More generally, the role of government in representing environmental interests' vis-à-vis economic agents and interests is shifting. This is a question of public versus private responsibility for pollution emission and resource depletion, as well as involving more mechanical issues of availability of knowledge for effective decision making (Sathre and Grdzelishvili, 2006).

In principle, market economies are coordinated by the flow of price information, and decisions on industrial activities are made individually by market agents. In contrast, economic decisions in command economies were made centrally, with industrial activity being coordinated by central authorities. Waste products of one enterprise, which in a market economy might be valued and used by an adjacent enterprise, may simply have been discarded by a factory manager obeying material flow decisions made by distant planners who were unaware of the local conditions (Åhlander, 1994). Thus the specific knowledge of by-product availability and potential usage may be locally available, but the authority and decision making in centrally planned economies was distant, a point also raised by Desrochers and Ikeda (2003).

Different levels of decentralization in the transition countries affect the outcome of economic measures and their impact on industrial restructuring. For example, it is often considered that the Czech Republic, Hungary, Poland, and the Baltic countries have been the more active reformers in many key aspects of intergovernmental fiscal relations (Dabla-Norris, 2006). Many other countries including Russia and some Central Asian states still need substantial reforms of the incentive structures that govern intergovernmental fiscal relations in order to obtain an efficient and well-functioning multitier system of government. The current movement towards democratic forms of governance is a means of increasing democratic participation in the decision-making process, thereby enhancing accountability and transparency of government actions.

Nevertheless, market conditions in transition countries are not always favorable for the implementation of industrial ecology activities (OECD, 1999). In the transition from a centrally planned economy to a market economy, many enterprises struggle for survival, facing unpredictable markets for their products. The level of production is difficult to predict, making it difficult to assess the needs for inputs and the availability of by-products.

4.2. PRIORITIZING INDUSTRIAL ECOLOGY

4.2.1. Valuation of resources and environmental externalities

Environmental damage that took place in the past in transition countries is now widely acknowledged, as is the continuing environmental disruption in many of these countries. However, populations generally consider environmental damage a secondary problem compared to the other hardships of the transition period such as high inflation, persistent unemployment, lessened social cohesion, financial arrears, adverse terms of international trade, and political instability (OECD, 2000). Due to such conflicting priorities, the measures implemented by other policy sectors, for example, economic policy and agriculture policy, often work contrary to environmental policy (Glasbergen, 1996).

One way this is manifested is the pricing or valuation of natural resources and external costs related to industrial activities. The use of economic principles to guide the efficient allocation of scarce resources depends on the existence of appropriate measures of value. In the command economies, central planners developed nonmarket methodologies to assign values to natural resource deposits and products (Thornton, 1978). This method has been criticized for inefficient allocation contributing to environmental degradation (e.g., Goldman, 1972). Near the collapse of the Soviet Union, Soviet scientists admitted that:

> [b]ecause of economic growth, there are also increasing problems with the utilization of waste materials. But in solving this utilization problem, there appears a negative side of the existing economic stimulation system of industry. Usually, industries seek immediate reduction of expenses, are not interested in complex use of raw materials, and do not take environmental damage into account. The negative influence of people on the environment is growing, and in some regions it has passed a critical point. (Turkebaev and Sadikov, 1988, p. 8)

The *Metodika* guidelines were adopted in 1987 by the former USSR State Committee for Environmental Protection, in an effort to calculate the true costs of environmental damage (OECD, 2000). The approach of the *Metodika* was to aggregate different pollutants into standard units and to assign economic value to a unit of aggregate pollution. The national guidelines used specified conversion coefficients to convert metric tons of emissions into "standard" tons of emission, based on epidemiological data on the relative harm caused by pollutants, emission source location, height of pipe, speed of emissions, and climatic conditions.

The significance of the choice of valuation method is illustrated in an example comparing the estimates of environmental damage costs as calculated by the *Metodika* and the OECD-recommended methodology based on dose-response function. As part of the analytical work to define priority environmental actions in the Regional Environmental Action Plan, a team of Russian and international specialists assessed the cost of environmental damages from pollution. The results for three major air pollutants are shown in Table 1. The Russian methodology consistently undervalued the cost of environmental damage.

