Redefining Industrial Symbiosis

Crossing Academic–Practitioner Boundaries

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Summary

The most commonly cited definition of industrial symbiosis (IS), by Chertow (2000), has served well to foster discussion and research for more than a decade. The definition reflected the state of research and practice at the time; as both have advanced, some terms have been interpreted in substantially different ways. In this article we analyze those generally used terms for their connection to the ecological metaphor that is the root of industrial ecology, and their varied interpretations in IS research and practice over time. We then propose an updated definition intended to communicate the essence of IS as a tool for innovative green growth: IS engages diverse organizations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs and value-added destinations for non-product outputs, as well as improved business and technical processes. We posit that, although geographic proximity is often associated with IS, it is neither necessary nor sufficient—nor is a singular focus on physical resource exchange.

Introduction

Industrial ecology (IE) postulates that the industrial system can learn valuable lessons in efficiency by examining the cycling of materials and energy in biological ecosystems (Frosch and Gallopoulos 1989); industrial symbiosis (IS) applies the ecological metaphor of IE to action between firms (Chertow 2000). As practitioners with a decade of experience delivering and researching IS in ten countries, the authors have had ample opportunity to introduce IS to a variety of stakeholders: academics, practitioners, governments, businesses, and international institutions, including the World Bank, the European Commission, the United Nations (Development Programme, Industrial Development Organization, and Economic and Social Commission for Asia and the Pacific), and the Organization for Economic Co-operation and Development, which recently identified IS as a tool for systemic innovation vital for green growth (OECD 2010). Our efforts to communicate clearly about IS highlighted variations in the interpretation of what is perhaps the most prevalent academic definition of IS (Chertow 2000), and then elicited a modification by one of us shortly after (Laybourn 2006). This article reflects our own journey to define IS in a way that conveys its richness and resonates with its practitioners and diverse stakeholders. In our experience, IS is *not* essentially localized waste and by-product exchanges, nor should it be confused with agglomeration economies or industrial clusters where geographic proximity is a necessary condition. We explicitly negate the geographic proximity argument in favor of one that is rooted in innovation and networks for knowledge sharing, *resulting in*, but not driven by, improved efficiency in the use of materials.

Chertow's definition was proposed based on the knowledge of IS at the time, well before the establishment of the National Industrial Symbiosis Programme (NISP) in the United

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Kingdom, the only national, facilitated IS program free and open to all comers. Since then, IS has been "uncovered" (Chertow 2007) in many countries, and the NISP model of IS has been rolled out regionally in ten.[1] Chertow's definition has served well to foster lively discussion and debate amongst the research community, in part through varying interpretations of its terms. Having reviewed almost 100 academic papers on IS from 1989 to the present, we unpack this definition from the point of view of practice and disciplinary bias, and then propose an updated definition that reflects some of the learning in the field since 2000. A final discussion raises research questions motivated by the new definition, focusing on liberating the potential of IS from strict categorization.

Unpacking a Commonly Cited Definition of Industrial Symbiosis

The definition of IS proposed by Chertow (2000, 313) is:

> The part of industrial ecology known as industrial symbiosis engages traditionally separate industries[2] in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.

Interpretations of IS have proliferated. A number of words and phrases describing IS (not all deriving from Chertow's definition) are used inconsistently in the literature. In this section we analyze the above definition phrase by phrase, starting with a dictionary definition, and common interpretation. We then unpack the language to determine (1) its connection to scholarly literature, especially on IE and IS; and (2) the elements with less clear linkage to IS, drawing on our experience as practitioners.

Traditionally Separate

The "traditionally separate" element in IS derives from the definition of symbiosis as a partnership of dissimilar organisms (Webster 1996), and is considered key to the success of IS, although its interpretation has varied: does it refer to different sectors of the economy (industry sectors), ownership, geography (facilities), or function (activities and processes)? How should it be handled when the boundaries of companies shift over time, through mergers, acquisitions (van Berkel et al. 2009), or long-standing IS relationships?

