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Industrial Symbiosis

**Current understandings and needed
ecology and economics influences**

Industrial ecology, and specifically industrial symbiosis, are tools for the promotion of environmental sustainability that sit at the intersection of engineering, ecology and economics. These three fields are of particular importance in today's world. Consider that engineering advancements have shaped human society and planet earth in unprecedented ways in the last 200 years, and the incredible infrastructure on which Western lifestyles are dependent. Consider the pressing environmental concerns the ecology has helped reveal and explain. Consider the current economic situation of repeated recession and governmental bankruptcy. Situated at the intersection of these issues, industrial symbiosis has significant potential as a tool for creating solutions. This essay argues that to realize this potential, a greater effort must be made to incorporate ecological and macro-economic knowledge and considerations into the discussion and development of industrial symbiosis practices and policy.

Industrial ecology (IE) is an interdisciplinary field seeking to understand and address the impacts of industrial systems on the environment by using a systems approach. IE offers a new conceptual framework for analyzing the physical, chemical and biological interactions between industrial and ecological systems [1]. Championed as the “science of sustainability”, this framework allows for a deliberate and rational approach to sustainability in a context of continued economic, cultural, and technological evolution [2]. This conceptual framework is informed by the analogy between natural ecosystems and industrial systems. The concept of *industrial metabolisms* is fundamental to IE, and refers to the flow, transformation and dissipation of energy and materials in industrial systems.

IE is concerned with changing industrial systems from linear, open systems to cyclical, closed systems [1].

Industrial ecology operates at three different levels: the global level, the interfirm level, and the individual facility level. The interfirm level is the focus of this work, as this is the interface between the global issues and the practical considerations. IE has developed several models and terminologies for interfirm relationships, including eco-industrial parks, industrial symbiosis, islands of sustainability, industrial recycling networks, and by-product synergies [3]. While these terms are highly interconnected, industrial symbiosis most closely captures the analogy to natural systems inherent to IE, and is a powerful aspect of the IE framework¹. An *industrial symbiosis* is defined as multiple firms from traditionally separate industries acting collectively in order to gain competitive advantage, typically through the physical exchange of energy and resources (materials, water, by-products) [4]. While traditional definitions focus on resources optimization among collocated companies [3], the collective activities need not be confined to energy and resource sharing, and can include sharing employee training and environmental monitoring systems [2].

In the IE literature, the term *symbiosis* is understood as the concept of biological symbiotic relationships in which two unrelated species coexist by exchanging energy, materials, or information to mutual benefit [4]. However, this is a misappropriation of the term from ecology, where it simply refers to “intimate relationships among species”, in contrast to competition or predation [5]. To use the ecology

¹ For a discussion of how these terms are related, see section 2, “Definition of Industrial Symbiosis and Related Terms” in [6]

terminology correctly, IE is interested in the formation of *mutualisms* (all parties benefit) or *commensalism* (one party benefits without harming the other), but not the formation of *parasitism* (one party benefits by harming the other) [5]. All three of these relationships are considered *symbioses*, and if IE is dedicated to the core analogy of natural ecosystems, its practitioners should use the terminology of ecology correctly.

The specific nature of the relationships between firms participating in an industrial symbiosis can take many forms. Van Berkel has classified them as follows: “synergies within a single supply chain, synergies from shared use of utilities, and synergies from local use of by-products,” energy, or waste [6]. With these exchanges in mind, it is easy to see the possibilities for both economic and environmental benefits. The economic benefits can include reduced waste management; by-product exchange, including purchasing goods below market price; reduced infrastructure costs; improved process efficiency; and the benefits of cooperative ventures like joint purchasing and disaster response [2]. It is the author’s opinion, however, that the benefits stemming from cooperative ventures should not be considered a direct benefit of industrial symbiosis, as they are merely encouraged or enabled by the closer interfirm relation created by the industrial symbiosis, and do not stem from the concept and goals of industrial symbiosis as it is expressed in the literature. The environmental benefits can include reductions in greenhouse gas emissions; reduction of air emissions and other pollution; improved energy; material, and energy efficiency; improved land use planning; green space development within industrial complexes; and the promotion of pollution prevention and recycling programs. Again, the author would

argue that the last three benefits are a direct outcome of industrial symbiosis. These benefits arise from a culture of sustainability that includes industrial symbiosis, but to realize these benefits, fields outside of typical industrial symbiosis efforts, such as urban planning, local governance and conflict resolution, are required.

There are many examples of industrial symbiosis. The idea originates from an industrial district in Kalundborg, Denmark [2]. Currently 20 exchanges are taking place between the main players, which includes a 1037 MW coal power plant, an oil refinery, a biotechnology and pharmaceutical company, as well as a soil remediation company [2]. The industrial district has reduced waste generation by 2.9 million tons per year, and water consumption by 25%. The district also supplies heat to 4500 local homes, and the synthesis includes the inter-municipal water waste treatment company [2]. The main exchanges include water, heat, steam, fly ash and scrubber sludge. Other significant examples include the symbiosis centered around the Kymi pulp and paper mill in Kouvola, Finland [7], the symbiosis around waste management companies in Chamusca, Portugal [8], and the Tianjin Technological-Economic Development Area in China [9].

