Industrial Ecology: A Review with Examples from the Canadian Mining Industry

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Introduction: Industrial Ecology

Industrial Ecology is a relatively new and prescriptive field of study which seeks to transform the current industrial system by placing it within, and modeling it after, natural systems (Jelinski et al 1992; Lifset 1997; Gallopoulos 2006). As a key analogy that motivates the field's thinking, Industrial Ecology relates the flow of energy, resources, and wastes in modern industry to their natural corollaries arguing that an "...ecological system operates through a web of connections in which organisms live and consume each other and each other's waste. The system has evolved so that the characteristic of communities of living organisms seems to be that nothing that contains available energy or useful material will be lost..." (Frosch 1992). Following this analogy, Industrial Ecology seeks to emulate mature ecological systems in order to reduce environmental impacts through maximized efficiency of energy and resource inputs and the minimization of unutilized waste (Jelinski et al 1992). Industrial Ecology argues that traditionally industry operates in a 'linear' fashion, creating 'open' resource and energy loops where "...the flow of material from one stage to the next is independent of all other flows..." (Jelinski et al 1992). This leads to 'end-of-the-pipe outcomes' where both useful and useless (waste) products are generated as part of the production process. It is argued that in mature ecosystems all resources loops are 'closed' and that nearly all resource

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utilization in nature results exclusively in products that are useful to other organisms – anything that is generated as ‘waste’ by one organism is eventually taken up by another as food. Following the natural model, Industrial Ecology seeks to ‘close’ the industrial loop so that all waste products and available flows of energy are put to a productive use (Jelinski et al 1992; Lifset 1997; Gallopoulos 2006). This involves the evolution of increased complexity and interconnectedness within the industrial system (Ruth 1998). Under this framework, industrial ecologists are concerned primarily with the study of “...local, regional, and global flows of materials and energy in products, processes, industrial sectors, and economies...” (Lifset 1997). It has been argued that Industrial Ecology, unlike many other industrial concepts, explicitly acknowledges that technology cannot replace the biosphere and that industrial processes must be made to operate sustainable within the ecosystems that they function in (Bourg and Kietsch 2006). The majority of the field research and case studies that inform this field arise from Europe and the United States and so a significant opportunity exists for industrial ecology research within Canada; this is shown later with an example from the Canadian mining industry.

A Genealogy of Industrial Ecology and Industrial Metabolism

The field of Industrial Ecology is highly multi-disciplinary and has gradually coalesced from work that was done in the fields of systems thinking and analysis, ecology, economics, social geography, economic geography, environment, resource productivity analysis and from industry itself (Ayres 1969; Ayres 1989; Frosch 1992; Jelinski et al 1992; Esty and Porter 1998; Fischer-Kowalski 1998; Fischer-Kowalski and Huttler 1999; Korhonen 2003; Kronenberg 2006). Industrial Ecology seeks to offer connections among these fields and the systems that they study (O’Rourke et al 1996).

Esty and Porter (1998) discuss how the oldest roots of Industrial Ecology, in an analytical sense, arose from industry itself and the study of resource productivity. From a business perspective the study of optimizing resource use, minimizing waste, and increasing efficiency has been undertaken wherever it offered a competitive advantage to a firm. Historically the costs of inputs, waste disposal, liability, and regulation motivated business thinking in this area. This is confirmed by Desrochers (2002, 2007) who discusses historical manifestations of Industrial Ecology and Industrial Symbiosis[1]. Desrochers argues that ‘loop closing’ Industrial Ecology behavior has been part of industry since the industrial revolution and that many industries have actively engaged in the application of Industrial Ecology projects such as recycling and the use of byproducts (for example, the birth of the glycerin industry as a byproduct of soap manufacturing). Through these initiatives industry has found ways to increase efficiency and turn

1. Industrial Symbiosis and its relationship to Industrial Ecology are discussed later.

waste into useful products. In the past business displayed early Industrial Ecology behavior where market factors, liability, engineering capability, and available technology permitted. This was part of normal business analysis and practice in a variety of industries by the 1920s (Desrochers 2007). Even Marx[2] recognized this, stating "The capitalist mode of production extends the utilization of the excretions of production and consumption ... The so-called waste plays an important role in almost every industry…"