Defining "separate" in economic classification terms—that is, industrial sectors—has proven a thorny issue (NAICS 2011),[3] although is common practice in policy where an industry's shared processes, flows, and products are deemed sufficiently similar to allow a sector-based regulatory approach (see, e.g., U.S. EPA 2009). Interpreting "separate" to refer to a synergy partner outside one's traditional supply chain raises the question of a temporal dimension to IS: as tradition changes over time, does IS? Drawing on the ecosystem metaphor, those natural species noted for symbiotic relationships (clown fish and anemone, or crocodile and plover) are not considered less symbiotic over time. The cement industry has been using alternative raw materials (ARMs) for at least 25 years (van Oss and Padovani 2002, 2003); at what point does the alternative supply chain become industry norm? Is there—or should there be—a temporal dimension to IS?

In the ecological metaphor, an industrial organism is likened to a biological organism; "traditionally separate" might thus refer to different organisms. The industrial organism's form or boundary is not agreed upon in the IS literature (van Berkel 2009): firms or companies are commonly referred to (Chertow 2000; Ehrenfeld and Gertler 1997; Frosch and Gallopoulos 1989; Jacobsen 2006; Jelinski et al. 1992), as are facilities (Graedel 1996; Jacobsen 2006) and processes (Frosch 1992; UNEP 1997), sometimes interchangeably (van Berkel 2009). According to Tibbs (1993, 6), "the identity of ecosystem players is defined in process terms," which supports specifying functions like scavengers and decomposers (Côté and Hall 1995). Krause (2003) and White (1994) target industrial activities more generally. From an analytical perspective, one can assess IS possibilities based on *processes*; practically, engagement is still at the *company* (Baas 1998) or *facility* level.

Industries

Industrial ecology evokes "industry" in its broadest sense—that of the sum total of human activity (Graedel and Allenby 2003). From a practical standpoint, however, it is largely industry in the usual sense of business, often heavy industry and manufacturing, that is the primary focus of IS, for obvious and well-substantiated reasons: industry is responsible for mobilizing and transforming resource flows (Ayres 1989), and industry is best suited to control its processes and resultant by-products.

In practice, limiting IS to only industry can be counter to the qualifying phrase "traditionally separate." Laybourn (2006) extended Chertow's definition to include "other organizations," making explicit the involvement of nonindustry partners in the NISP network, including research and government organizations. Academic and other research organizations have been important in co-developing the innovative technologies central to certain synergies: in the United Kingdom, academic research identified new processes to extract precious metals from road sweepings, and to recover silver from x-ray films. Close collaboration with authorities is central for the authorities' convening power and clarification of policy and regulation (Lombardi et al. 2009; Lowe and Evans 1995), especially when the resource in question is closely regulated. Note that this role for authorities differs from that of knowledge banks or knowledge brokers as proposed by von Malmborg (2004).

In a Collective Approach

When consulting a dictionary for "collective" one finds "relating to, consisting of, or denoting an aggregate or group as opposed to an individual" (Webster 1996). An interpretation of this phrase may therefore simply be any activity involving more than one organism (however defined).

Competitive Advantage

There is a strong association between IS and improved competitiveness in the IS literature (Côté and Hall 1995; Geng and Côté 2002; Lowe and Evans 1995), often attributed to improved natural resources productivity (Esty and Porter 1998; Porter and van der Linde 1995). In our experience, the opportunities to improve competitiveness through IS are much broader than improved resource efficiency. They include reducing cost through innovative product or process changes, increasing revenue, diversifying business, and managing risk (Laybourn and Morrisey 2009). The importance of each synergy being demonstrable as an economically beneficial business deal has been documented for Kalundborg (Chertow 2007; Ehrenfeld and Gertler 1997; Jacobsen 2006), Rotterdam Harbor (Baas 1998), networks in Austria and Germany (Posch 2010), and more generally (van Berkel 2006).

Physical (Exchange of) Materials, Energy, Water, and/or By-products

Maintaining a focus on physical materials and energy propagates the approach of the early definitions of IE, and thus IS. Laybourn's (2006) extended definition includes "collaboration on the shared use of assets, logistics, expertise and knowledge transfer," which captures Hart's (1995) broad concept of a firm's resources as including employees' skills and organizational/social processes, as well as physical and financial assets. Other authors have recommended broadening the focus of IS to include information (Erkman 1997; PCSD 1996; Schwarz and Steinenger 1997).

