INDUSTRIAL SYMBIOSIS: CURRENT UNDERSTANDINGS AND NEEDED ECOLOGY AND ECONOMICS INFLUENCES

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ONTARIO CENTRE FOR ENGINEERING AND PUBLIC POLICY

INDUSTRIAL ECOLOGY (IE) 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 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. 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.

IE is an interdisciplinary field seeking to understand and address the impacts of industrial systems on the environment by using a systems approach. Industrial Ecology offers a new conceptual framework for analyzing the physical, chemical and biological interactions between industrial and ecological systems (Garner and Keoleian, 1995). 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 (Kapur and Graedel, 2004). 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 (Garner and Keoleian, 1995).

IE 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 (Jacobsen, 2006). 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 framework.[1] An industrial symbiosis is defined as multiple firms from traditionally separate industries acting collectively to gain competitive advantage, typically through the physical exchange of energy and resources (materials, water, by-products) (Chertow, 2000). While traditional definitions focus on resources optimization among collocated companies (Jacobsen, 2006), the collective activities need not be confined to energy and resource sharing, and can include sharing employee training and environmental monitoring systems (Kapur and Graedel, 2004).

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 (Chertow, 2000). 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 (Freedman et al., 2011, 246-247). To use the ecology 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) (Freedman et al., 2011, 246-247). 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 (Chertow, 2004). 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 co-operative ventures like joint purchasing and disaster response (Kapur and Graedel, 2004). It is the author's opinion, however, that the benefits stemming from co-operative 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 (Kapur and Graedel, 2004). Currently, 20 exchanges are taking place among the main players, which include a coal power plant, an oil refinery, a biotechnology and pharmaceutical company, as well as a soil remediation company (Kapur and Graedel, 2004). The industrial district has reduced waste generation by 2.9 million tons a year, and water consumption by 25 per cent. The district also supplies heat to 4500 local homes, and the synthesis includes the inter-municipal waste water treatment company (Kapur and Graedel, 2004). 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 (Lehtoranta et al., 2011), the symbiosis around waste management companies in Chamusca, Portugal (Costa and Ferrao, 2010), and the Tianjin Technological-Economic Development Area (TEDA) in China (Shi, Chertow and Song, 2010).

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 Chertow (2004). However, it is worth mentioning the concept of cascading, which occurs when a resource is used repeatedly in different applications (Chertow, 2004). 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 (Chertow, 2004). 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) (Kapur and Graedel, 2004). 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 waste water treatment facility (Kapur and Graedel, 2004). 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 co-operative effort among proximate firms to source water and energy resources collectively, instead of individually or from a large central authority (Chertow, 2004). 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 (Shi, Chertow and Song, 2010). These projects are funded through a general local tax on the tenants of TEDA, which is an alternative co-operation model to that seen in Kalundborg (Shi, Chertow and Song, 2010).

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 (Lehtoranta et al., 2011, and Costa and Ferrao, 2010). 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 Lehtoranta et al., 2011). 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 (Costa and Ferrao, 2010). 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 (Freedman et al., 2011).

There has been significant work in the area of public policy and the development of industrial symbiosis (Lehtoranta et al., 2011, and Costa and Ferrao, 2010). 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, which has the potential to have significant environmental impact. In their analysis of the Kymi plant, Costa and Ferrao (2010) conclude that the creation of the industrial symbiosis was motivated by a desire to expand production. Lehtoranta et al. (2011) agree that the spontaneous formation of industrial symbioses is often motivated by economics rather than environmental concerns. In addition, these have also been the more resilient and durable symbioses. 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 for attracting foreign investment to the industrial park (Shi, Chertow and Song, 2010). The presence of this "local government" provides a useful framework for co-operation 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 (2010) discuss the contextual factors in the development of 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 who study the natural systems that industrial ecology seeks to emulate. A discussion of a similar debate is presented in Korhonen (2004). It does not seem to the author of this article that the true driving force behind industrial ecology is protection of the environment. If that were the case, a greater use of ecology understandings of natural systems would be present in the literature. Discussions of how ecology concepts–like the intermediate disturbance hypothesis, 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 Freedman et al., 2011 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. For instance, the rebound effect that results in increases in energy and material efficiency resulting in more economic growth may mean that the efforts of industrial symbioses are for naught (see Greening, Greene and Difiglio, 2000 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.

NOTES

1. For a discussion of how these terms are related, see section 2, "Definition of Industrial Symbiosis and Related Terms," in Chertow, 2004.