While the origins of Industrial Ecology type interactions are found in business, the study of these systems first arose from the systems analysis tradition, developing into a separate field of study relatively recently (Fischer-Kowalski 1998; Fischer-Kowalski and Huttler 1999). The theoretical precursor to Industrial Ecology, Industrial Metabolism,[3] is credited to the economist and theorist Robert Ayres (originally a physicist) who first proposed the term in relation to his work on materials flow analysis. Ayres proposed the idea that natural systems all have a 'metabolism' surviving on inputs of energy and materials which are then transformed by organisms and turned into waste. Waste is then reprocessed and used by other organisms. Similarly, Ayres argued, society has a metabolism which takes in energy and resources and processes them through industry, thus creating products and waste. The difference that Ayres saw between industry and natural systems is that while nearly all waste is reused in nature, very little waste is reused in industry (Ayres 1969; Ayres 1989; O'Rourke et al 1996; Fischer-Kowalksi 1998; Fischer-Kowalski and Huttler 1999; Korhonen 2003). The concept of Industrial Metabolism links natural and industrial metabolic processes through Ayres' metaphor. Thus, Industrial Metabolism is primarily concerned with the flow of materials and energy going through the industrial system (Ayres 1969; Ayres 1989; Korhonen 2003).

While Industrial Metabolism is the theoretical precursor to Industrial Ecology, the expansion of ecological and environmental knowledge and the increasing demand for such knowledge motivated the creation of a more holistic industrial metaphor. This lead to the eventual articulation of the Industrial Ecology metaphor discussed above. The primary differences between Industrial Ecology and Industrial Metabolism are scale and place. When first proposed by Frosch and Gallopoulos (1989) the term Industrial Ecology was meant to go "…somewhat beyond the metabolic analogy, in the sense of carrying the analogy to another level…" (Frosch 1992). This 'other level' involved not only viewing industrial systems as analogous to their natural equivalents, but also as a part of the world's ecology. In this way industrial systems are seen to influence, and be influenced by, the ecosystems that they function within (Frosch and Gallopoulos 1989; Frosch 1992; Lifset 1997). Initially there was some debate over which of these two terms should be applied to the growing field, however, Industrial Ecology eventually emerged as the dominant terminology. This shift reflected the fact that while ecology is a science, metabolism is a phenomenon, and the idea that 'metabolism'

2. Quoted in Desrochers (2007: 362) from Marx, Capital, Volume III, n.p.
3. Industrial Metabolism is also known by the closely related term Societal Metabolism.

is encompassed by the term 'ecology' (Lifset 2004). Debate over which term was to be dominant in this emerging field was essentially silenced in 1996 when Robert Ayres himself published a book entitled *Industrial ecology: Towards closing the materials cycle* (Lifset 1997).

Situating Industrial Ecology: Related Terminology

Industrial Symbiosis is a third metaphor that is closely related to Industrial Ecology and Industrial Metabolism. The symbiosis metaphor "…builds on the notion of biological symbiotic relationships in nature, in which at least two otherwise unrelated species exchange materials, energy, or information in a mutually beneficial manner – the specific type of symbiosis known as mutualism…" (Chertow 2000). Industrial Symbiosis is particularly informed by geographic thinking and is hence concerned with Industrial Ecology type interactions as they occur between industrial entities in close geographic proximity[4] (Chertow 2000).

Together Industrial Ecology, Industrial Metabolism, and Industrial Symbiosis summarize most of the thinking in this area of study. While each of these terms has been defined already their relationship to one another is further clarified by Chertow (2000). Chertow (2000) argues that Industrial Ecology is a more general term that seeks to encompass the arguments and work of a wide range of fields but especially the closely related work of Industrial Metabolism and Industrial Symbiosis. As shown in Figure 1, Chertow (2000) believes that Industrial Ecology analysis can be divided into three categories based on the type and scale of interaction:[5]