Exchanges

The first dictionary definition of "exchange" is "the act of giving or receiving one thing as an equivalent for another; trade; barter" (Webster 1996). In the IS literature, both "resource exchange" (Chertow 2007; Côté and Cohen-Rosenthal 1998) and "exchange of resources" (Chertow 2000; Ehrenfeld and Gertler 1997; Harper and Graedel 2004) are used. Through stock exchanges, the word has gained an economic association in common parlance. The latter term, "exchange of resources," can also imply reciprocity: a flow of a (physical) resource from Organization A to Organization B, with a reciprocal flow of a (presumably also physical) resource from B to A. While possible, this is by no means the usual manifestation of IS.

In addition to exchange, the scholarly literature also uses the term "sharing," as in sharing resources (distinct from sharing utilities) (Chertow 2007; Chertow et al. 2008; Graedel 1996; Hardy and Graedel 2002; PCSD 1996). Sharing does not have a common economic association; its first definition (Webster 1996) is "a portion; allotted or equitable part," which may be why the question of the distribution of benefits in synergies arises in the research community. The difficulty of quantifying the relative financial benefits within a synergy has been established (e.g., Chertow and Lombardi 2005; Van Berkel et al. 2009). Paquin and Howard-Grenville (2009, 106) recently cited the "typically unequal distribution" of environmental and economic benefits as a barrier to IS; to our knowledge, there is no evidence in the NISP experience to support this conclusion.

Financial benefits are only one of the business benefits that may be difficult to quantify. Other benefits include risk reduction, achieving a zero waste to landfill policy, or improved community and/or government relations, and firm, or brand reputation (Accenture 2010; Jacobsen 2006; van Berkel et al. 2009). NISP often facilitates synergies where the benefit to one party is the removal of a problem with no associated financial transaction among the parties. For example, NISP facilitated a synergy for a hazardous compound, potassium aluminum fluoride, with no financial transaction between parties. Finding a recipient for this material allowed its provider, Denso, to progress toward its target of zero waste to landfill, in addition to avoiding its disposal cost as a hazardous material.

The term exchange is consistent with the ecological metaphor of mutualism; nevertheless, it seems to be the source of, to date, unsubstantiated academic concerns about reciprocity and equity. Recent research posits that although people want to be treated fairly, they recognize that fair does not mean equal (Benkler 2011).

Key: Collaboration

Collaborate is defined in terms of cooperation, as "to labor or cooperate with another, especially in literary or scientific pursuits;" cooperation is defined as "joint action; profit sharing" (Webster 1996). In a content analysis of 12 IS research articles spanning 14 years and seven countries, collaboration was mentioned by one, whereas cooperation was mentioned by nine. Similarly, content analysis on a recent Spotlight on Collaboration in the *Harvard Business Review* yielded six occurrences of *collabor* (as the root of collaborative, collaborate, collaborators, etc.)[4] and 66 occurrences of *cooper* (as the root of cooperate, cooperation, etc.) (Benkler 2011). Clearly the term "cooperation" is favored in the literature.

These terms in the IS literature tend to be used to indicate a group effort to achieve public goods or benefits beyond that which the firm would normally aim to achieve in its self-interest (Zhu et al. 2007). Particularly in the eco-industrial park (EIP) literature, the cooperative approach is associated with economic, environmental, and social gains for business and the local community (Cohen-Rosenthal 2000; PCSD 1996); this may derive from the greater role of community in much of the EIP literature compared to IS more generally (Côté and Cohen-Rosenthal 1998; Krause 2003). Ehrenfeld observed that the greater public benefit from industrial ecosystems was motivation for some type of public assistance to support industrial networks, as, "left to their own devices, private firms will typically underdeliver (public benefits)" (Ehrenfeld 2003, cited in Chertow 2007, 24). The ecological metaphor supports this: "With rare exception there is in nature's rule book no ethical or moral ingredient beyond *self interest*" (Smart 1992, 804, emphasis added).

There is also the perception that the IS supplier–customer relationship somehow goes above and beyond the traditional relationship—that it is either closer (Graedel 1996), or collaborative for competitive and/or environmental benefit (Schwarz and Steininger 1997; van Berkel 2009). Nevertheless, Ehrenfeld and Gertler (1997, 73) found that "the exchange of by-products and cascades of energy use, however, is not inherently different from traditional supplier-customer relationships." In addition, a recent study of IS networks in Austria and Germany found that "intercompany recycling activities are regarded by the company representatives as bilateral market transactions, not as collaborative network activities" (Posch 2010, 242). Synergies characterized by a critical supplier relationship seem to raise concerns of vulnerability *particular to IS*, which to date remain unsubstantiated. The scholarly literature details both advantages (Coase 1937; Kalwani and Narayanda 1995) and disadvantages (Klein et al. 1978) associated with critical supplier relationships.