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THERMAL ENERGY GENERATION FROM UNDERGROUND POWER TRANSMISSION CABLES

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LAND-USE CONVERSION of power transmission corridors, such as the ones criss-crossing the Greater Toronto Area (GTA), offers a unique and strategic opportunity to realize the potential of underground high-voltage transmission cables. These can be used for the development of innovative thermal energy generation technology, as well as creating the potential for the planning and development of sustainable urban and rural communities. Current practices in urban development and, subsequently, the pattern of urban growth have given rise to increased concerns over sprawl, traffic congestion, loss of bio-diversity and farmlands, and the quality of air across major urban centres in North America and around the world. Urban planners and others are calling for a sustainable approach to urban development–in which opportunities for incorporating sustainable development features and practices, such as increasing affordable housing and access to public transportation, and creating more compact and energy-independent communities–are the key considerations.

Ontario's Long-Term Energy Plan states that, by 2030, Ontario's population is expected to rise approximately 28 per cent, a gain of almost 3.7 million people. Ontario's population will become more urbanized, with population growth taking place in primarily urban centres. The GTA population will increase by almost 38 per cent over the same period. These challenges will require new and innovative partnerships and approaches, especially in dealing with the issues of providing the necessary infrastructure to promote growth and economic development on one hand, while protecting our social fabric and the environment on the other.

A triple-bottom-line approach to urban investment strategies can be achieved by releasing the potential for energy and sustainable urban development within the GTA power transmission corridors. This approach is sometimes referred to as full cost accounting (FCA), a process to ensure sustainability in infrastructure delivery by evaluating projects according to three sets of criteria or benchmarks: financial viability, social equity and environmental responsibility.

OVERVIEW

The GTA power corridor's total network, starting from the substation in Pickering, is made up of three main branches. A north corridor (500kV) runs west for most parts along Highway 407 to the border of Milton. Also from the east a central corridor (230kV) runs west along Highway 401 to Highway 407 at Highway 403 and then continues along Highway 407 to the substation at Queen Elizabeth Way (QEW) and Highway 403 at Highway 407 in Burlington. There is a south corridor connected to the central branch at Route 27 and Highway 401, running just east of Highway 427 to QEW. The third corridor (115kV) runs south from the Pickering substation diagonally and through the centre of Toronto's central business district. It merges with the south arm of the central corridor at Highway 427 and the QEW and continues west along the QEW to Oakville.

The corridor comprises some 4000 hectares stretching more than 200 kilometres across the GTA, traversing diverse urban communities and other land-use patterns. The corridor offers ease of access to all major modes of transportation, as well as institutional, commercial, industrial and community facilities. The proposed development would include a built-out population of between 220,000 to 400,000 people over a 20-year planning cycle, and an innovative renewable energy technology, which is expected to generate in excess of 2500 megawatts of electricity to supply approximately 1.6 million homes and produce some 220 million short tons of steam for space heating and cooling as well as hot water for industrial processing.

The project would involve replacing the entire network with a more efficiently laid-out system of underground cable tunnels with smaller branches where necessary by combining both the north and central corridors in one tunnel with a 500 kV double-circuit cable system integrated with an underground state-of-the-art smart grid system. The new grid system should be designed to withstand extreme climatic incidents of hazardous floods, snow storms and earthquakes. The smart grid concept would envision the full modernization and automation of electric power networks to be responsive to supply-and-demand pressures in an efficient and sustainable manner.

This would involve the province transferring development rights to a consortium that, in turn, would assume all responsibility for the planning, financing and development of a number of mixed-use and urban communities on these lands to include district energy for heating and cooling.

SOCIAL, ECONOMIC AND ENVIRONMENTAL BENEFITS

The project's estimated cost is approximately $13.4 billion, of which $3 billion could be financed with public-private equity investments and the remaining long-term debt of approximately $10 billion secured in part against annual certified emission credits of roughly $328 million over the life cycle of the project.

The environmental benefits would create the largest sustainable urban development in North America, as the renewable energy component, based on the United States Environmental Protection Agency's estimates, results in offsetting approximately 12.4 million metric tons of carbon dioxide annually. Annual greenhouse gas emission reductions would be equivalent to 2.3 million passenger vehicles, 64,804 railcar loads of coal and 5.3 billion litres of gasoline. The social and economic benefits in terms of job creation and providing a secure and sustainable source of funding for affordable housing development as well as the province's infrastructure and strategic transportation plans are significant and supported by the project's financial analysis.

POLICY IMPLICATIONS

In 2004, the Ontario government introduced a comprehensive policy framework to make it easier for the province, municipalities and other public-sector partners to plan for, finance and procure public infrastructure assets to support sustainable urban development as well as to enhance the efficient delivery of public services.

The Ontario Ministry of Infrastructure (MOI) was granted jurisdiction over the power corridor lands pursuant to an order-in-council (1487/2005), which took effect on September 21, 2005. This effectively transferred all powers relating to the ownership of Crown real estate, previously residing with the chair of the Management Board of Cabinet and the Management Board Secretariat, to MOI.