There are several elements of industrial symbiosis. These include loop closing, co-generation, input/output matching, life cycle design and perspective, and industrial inventories, all of which are discussed in detail in [6]. However, it is worth mentioning the concept of *cascading*, which occurs when a resource is used repeatedly in different applications [6]. Cascading most frequently occurs with water or energy, and generally means that in successive uses, the resource is of lower quality, less refined, or of lower value. It is relatively simple to make cascading economically beneficial, as it, by definition

removes the use of virgin, high-quality, expensive materials. There are obvious environmental benefits associated with using fewer virgin resources, but cascading can also reduce the deposition of waste into the environment [6]. Kalundborg uses this principle extensively. The refinery takes in surface water to use for cooling, and this water is then used in the power plant for steam production (after upgrading it to boiler-quality) [2]. This is an example of both water and energy cascading, as the plant does not need to pre-heat the water before treating it. The economic implications of this exchange have been significant, and include indirect savings such as the refinery postponing the installation of an extended wastewater treatment facility [2]. Cascading multiple uses of the same resource is an important part of any industrial symbiosis.

Another important concept worth expanding upon is that of *utility sharing*: the cooperative effort among proximate firms to source water and energy resources collectively, instead of individually or from a large central authority [6]. In the Tianjin TEDA, the TEDA Administrative Commission cross-subsidizes several infrastructure services for the firms in TEDA, including a water reclamation plant and a solid waste and energy recovery incinerator [9]. These projects are funded through a general local tax on the tenants of TEDA, which is an alternative cooperation model than seen in Kalundborg [9].

Industrial symbiosis develops in many different ways. It is interesting to note, however, that two of the most common case studies, Kalundborg and Kymi, evolved spontaneously [7, 8]. The key to their development was an *anchor tenant*, a core, stable business that motivated and encouraged the development of the industrial symbiosis. In

Kalundborg, the anchor tenant is the coal-fired power plant, and it is clear that a significant number of the exchanges occur with the power plant (see Figure 2 of [7]). In Kymi, the pulp and paper mill is the anchor tenant. Most of the plants in the system were at one point a part of the Kymi pulp and paper mill, but broke off to establish a separate business, while still providing the original service to the pulp and paper mill [8]. It would be fascinating to conduct an analysis of anchor tenants and identify key properties and attributes of firms that make good anchor tenants, and possibly industries that are well-suited to this role. This process could be informed by a comparison of existing industrial symbioses to ecosystem food webs, as well as the ecology concepts of keystone predators, trophic levels, and mutualism [10].

There has been significant work in the area of public policy and the development of industrial symbiosis [7, 8]. From a policy perspective, the identification of good anchor tenants would be useful for promoting the development of industrial symbiosis. It would allow for the creation of policy targeted at the correct industries and companies, allowing for the creation of appropriate policy without the challenges of being applied universally that has the potential to have significant environmental impact. In their analysis of the Kymi plant, Costa and Ferrao conclude that the creation of the industrial symbiosis was motivated by a desire to expand production [8]. Lehtoranta et al agree that the spontaneous formation of industrial symbioses are often motivated by economics rather than environmental concerns. In addition, these have also been the more resilient and durable symbioses [7]. It is interesting to note, however, that the economic benefits are often distributed unevenly among the players. This may be a possible advantage of the

Chinese TEDA model, where a central organizing authority is responsible to attracting foreign investment to the industrial park [9]. The presence of this 'local government' provides a useful framework for cooperation between the firms, and can remove the need for the firms to modify their normal operating procedures to participate in the industrial symbiosis. Regardless of these findings, however, Costa and Ferrao discuss the contextual factors in the development in industrial symbioses, and propose a middle-out policy approach to creating effective and durable industrial symbioses.

The opportunities for industrial symbiosis are clear. However, the author argues that substantial value can be derived from an increased dialogue between the experts of industrial ecology and those that study the natural systems that industrial ecology seeks to emulate. A discussion of a similar debate is presented in [11]. It is not clear to the author of this essay that the true driving force behind industrial ecology is protection of the environment. If that were the case, then a greater use of ecology understandings of natural systems would be present in the literature. Discussions of how ecology concepts like the intermediate disturbance theorem, biodiversity, resiliency of ecosystems, succession, and the mechanisms by which natural evolution occurs (reproduction and death cycles) impact and could shape industrial ecology and the systems it seeks to design are sorely missing (see [10] for definitions of these concepts). Further, if industrial ecology truly wants to be the "sustainability science," more discussion with concepts of macro-economics needs to take place as well. For instance, the rebound effect that results in increases in energy and material efficient resulting in more economic growth may mean that the efforts of industrial symbioses are for naught (see [12] for a discussion of the rebound effect). The

author proposes that industrial symbiosis practices can be modified to address the rebound effect and other important economic realities, but not without an increased dialogue between the industrial ecology field and economics and ecology.

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