The level of cooperation people demonstrate depends strongly on our perception of the rules of the game—we are more inclined to cooperate if we perceive others cooperating than if we do not (Benkler 2011). Perhaps organizations' perception of participating in a network results in more cooperative behavior. In our experience, members cooperate (i.e., take a joint action) in a network with other organizations motivated by self-interest. Few members are motivated by ecological impact, although that is often a *result* of their participation. They engage in IS transactions the same way they would any other contract, where fair may or may not correlate with equal.

Key: Geographic Proximity

Geographic proximity has been linked to the functioning of the biological ecosystem by Graedel (1996), who observed that both energy cost and transaction cost (in terms of monitoring resources at a distance) for closing resource loops are lower at a smaller spatial scale; Coase (1937) supports this hypothesis for the economic system. Geng and Côté (2002) further likened the physical location in which a business operates as analogous to the organism's habitat. This spatial relationship has been translated to IS in two ways: analogously, for the impact of transport, and for the close "mental distance" of the participants. Such factors may influence the viability of a synergy, but neither is exclusive to IS transactions—thus we take the somewhat controversial position that geographic proximity is neither necessary nor sufficient for IS, unlike the concepts of agglomeration economies and industrial clusters, which are explicitly geographically based.

Geographic proximity is a factor in calculating cost for any business transaction where the cost of transport scales directly with distance. Some have argued that this is more relevant for IS because much of the resource involved is expected to be of low economic value, and thus transport will be uneconomical over long distances (Lowe and Evans 1995). Our experience, however, counters this: Jensen and colleagues (2011b) recently demonstrated the perhaps surprising lack of statistical correlation between distance traveled in physical resource-based NISP synergies and either economic value or tonnage; in addition, transport costs were shown to be substantially smaller than the economic benefit of the synergies examined. Physical limits are clearly critical for transporting resources that degrade in transport (such as steam), but this is not unique to IS. In our experience, the relative importance of proximity will be determined by the economic (Côté and Cohen-Rosenthal 1998; Lyons 2007) and regulatory conditions governing the resource's transport.

The close mental distance may be disaggregated into two parts: access and trust, both associated with network participation (Ehrenfeld and Gertler 1997; Johannisson et al. 2002)—through participation in networks, members have gained access to partners they would not otherwise meet (Paquin and Howard-Grenville 2009). As for trust deriving from geographic proximity, however, international supply chains are quite prevalent and the opportunities for geographic proximity to enable these relationships quite limited, casting doubt on the criticality of geographic proximity in building trust among parties. There is, however, evidence for the role of trust in determining an organization's level of engagement with the NISP network itself (as opposed to partners in a particular synergy).

There is also the expectation that resource synergy opportunities will be sufficient to dictate a firm's locational decision, particularly in designing EIPs. The ability to access particular resources will only be crucial in locational decisions if they are the most important inputs of a firm (Desrochers 2004), or where materials and energy comprise a large part of the budget (Cohen-Rosenthal 2000). In the United Kingdom and Mexico, NISP member companies in the construction and paper industries have made locational decisions based on the availability of inputs through NISP, albeit not to EIPs—but this is still the exception rather than the rule. Efforts to plan EIPs on this basis have so far met with limited success (Chertow 2007).

Proposing a Practitioner-b(i)ased Definition of Industrial Symbiosis

All terms in Chertow's definition relate back to the ecological metaphor that is considered the foundation of IS, and IE more broadly. Many have a strong (not singular) association with a particular academic discipline, such as "exchange" with economics, "competitive advantage" with business, and "physical resources" with engineering and the natural sciences. Based on our experience communicating with practitioners and policy makers, we propose an alternative definition that positions IS as a business opportunity and tool for eco-innovation; eco-efficiency gains are generally a result of IS, not a driver, and geographic proximity is not mentioned because it is neither necessary nor sufficient for IS. Our definition carries forward various concepts from Chertow.

> IS engages diverse organizations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually

profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes.

In the previous section, the analysis of terms was based largely on the scholarly literature with some context from practice. The following analysis unpacks this new definition from a practitioner perspective.