Planning for the GTA power transmission corridors underscores the need for integrated planning and would greatly influence the policy debate over rising population growth trends, infrastructure deficits, and the environmental impact of unabated urban sprawl. The "Growth Plan for the Greater Golden Horseshoe, 2006" is Ontario's growth management policy framework for the entire southwestern Ontario urban enclave around Lake Ontario, extending from the Niagara Region to Durham Region in the east. Including the GTA, the plan seeks to address questions of urban growth and, in particular, how to accommodate some 8.6 million people by 2031 and at the same time ensuring the best quality of life for those who will be making the GTA a place to live, work and play.

The power transmission corridor lands project provides the answer and, more importantly, helps to accomplish key policy goals of the Ontario government relating to growth and infrastructure management initiatives; starting with the *Capital Investment Plan Act* (1993) and the announcement in 2004 of a new infrastructure, financing and procurement policy framework, "Building a Better Tomorrow."

As governments around the globe actively debate measures and develop policies to combat climate change, this concept of using major power transmission corridors to facilitate sustainable urban developments could also serve as a model for the implementation of integrated planning policies for urban growth management.

An overall planning and development concept should seek to incorporate a land-use pattern or distribution having approximately 46 per cent residential uses, 27 per cent industrial, commercial and institutional, and 25 per cent infrastructure and open spaces. The goal is to preserve much of the existing active open space but more significantly to create greenhouse gas emission reduction equivalency in the form of carbon sequestration by some 2.8 million acres of pine and fir forest within the GTA.

INNOVATIVE THERMAL ENERGY TECHNOLOGY

This thermal energy technology uses the heat generated from underground power transmission cables to drive steam turbines or other similar technologies to produce electricity and steam. Water (or another working fluid) is pumped under pressure into an encasement around the cables or an external pipe running alongside the transmission cables. In assessing the feasibility of a 500 kV alternating current underground cable system for Alberta Electric System Operator (AESO), Cable Consulting International Limited (CCI) asserts in its February 2010 study that "forced cooling in which water pumped under pressure in circulating pipes alongside each cable (integral sheath cooling) can absorb up to 100 per cent of the power loss (dielectric) by an increase in the water temperature."

The encased power cable system would be in a loop, with a temperature differential between the exit point (heat exchange station) and the entry (recharge or injection) point. The temperature differential within the looped system is maintained in part by cool or cold makeup water mixed in with condensate from the turbine before travelling to a cooling tower where air cooling reduces the water temperature before it returns to the loop at the injection point. The process of heat recovery and cool recharge to the loop is repeated at intervals to be determined by load capacity and requirements. Sizing the thermal energy system will be a function more specifically of rate flow, pressure and cable surface temperature due to power loss.

The use of thermal energy generation from underground power transmission cables could also impact rural economic development by facilitating the creation of "winter farmlands and tropical farm belts" in which thousands of acres of farmlands along the outer rural fringes of the GTA are transformed into greenhouses for growing crops year-round. A network of small irrigation-like pipes could carry heat directly to the soil as well as nutrients to the plants and could also replenish our watersheds.

The groundwater replenishment system (GWRS) is an innovative sustainable technology that can be integrated with the heat recovery process from underground power cables. This would allow the use of "grey water" to provide heat and nutrients to winter greenhouses while recharging our watersheds. GWRS is being used in the United States, and according to Michael Markus, 2011, highly treated wastewater could be used to recharge the underground system: "The groundwater replenishment system (GWRS) takes highly treated wastewater that would have previously been discharged into the Pacific Ocean and purifies it using a three-step advanced treatment process consisting of microfiltration, reverse osmosis and ultraviolet light with hydrogen peroxide. The process produces high-quality water that exceeds all state and federal drinking water standards."

CONCLUSION

Increasingly, the public is demanding greater accountability in how major infrastructure is procured, planned and developed to ensure a safe, secure and healthy region in which to work, live and raise a family. This requires government to evaluate its capital investment decisions within the context of the triple-bottom-line approach, as attention to value capture as a source of public revenue has been increasing where some governments are experiencing declines in revenue from traditional sources and others face rapid urban population growth and require large investments in public infrastructure (Ingram et al., 2012).

The region's growing and diverse population could one day have access to cheaper, organically grown green produce and crops harvested from year-round greenhouses forming a "winter farm belt" along urban fringes, supported by underground power cable thermal energy. This would reduce the need for imported agricultural produce and lessen the environmental impact of freight transportation in terms of congestion and harmful emissions as well as developing a sustainable means of recharging our watersheds.

Supporting sustainable urban and rural development with investments in the thermal energy potential from power transmission corridors will have profound environmental benefits and at the same time allow for the creation of a secure source of revenue to fund the region's growing infrastructure needs in partnership with private consortiums. Σ

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