Nevertheless, market-based industrial systems have also been criticized for lacking appropriate valuation of natural resources and environmental externalities. In the practice of modern resource economics, the "optimal" use of environmental resources and the most "efficient" level of pollution can be consistent with environmental unsustainability (Ekins, 1996). Environmental externalities, which were belatedly recognized by Soviet authorities as detrimental to social

TABLE 1. Estimates of rates of health damage from air pollutant emission in Sverdlovsk Oblast, using the *Metodika* methodology and the OECD-recommended methodology. (From OECD, 2000)

Damage (thousands of dollars/t)	OECD method	*Metodika*
Particulates	5	0.2
Lead	123	13
SO_2	0.2	0.1

well being (Goskompriroda, 1989), are potentially significant in modern industrial systems as well. Other valuation issues include intergenerational equity questions linked to discount rates choices, intragenerational equity based on the ability to participate in the market economy, and differentiation of nonrenewable and renewable resources. For these reasons it has been argued that, while the centrally planned system lacked appropriate short-term to medium-term signals to properly allocate natural resources, the market-based industrial system may lack the necessary signals to properly allocate resources in the medium to long term (Sathre and Grdzelishvili, 2006).

4.2.2. Levels of production and consumption

Possibilities of optimizing industrial processes and systems are limited if overall levels of consumption are not addressed, with consideration of the underlying goals of industry and of the society it serves. Consumption level is a critical issue, particularly in the context of evolving material aspirations of the populations of transition countries. Shevchenko (2002) observed the changing consumption patterns in Russia during the transition from state socialism to a market economy. Parallel to the dramatic increase in availability of consumer goods, numerous socioeconomic factors encouraged a rise in consumption. These include the use of goods as a form of investment and savings in the face of unstable currency valuation, a form of insurance in case of future supply disruption, and the purchase of security equipment as a response to uncertain police protection. The introduction of a market economy has led to increased car transportation causing urban air pollution, and rapidly increasing waste production by households (Pavlínek and Pickles, 2004).

A significant increase in overall consumption levels has the potential to trivialize marginal increases of production efficiency gained through industrial ecology. This can be represented by the well-known equation

$$I = P \times A \times T$$

where I is environmental impact, P is population, A is affluence (or per capita consumption), and T is the effect of technology. Industrial ecology activities improve the efficiency of technology, T, allowing reduced environmental impact for a given production level. If, however, per capita consumption is simultaneously increasing, the total environmental impact may rise or remain unchanged. It is acknowledged that population change will also affect the outcome of the equation, a significant issue in some transition countries.

Thus the contribution of industrial ecology to societal sustainability will depend not only on the technological increases in resource use efficiency gained within the production sphere, but also on the extent of overall production and consumption within the context of societal metabolism.

5. Conclusions

Here we have outlined the theories of industrial ecology as developed under centrally planned economies, and presented brief examples of combined production and waste-free technology as practiced in the former Soviet Union. We find that elements of industrial ecology were appreciated and practiced from the early years of the Soviet Union and other command economies. By the time of the collapse, industrial ecology was viewed by central planners as an important approach to increase industrial efficiency. Soviet theories of Industrial symbiosis were well developed, and included such elements of modern industrial ecology as the analogy between natural ecosystems and industrial ecosystems, and the benefits of having a diverse range of actors within an industrial ecosystem. However, while the potential environmental benefits of industrial ecology were eventually recognized and valued, central planners pursued industrial ecology primarily as a means to increase production.

In the transition countries today, the potential exists to integrate the modern environmentally focused technologies of Western countries together with the extensive practical industrial experience of the centrally planned era. Large-scale eco-industrial parks could be created based on existing infrastructure, by extending cooperative links between individual facilities (Coyle, 1996). Perhaps the implementation of industrial ecology seems unrealistic in the current climate of economic fragility, persistent unemployment, and political instability experienced in many transition countries. However, as the industrial systems in the transition countries are (re)developed in the coming years, it appears beneficial to incorporate industrial ecology practices for both economic and environmental benefits (Grdzelishvili and Sathre, 2005).

Rehabilitation of industrial infrastructure in a way that encourages efficient utilization of material and energy resources is a timely and appropriate task for transition countries needing to build flexible, vibrant economies while protecting natural heritage. Industrial ecology is a progressive framework that guides the structuring of industrial activities to provide needed materials and services while minimizing impact on the environment. While industrial ecology is not a technological panacea that allows unlimited, eco-friendly production, it could be one element in a larger strategy of transforming society's production and consumption patterns toward more sustainable forms.

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