Diverse

Increasing diversity broadens the knowledge and resource base available to the IS network, and fosters innovation and variety in solutions (Boons and Berends 2001; Duranton and Puga 2000; Jacobs 1969; Steiner 2002). Replacing "traditionally separate" with "diverse" avoids the lack of clarity around "traditional" and the ambiguity over whether separateness refers to sector, ownership, process, or relationships. Use of the term "diversity" recognizes the need to engage processes (industrial activities) to identify opportunities as well as the companies or facilities (more likely in our experience) that own the process. Preliminary results indicate that industrial diversity determines the distance resources travel in a synergy, not value or quantity (Jensen et al. 2011a).

Organizations

Broadening to "organization" is intended to capture the role of research and government alongside industry in advancing IS. Such flexibility may not facilitate taxonomy; our concern, however, is the possibility of an exclusionary definition diminishing the potential impact of an IS network.

Network

The use of "network" evolves the collective/collaborative aspect in the earlier definition to capture the mutual learning and information sharing among members (Aarts et al. 2007; Boons and Berends 2001; Cohen-Rosenthal 2000; Johannisson et al. 2002) without invoking a motivation beyond self-interest. The IS literature has tended to focus on the role of existing professional or social networks in facilitating IS through closer mental distance (Ashton 2008; Chertow and Ashton 2009; Gibbs et al. 2004; Lowe and Evans 1995; Paquin and Howard-Grenville 2009); we refer here to the IS network itself for its role in the identification and advancement of IS opportunities, and its opening of access to other members and new knowledge.

Eco-Innovation

The conditions that foster innovation are inherent in the mutual learning and information sharing of the network. In 1934, well before the 1987 Brundtland report and the rise of the sustainability movement, Schumpeter explained that times of great change brought opportunity for new ways of doing business. Concerns about global warming, energy, and materials security (rare earths, precious metals) are coming from both within and outside industry, changing the rules of engagement; these changes in industry drivers along with new information are sources of innovation (Drucker 1985).

More recently, the term "eco-innovation" has been associated with actions taken by business resulting in environmental benefits concomitant with competitiveness and economic growth (EIO 2011; OECD 2009). A study of 154 NISP synergies (Boardman and Gardner 2006) supports the OECD's identification of IS as fertile ground for eco-innovation: 70% of the synergies examined included some form of innovation, the majority of which involved cross-sectoral knowledge transfer—that is, leveraging knowledge and resources beyond one's usual purview; 19% involved the pull of new research and technology development.

Historically IE has focused on material and energy flows; Chertow extends to water and by-products, which are forms that the materials and energy take. Our experience indicates that the exchange of knowledge, information, and expertise also positively influence the physical flows of materials and energy—thus we replace the physical exchange of resources as the *core* of IS with eco-innovation as the *result* (EIO 2011; OECD 2009).

Long-Term Cultural Change

NISP synergies generally address inputs, outputs, or production processes rather than the business model of the member, which would be required for a fundamental shift toward sustainability (Ehrenfeld 2007; Hopwood et al. 2005). However, there are cases of transformation that we attribute to engagement with the IS network and the introduction of new tools like life cycle thinking and best practice. As articulated by Cohen-Rosenthal (2000, 258), "Tapping into the power of networks alters the sense the organization has of itself and how it operates." Through the network, organizations literally begin to change their own culture, becoming more attuned to new opportunities and more efficient in their own processes. For example, NISP member John Pointon and Sons was an animal renderer, which provided the service of incinerating fallen stock. The ash was sent to a landfill. When regulatory changes forced a reassessment of their business model, the NISP network provided access to research to improve products and processes as well as information about a biofuel feedstock market for by-products. Exposure to the network enabled the Pointons to transform their business into an energy supply company within 5 years with the same basic input of fallen stock. They are now investing in new energy production technologies.

Creating and Sharing Knowledge

A member organization operates on public, industry, and firm-specific knowledge (Micklethwait and Woolridge 1988); through an IS network, members gain access to new industry and firm-specific knowledge, as well as mutual learning. In a facilitated network such as NISP, members also gain access to dialogues with regulators and policy makers, thus informing and shaping public information.

