Industrial symbiosis in the former Soviet Union

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Abstract: In this contribution we discuss the context, theory and significance of industrial symbiosis in the former Soviet Union, drawing information from original documents in Russian as well as international scientific literature. We describe the Soviet concepts of 'combined production', present from the earliest years of the Soviet Union, and 'waste-free technology', introduced in the final decades before collapse. We show that Soviet scientists were familiar with such elements of modern industrial ecology as the analogy between natural and industrial ecosystems, and the need for a diverse range of actors within an industrial ecosystem. Although the potential environmental benefits of industrial symbiosis were eventually recognised, Soviet planners pursued industrial symbiosis primarily as a means to increase production. We provide examples of Soviet implementation of industrial symbiosis in various industrial sectors. We then discuss strengths, weaknesses, possibilities and limitations of Soviet industrial symbiosis, and draw possible lessons for modern industrial ecology.

Keywords: industrial symbiosis; Soviet Union; central planning; environmental impact; recycling; combined production; waste-free technology; industrial ecology; history.

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1 Introduction

The integration and optimisation of the material and energy flows of industrial activities have potential environmental and economic benefits (Graedel and Allenby, 2003). One way that this can be realised is through industrial symbiosis, defined here as 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 than if the first enterprise extracted virgin material and the other released its waste into the environment. It is recognised that this insight into mutual benefits is not new, but has existed for decades (Erkman, 1997) or longer (Desrochers, 2005).

Several authors have noted the parallels between particular aspects of modern industrial ecology and the structure of industry in the former Soviet Union. Johansson (1997) mentioned Soviet industrial symbiosis as a bad example of industrial ecology, because of its economic failure in spite of its technical potential. 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 optimisation, but did not describe or document these 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 re-establish 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. Although not specific to the Soviet Union, this study shed light on the motivations, policies and ‘pathologies’ of industrial symbiosis in a centrally planned economy. Desrochers and Ikeda (2003) contrasted this Hungarian experience to historical efforts towards waste reuse in market economies. They argued 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. In this view, central planners have lacked the nuanced knowledge needed to implement successful industrial symbiosis.

The present paper contributes to this growing literature on the successes and failures of industrial symbiosis in the former communist states. We draw on original Soviet-era documents written in Russian, as well as other works from the international scientific literature, to describe certain elements of the context, theory and practice of Soviet industrial symbiosis. This paper explores the industrial production system in the Soviet Union prior to the political and economic collapse in 1991. For readers interested in the industrial and environmental performance during the transition from centrally planned to market-driven economies, we recommend Oldfield (2000), Gille (2000), Coyle (1996) and Mont *et al.* (1999).

2 Soviet theories of industrial symbiosis

To understand the conditions under which industrial symbiosis could develop in the former Soviet Union, it is instructive to view technology and industry within the context of Soviet societal development. In contrast to other countries such as Japan or the USA, for which industrialisation was a single (albeit important) phase of a longer developmental pathway, the Soviet Union was partially defined precisely in terms of its industrialisation. When the Soviet Union was created, Russia and most other eventual Soviet republics were largely non-industrialised societies with peasant economies (Blackwell, 1994). Industrialisation played a central role in the mental construction of the new Soviet state. Lenin (1920, p.419), in stating that "Communism is Soviet power plus the electrification of the whole country", presented his supreme goal – communism – not in economic terms but primarily in political and technological terms (Hutchings, 1976). Electrification was, however, only the first in a series of technological panaceas that Soviet leaders pursued. Later ones included mechanisation, chemicalisation, automation and cybernetics. In this light, Khrushchev (1963) later updated Lenin's formula by saying that "Communism means Soviet power plus the electrification of the whole country, plus the chemicalisation of the economy".

Lenin and other leaders asserted that large-scale industry would best create the material basis of a communist society. To increase industrial productivity, they promoted a form of industrial symbiosis termed 'combined production' (*kombinirovanaia produksia*). A year before the Bolshevik revolution, Lenin (1916) outlined the economic benefits of combined production, a practice 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 by-products, the production of packing materials, *etc.*)." (p.312)[1]

Influenced by Lenin's directives, Efimov and Zhukova (1969) categorised 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 was the Magnitogorsk Iron and Steel Works at which all stages of metallurgical production were 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 utilisation 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 recognised combination through the utilisation of waste, which is similar to the complex utilisation 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." (p.201)

Note that the benefits listed are those that increase production or decrease costs, with no emphasis given to the potential environmental benefits that may result. As environmental awareness began to grow in the 1970s, however, 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." (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 recognised, 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, pp.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 what would later be labelled the environmental Kuznets curve[2] 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' (*bezotkhodnoyi tekhnologii*). This concept, introduced in the late 1970s, shared much in common with the earlier ideas of combined production, though it placed emphasis not only on raising the indices of resource utilisation 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 and 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 diversity of actors were acknowledged by Soviet scientists who stated that:

> "[t]he principle of waste-free technology cannot always be introduced in an individual enterprise, but is definitely applicable in a large industrial economic system, *e.g.*, a territorial industrial complex with multi-sectoral structural management. Here, based on deep inter-sectoral cooperation, the 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, pp.18–19)

Notwithstanding these progressive considerations, and despite the growing awareness of the severity of environmental problems, in practice the primary *raison d'être* of Soviet industrial symbiosis continued to be 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, 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 bioresources and secondary resources into the economic circulation." (KPCC, 1986, p.274)

It thus appears that industrial symbiosis had become the last of the technological panaceas designated by Soviet leaders to satisfy the material demands of society. With the collapse of the Soviet Union in 1991, the economic integration of the Soviet republics was dissolved, and overall industrial activity declined substantially (Oldfield, 2000). A lasting legacy remains in the physical infrastructure created during decades of combined production practices. It is unclear, however, to what extent the current industrial production in the former Soviet republics continues to benefit from its heritage of industrial symbiosis.

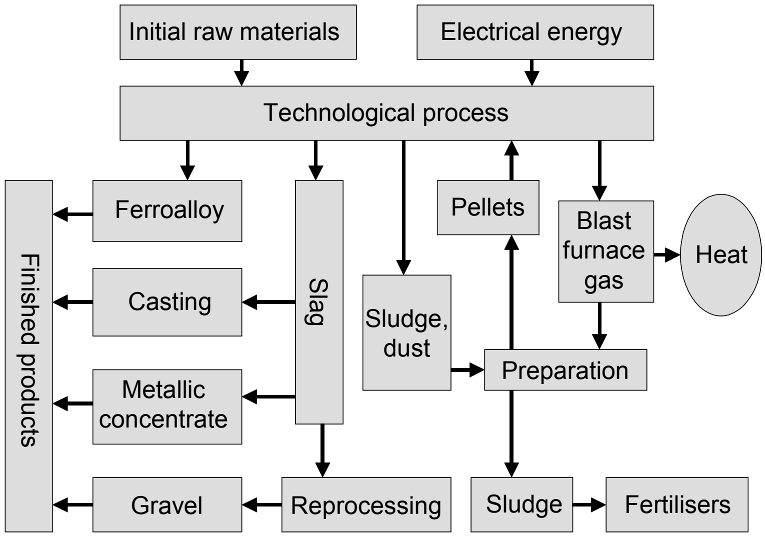
3 Examples of Soviet industrial symbiosis

We briefly illustrate the implementation of industrial symbiosis techniques in the Soviet Union by presenting examples of combined production and waste-free technology in several sectors: a metallurgical facility in Ukraine, mining activities in Kazakhstan, the forest products sector in Latvia, and heat cascading in many areas of the Soviet Union.

3.1 Metallurgy

The Nikopol manganese ferroalloy facility in Ukraine was a large electrometallurgical 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 tonnes 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, wherein a total of more than 75 million tonnes of slag were produced annually from 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 1). 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 pelletised 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 fertiliser. Scientists found that the crystallised 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' (*shlakokamennoe*) was produced by the casting or moulding of molten slag. The key to this method was the regulation of the crystallisation of slag. Slagstone products produced included fire blocks, refractory linings, pipes and panels.

Figure 1 Schematic diagram of the utilisation of wastes from the Nikopol metallurgical complex in Ukraine



Source: Zubanov and Velichko (1988), translated and redrawn by the authors

3.2 Mining

Mining was a major industrial sector in Kazakhstan during the Soviet era, and continues to be so. Kazakh miners extract coal, iron, manganese, chromium, nickel, cobalt, copper, molybdenum, lead, zinc, bauxite, gold and uranium, as well as petroleum and natural gas. Turkebaev and Sadikov (1988) described the traditional mining techniques in Soviet Kazakhstan that resulted in only about 50% recovery of useful mineral resources, owing to the incomplete use of technological processes for minimising loss, and the lack of sufficient systems for accounting, control and responsibility for the use of natural resources. They suggested that an additional 25% could be recovered through the use of a more comprehensive mining approach that included secondary processing to extract co-occurring resources (termed 'hitchhiker resources' by Graedel and Allenby (2003)). To increase the efficiency of overall resource use, Soviet scientists in Kazakhstan recommended this sequence of methods for the rational complex use of mineral materials:

1 "Effective extraction of crude ores and by-products

2 Development of technologies for maximal extraction of the main components of ores

3 Comprehensive study of all substances contained in the ores

4 Determination of the value of these substances and the technological possibilities of their extraction

5 Assessment of substances that cannot be technologically extracted, but are significant components of the ores

6 Balanced characterisation of all types of wastes that are generated

7 Complex evaluation of the influence of the wastes on the environment.” (Turkebaev and Sadikov, 1988, pp.8–9).

An example of the potential implementation of this process is the Jezkazgan region where about 17 useful mineral elements were said to exist, only 12 of which were exploited. Through the secondary processing of the materials that were dumped as mine tailings, additional resources of cadmium, selenium, tellurium, bismuth and nickel could also be economically extracted. Another example is the Shalkiya region, where during the primary process of mining for zinc, cadmium, gallium and silver, the overburden would have been suitable for use as aggregate for concrete and asphalt.

3.3 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 utilisation 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 tonnes 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 specialised 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.

3.4 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 an 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 favour utilisation 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 one tonne of ferrous metal, for example, required the heating of 100 tonnes of water that could then be used for secondary purposes. Additional waste heat was recovered from slag and blast furnace gas. It is reported that 55% of recoverable heat in the metallurgical sector was utilised as a secondary resource (Efimov, 1968).

4 Discussion: lessons for modern industrial ecology

What can current practitioners of industrial ecology learn from the historical experiences of the now-defunct Soviet industrial organisation? Given the collapse of industrial activities that occurred at the break-up of the Soviet Union, it can be said that Soviet industry ultimately failed to achieve a fundamental goal of industrial organisation, which is to satisfy the societal demand for material goods. Many economic and political factors contributed to the collapse of the Soviet Union, making isolated conclusions about industrial effectiveness difficult. Soviet efforts at industrial symbiosis, in spite of their primary aim of allowing higher production at lower cost, were by themselves insufficient to make Soviet industry economically tenable over the long term. Furthermore, given the severity and extent of environmental problems resulting from industrial activities in the Soviet Union, reported by both official Soviet sources (*e.g.*, Goskompriroda, 1989) and by Western sources (*e.g.*, Peterson, 1993), it can be concluded that the secondary aim of Soviet industrial symbiosis of reducing the environmental impact from industrial activities was also a failure.

Several issues can be explored as we seek to understand both the positive and negative aspects of industrial symbiosis in the Soviet Union, and how they contributed to the initial development as well as to the eventually unsuccessful transition to sustainability of Soviet industry. One important question is that of central planning versus spontaneous organisation of industrial interactions, and more generally, the role of government in representing environmental interests *vis-à-vis* economic agents and interests. On one level, this is a question of public versus private responsibility for waste and pollution, and intrinsically linked to the issue of property rights. On another level it involves more mechanical issues of availability of knowledge for effective decision-making. 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 the Soviet Union 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 Soviet 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).

It might be argued that centralised planning was an effective organisational method during the early phase of industrialisation in the Soviet Union, when natural resources and environmental services were relatively unlimited. In that phase, the management of capital to create industrial infrastructure and the focusing of industrial labour efforts were necessary to develop industrial production systems, and central planning techniques accomplished this goal arguably as well as free-market techniques in Western countries did. However, during the later phase of development when natural resources and environmental services had become limited, central planning lacked the finesse and fine-scale knowledge of local conditions needed to effectively use resources.

This issue of approaching environmental limits inevitably raises the deeper question of the goals of industry and of the society it serves. If the core goal is to increase material consumption (that is, physical growth), then marginally increasing the technical efficiency of industrial processes will not eliminate environmental problems, but at best postpone them. 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 resource utilisation with the specific intent of raising total production and consumption. This is in contrast to the modern concept of industrial ecology, which focuses on reducing the overall environmental impact caused by industrial activities. "The analytic question [in IE] is straightforward: which configuration leads to the lowest level of environmental damage at a given level of economic output?" (Chertow, 2000, p.331). The importance of the magnitude of the 'given level of economic output' is gaining in appreciation in modern thinking (*e.g.*, Herring and Moezzi, 2004; Hertwich, 2005). Such appreciation was lacking in Soviet thought, which remained production-centred.

Framed in terms of the ecological modernisation debate (Huber, 2000), Soviet industrial organisation was not oriented towards *sufficiency*, in which production and consumption is intentionally limited to harmonise with ecological limits. Soviet production was instead oriented towards *efficiency*, by applying principles of input-output rationalisation to increase specific resource productivity. The Soviet system made no attempt at *consistency*, which would have resulted in industrial material flows and energy use of an environmentally compatible nature. It remains to be seen whether the modern industrial system of production and consumption will achieve sustainable development through ecological modernisation, and what role industrial symbiosis may play. As in Soviet industry, modern efforts at industrial symbiosis focus mainly on increasing the efficiency of use of materials and energy. The industrial network at Kalundborg, for example, is centred around a power plant that is dependent on fossil fuel. While the technical efficiency of that system can be improved, it can never become sustainable. To reach towards that goal, it is necessary to consider which sources of energy and which types of materials are used. Various frameworks have been offered (*e.g.*, Azar *et al*., 1996) as criteria for achieving 'real' or absolute sustainability. These ideas, increasingly appreciated by modern industrial actors, were apparently not considered in Soviet theories of industrial symbiosis.