- <u>Facility or Firm Level</u>: Often the level most pertinent to industry analysts, this level applies Industrial Ecology concepts to individual firms. Analysis in this area has focused on design for the environment, pollution control, green accounting, resource productivity analysis, the environmental competitiveness of a firm, corporate responsibility, etc. (Esty and Porter 1998; Chertow 2000).
- <u>Inter-Firm Level</u>: At this level Industrial Ecology examines the interaction and creation of Industrial Ecology type linkages between firms. Analysis at this level usually falls within the label Industrial Symbiosis and includes product life cycle analysis, the study of eco-industrial parks, industrial sector initiatives, efforts at byproduct utilization, etc. (Chertow 2000; Desrochers 2002; Fichtner et al 2004; Desrochers 2007; Ristola and Mirata 2007).

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4. Desrochers (2002) argues that Industrial Symbiosis need not be limited to 'close geographic proximity' but that it should also consider interactions at a regional (city wide) scale or larger.
5. Fichtner et al (2004) have also tried to create an Industrial Ecology classification system based on interaction and project characteristics.

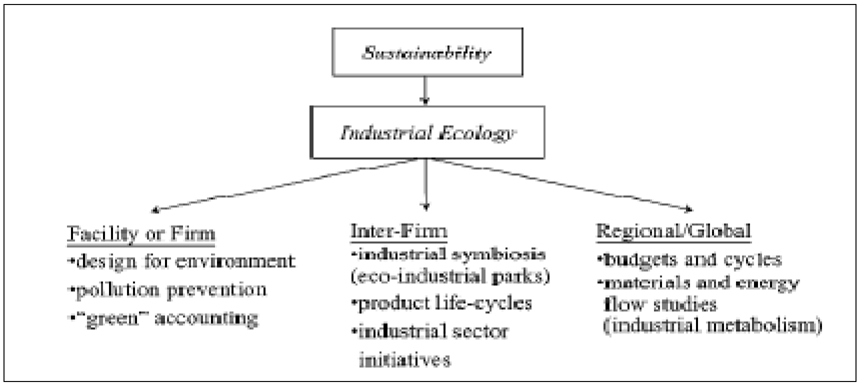

FIGURE 1 Industrial Ecology Operates at Three Levels (Chertow 2000)[6]

- Regional/Global Level: At this level Industrial Ecology studies interactions at a regional, global, or industry wide scale. Analysis at this level usually fallswithin the label Industrial Metabolism and is primarily concerned with budgeting and accounting, energy and materials flow analysis, dematerialization, and decarbonization (Chertow 2000).

Thus, as Chertow (2000) argues, Industrial Ecology can be seen as a more general term which encompasses the closely related analysis offered by firm level studies, Industrial Metabolism, and Industrial Symbiosis.

Industrial Ecology and Corporate Social Responsibility

While the link between Corporate Social Responsibility (CSR) and Industrial Ecology is somewhat underdeveloped in the literature, in practice CSR and Industrial Ecology are closely related to one another. While CSR thinking is designed to help a corporation set sustainability goals and integrate concepts of social and environmental responsibility into their core business strategy in a profitable manner, Industrial Ecology concepts and tools provide the mechanisms by which some of CSR's ambitions can be fulfilled (Korhonen 2003; Waage et al 2005). Industrial Ecology, and the closely related concepts already discussed, directly study the mechanisms by which aspects of CSR can be implemented, through approaches that include eco-efficiency, analyzing 'symbiosis' partnerships between organizations (ex. Corporate – NGO partnerships), green accounting, design for the environment, and resource productivity analysis (Esty and Porter 1998; Chertow 2000; Elkington 2004). Industrial Ecology concepts and tools have

6. Diagram taken directly from Chertow (2000).

been developed to simultaneously increase profitability and environmental performance and hence they are compatible with CSR (Esty and Porter 1998; Jackson and Cliff 1998).