Profitable

The essence of "competitive advantage" has been established as central to IS, but the term itself is associated specifically with the business literature. Profitable, defined as "bringing profit or gain, remunerative, advantageous" (Webster 1996), has a wider understanding, and has already been used in the IS literature: the "original motivation was to reduce wastes by seeking profitable uses for them, a traditional business goal" (Lowe and Evans 1995, 49). At least in the case of NISP, there are synergies not involving payment for physical resources that meet business goals, such as risk or reputation management, diversification, and asset utilization, which also go to the bottom line. Classifying synergies by commensalism (where a single party derives benefits) is not useful in practice: members do not invest time and energy in pursuing synergies without a perceived benefit. The potential for unequal distribution of financial gain was raised in both the 2004 and 2006 IS research symposia; note that profitable in no way implies equally distributed financial gains, just as fair does not imply equal (Benkler 2011).

Transactions

"Transaction" replaces "exchange" in the definition because, outside the rigor of the economic literature, the latter implies a reciprocal transfer of comparables, whereas transaction is defined as "something transacted, an affair, a business deal" (Webster 1996).[5] Rather than focus strictly on the concept of the physical transfer or movement of resources (as implied by the earlier definition), this language allows for consideration of activities that result in more sustainable resource use, such as fuel substitution, materials transformation, less carbon-intensive inputs, and sharing best practices.

Novel Sourcing of Required Inputs

Through the IS network, opportunities arise to source alternative inputs that may reduce or eliminate cost. It is usually the case that the new supply is not from virgin materials, thus also saving carbon emissions associated with extraction. The resources may be essentially perfect substitutes from a new source; alternatively, what is sourced may itself look to function rather than form—for example, substituting waste heat for primary fuel use for heating. Making explicit the link between IS and the inputs and outputs of business as usual helps network members understand how IS opportunities relate to their processes.

Value-Added Destinations for Non-product Outputs

Graedel and Allenby make the point that "one of the most important concepts of IE is that, like the biological system, it rejects the concept of waste ... wastes are merely residues that our economy has not yet learned to use efficiently" (2003, 19). Companies rarely stockpile non-product outputs; in some NISP synergies, a non-product output is already being sold or legally disposed of, and through the IS network a more profitable (value-added) opportunity is identified.

Improved Business and Technical Processes

This phrase goes directly to the limitations of thinking only about physical inputs to and outputs of the required assets and processes that manage them. NISP members have modified existing processes and introduced new ones to leverage an IS opportunity. Through the IS network, members share quality processes, environmental management systems, and opportunities for reverse logistics and improved asset utilization. For example, a synergy was completed where one member was able to utilize another member's spare effluent treatment capacity.

Discussion

We write from a NISP perspective, the only model of IS to have operated nationally for eight years, and regionally in ten countries; both authors have had extensive engagement with other IS models worldwide. The applicability of this definition and its key elements (i.e., diverse networks, eco-innovation, and profitable transactions) has been considered against other well-known occurrences of IS networks: for example, the IS models in Kalundborg, US-BCSD By-Product Synergy, and South Korea's EIP are all consistent with this definition.

The authors proposed a research agenda for the IS community resulting from the 2006 International Research Symposium on IS in Birmingham, United Kingdom (Lombardi and Laybourn 2007). In this article we have raised a number of research questions, some new and some evolving. We postulate that the role of research into IS is twofold: first, descriptive in understanding its barriers, enablers, and impacts; and second, normative in advancing its implementation where it can successfully advance eco-innovation. Research can help expand the practical evidence base that advocates for symbiosis; standardized methodologies and metrics can facilitate this communication (van Berkel 2009). Our definition presents some challenges to this standardization.

Entity Boundary: Is There a "Right" Answer?

As discussed, the "traditionally separate" part of the definition of IS has been difficult to standardize. The language conflates industry, company, facility, activity, and process; the intent is apparently to map the dissimilarity in the ecosystem metaphor onto the industrial system. The activities at Kalundborg that so captivated the IS community obeyed relatively clear boundaries: no subsidiaries of the same company, no companies in the same sector. Is it possible that such clear boundaries have carried on only as an artifact of Kalundborg's status as IS poster child?

Industrial symbiosis engages both ends of the spectrum, with *processes* and *companies*. Addressing process productivity is generally the domain of pollution prevention and cleaner production, and is usually distinguished from IS as being within a firm versus among firms. The status of same-ownership and same-industry transactions remains unclear: with highly diversified (or vertically integrated) companies, many standard industrial classification (SIC) categories could potentially be under the same ownership; and NISP has completed many synergies within the same SIC category among different ownership. Chertow (2000) does not consider material exchanges occurring primarily inside the boundaries of one organization as IS, although NISP does. From the research side, a standardized approach to taxonomy certainly facilitates comparison and knowledge transfer. From the practitioner experience, boundaries vary with context (e.g., institutional, cultural), and thus standardization may limit opportunities for impact.