Industrial symbiosis in both its Soviet and modern forms is opportunistic, and limited by technical and economic constraints of potential interactions. The closing of material loops involving wastes and by-products, for example, is limited by the opportunities for material reuse. Gille (2000) described the accumulation of waste materials that were recovered by central decree in Hungary, but which had no further use in industry. A modern example is the emission of carbon dioxide as a waste of fuel combustion and process reactions. Existing uses for carbon dioxide as an industrial input are very limited compared to the quantities available, thus the excess is released into the environment. Thermodynamic principles suggest that joint production of unwanted output is an unavoidable consequence of the production of wanted goods (Baumgärtner *et al.*, 2001). This limitation ultimately restricts the potential of industrial symbiosis to *eliminate* environmental impact, although scope remains to modify industrial processes and interactions to *reduce* impacts.

The issue of pricing or valuation of natural resources and external costs is important in both Soviet and modern systems. The use of economic principles to guide the efficient allocation of scarce resources depends on the existence of appropriate measures of value. In the Soviet Union, central planners developed non-market methodologies to assign values to natural resources and products (Thornton, 1978). This method has been criticised 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 environmental is growing, and in some regions it has passed a critical point." (Turkebaev and Sadikov, 1988, p.8)

Modern industrial systems have also been criticised for lacking appropriate valuation of natural resources and environmental services. 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 recognised by the Soviet authorities as detrimental to social well-being (Goskompriroda, 1989), are potentially significant in modern industrial systems as well. Other valuation issues include inter-generational equity questions linked to discount rates choices, intra-generational equity based on the ability to participate in the market economy, and differentiation of non-renewable and renewable resources. For these reasons it might be argued that, while the Soviet system lacked appropriate short- to medium-term signals to properly allocate natural resources, the modern industrial system may lack the necessary signals to properly allocate resources in the medium- to long term.

Industrial symbiosis, in both its Soviet and modern forms, is an incomplete representation of material and energy flows, to the extent that consumers and consumption are omitted. In a natural ecosystem, producers, consumers and recyclers all play important roles in material cycling. By practising industrial symbiosis, by-products and wastes from the production process are more efficiently utilised by passing them on to other producers, while a significant proportion of the total material flow leaves the system in the form of finished products. To effectively close material cycles, post-consumption recycling must also be addressed. Anecdotal evidence suggests that, for example, reuse of beverage containers and household recycling of paper and metals were relatively widespread in the Soviet Union. Additional research is needed, however, to allow conclusions on material flows outside of the industrial sectors.

5 Conclusion

Here we have outlined the context and theories of Soviet industrial symbiosis, and presented brief examples of combined production and waste-free technology as practised in the former Soviet Union. We find that elements of industrial symbiosis were appreciated and practised from the early years of the Soviet Union. By the time of the collapse, industrial symbiosis was seen by Soviet leaders 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 symbiosis were eventually recognised, Soviet leaders pursued industrial symbiosis primarily as a means to increase production.

While it must be concluded that the Soviet endeavour was a failure, both in economic and environmental terms, it may be possible to learn from that failure. Experience indicates that the availability of current, local information on industrial process integration possibilities, as well as the institutional motivation to action, influence the success of the symbiotic venture. This is relevant to the question of an organisational strategy to encourage spontaneous local exchanges or to mandate centrally planned exchanges. Acknowledging the environmental impacts resulting from industrial production is a necessary, but insufficient, step towards sustainable industry. A critical issue appears to be the definition of goals, and not only the methods employed to achieve those goals. The integration of a respect for ecological principles into the economic mechanisms used to guide production and consumption decisions appears to be necessary. Consideration of material and energy flows beyond the industrial production sectors may allow a more complete understanding of overall environmental impact and the scope for its reduction.

Industrial symbiosis is not a technological panacea that allows unlimited, eco-friendly production, but could be one element in a larger strategy of transforming society's production and consumption patterns towards more sustainable forms. In such a context, industrial symbiosis has the potential to play a more valuable role over a longer time period than it did in the former Soviet Union.

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Notes

1 This and most of the following quotations are from sources written in the Russian language. They have been translated into English by the authors.

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