Resource Boundary: Knowledge-Based Synergies

In physical flow-based synergies, a change is expected in the physical flows for all parties involved: for example, if Member 1 provides a physical resource to Member 2, then Member 1's productivity has improved because the resource is no longer waste, and Member 2's productivity has improved through substitution. Consider instead the case where, through the IS network, Member 1 is introduced to a new technology by Member 2. The result of implementing this technology is improved productivity for Member 1, but only knowledge flows between members, no physical resources. This is an important distinction: our proposed definition focuses less on the physical exchange basis of IS, and more on the richness of the processes involved in, and inspired by, participation in an IS network. New investment is encouraged by eco-innovation, changes in business practices, market pull for research and development, new businesses, and joint ventures. These are the elements that distinguish IS as a path to green growth.

Temporal Boundary: Transient, but on What Timescale?

Another intriguing question relevant to both definitions of IS: Is IS transient? That is, is a synergy today still a synergy tomorrow, and next year, and next decade? If a synergy idea is translated from the United Kingdom to Mexico, or replicated from the north of the United Kingdom to the south, is it IS? Ecological symbioses continue through generations: is the cement industry's use of ARMs now business as usual, or is it still IS?

Final remarks

Synergies within the NISP networks and elsewhere demonstrate both weak and strong sustainability (Ehrenfeld 2000; Hopwood et al. 2005; Lombardi et al. 2011; Springett 2003). Weak sustainability focuses on technological fixes for improved eco-efficiency, and manages business risk within the existing market structure; strong sustainability transforms both product and process toward innovative green growth. The IE community has long debated how far technological fixes can advance sustainability (Ehrenfeld 2000, 2007; Harper and Graedel 2004; Lifset and Graedel 2002; White 1994). The question of how far along the path to sustainability IS can move us is an open one (Baas 2008; Cohen-Rosenthal 2000). However, it is a viable alternative, delivering impact today in terms of eco-innovation for green growth, carbon emissions avoided, landfill and virgin material use avoided, and so on. The impact of facilitation has not yet been proven (another research question), but in our experience facilitation certainly accelerates the identification and, more importantly, the completion of synergies.

A focus on physical exchanges and geographic proximity is not useful to the advancement of IS—its ability to foster innovation and transformation, economic development, and regeneration is what has caught international attention on the part of the European Union, the Organization for Economic Co-operation and Development, the International Finance Corporation, and the World Bank. The European Union Commission, via its 2011 Environmental Technologies Action Plan 10th Eco-innovation Forum, as well as the commissioned COWI (2011) report, recommended replication of the NISP model across Europe. New policies and governance structures are being considered from the Republic of Korea to Mexico, replacing the traditional sectoral approach with a new integrated approach. Central planning of new EIPs for IS has had limited success, although International Synergies Ltd. has worked with companies and local and regional government bodies to identify inward investment opportunities based on IS. As the international spotlight increasingly focuses on IS as a pathway to a low-carbon sustainable economy, it becomes increasingly important to communicate clearly the innovative and transformative potential of IS without unnecessary constraints.

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Notes

1. Brazil, China, Hungary, Mexico, Romania, Slovakia, South Africa, Turkey, the United Kingdom, and the United States.
2. The abstract uses "industries," the text uses "entities."
3. See also a set of three papers by the Economic Classification Policy Committee in 1993, available at http://www.census.gov/epcd/naics/issues1; http://www.census.gov/epcd/naics/issues2; and http://www.census.gov/epcd/naics/issues3.
4. Occurrences in the phrase "and his collaborators" (of which there were five) were not counted.
5. The definition of transaction from the economic literature is also appealing, although it does not succeed in lowering the disciplinary boundaries, as we have set out to do. According to Commons (1931, 652), "transactions are not the 'exchange of commodities,' but the trading of the alienation and acquisition, between individuals, of the rights of property and liberty created by society, which must therefore be negotiated between the parties concerned before labor can

produce, or consumers can consume, or commodities be physically exchanged."

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