Industrial Ecology in Practice

In practice Industrial Ecology is studied and implemented by a diverse group of academics, researchers, planners, and industry people. While the concept of Industrial Ecology is founded in a relatively simple metaphor in practice the field is highly technical and complex, hence it is primarily oriented towards a highly educated and professional audience; one which is receptive towards a more progressive industrial vision (Jelinski et al 1992). Due to its highly technical nature Industrial Ecology has not been approachable by an amateur audience and it has been primarily practiced and studied in the developed world. Furthermore, many tools developed by the field of Industrial Ecology have not been extensively mobilized by the mainstream environmental movement (O'Rourke et al 1996). As discussed earlier, Industrial Ecology is informed by a diverse array of fields and academic traditions and in practice the concept is used by people in each of the fields mentioned already, though it is also applied by engineers, industrial designers, and business people (Ayres 1969; Ayres 1989; Frosch 1992; Jelinski et al 1992; Esty and Porter 1998; Fischer-Kowalski 1998; Fischer-Kowalski and Huttler 1999; Korhonen 2003).

The application of Industrial Ecology concepts has resulted in a shift from 'end-of-pipe' approaches to environmental problems towards more holistic strategies that incorporate environmental considerations into planning and design (O'Rourke et al 1996). It is argued that Industrial Ecology must be implemented in a pro-active, designed in, flexible, encompassing, and business friendly manner (Jelinski et al 1992). Industrial Ecologists, when applying Industrial Ecology concepts, have worked closely with industry and projects have been highly responsive to the needs of business and economic conditions (Jelinski et al 1992; Esty and Porter 1998; Korhonen 2003; Desrochers 2007). Industrial Ecology studies and the tools that emerge from them tend to focus on the following real world applications:

Firm Level Application

- Pollution prevention (Korhonen 2003)
- Clean technology (best available technology) (Korhonen 2003)
- ISO 14001 standards (Korhonen 2003)
- Eco-Management and Auditing schemes (Korhonen 2003)
- Corporate Social/Environmental Responsibility (Korhonen 2003)
- Resource and Energy Productivity Studies (Esty and Porter 1998)

Inter-Firm Level Application

- Eco-Industrial Parks with numerous industries exchanging waste, energy, and materials[7] (Chertow 2000; Fichtner et al 2004; Chertow 2007)
- Recycling and Byproducts Industries (Desrochers 2002; Desrochers 2007)
- Product Life-Cycle analysis (Chertow 2000)

Regional/Global Application

- Material and energy flow studies (Ayres 1969; Ayres 1989; Chertow 2000)
- Decarbonization and dematerialization (Chertow 2000)

As the globalization of industry increases these economic and geographic scales are becoming less distinct and some tools apply on multiple scales, eg. Product life-cycle analysis (O'Rourke et al 1996; Chertow 2000). Due to the rapid growth of the field these tools are continually growing in sophistication and number.

Critiques of Industrial Ecology

As discussed, Industrial Ecology is a field that has coalesced rapidly from a variety of other disciplines. As is typical of emerging disciplines, Industrial Ecology has been subject to internal debates and criticism. O'Rourke et al (1996) reviewed the main critiques of this field and identified several dominant criticisms. First and foremost it was argued that "…Industrial Ecology is currently a broad umbrella of concepts rather than a unified theoretical construct…". Furthermore, O'Rourke et al (1996) stated that:

- The field is poorly defined (Allenby 2006)
- The field's tools continue to have methodological weaknesses
- The strategies employed by the field are often not the best way to reach its ultimate environment goals (as they compare to reduced consumption strategies for example)
- Implementation reflects the needs of industry too heavily and not the ideas expressed in the literature
- It is not a holistic solution to environmental problems and does not deal with some issues well (eg. Biodiversity….It has been countered that Industrial Ecologists do not claim to offer a complete solution to all environmental problems)
- Social considerations are systematically excluded from analysis and the social

7. One of Industrial Ecology's (and more specifically Industrial Symbiosis') most famous case studies involves the Kalundborg industrial park in Denmark where numerous industries exchange a variety of waste products (including steam). This symbiosis network includes an oil refinery, power station, gypsum board factory, pharmaceutical plant, the city of Kalundborg, and others (Chertow 2000).

impacts of industrial restructuring are neglected (Vermeulen 2006).
- Considerable dissension exists within the field between those who advocate incremental change and those who argue for more revolutionary adoption of Industrial Ecology principles

In addition, Desrochers (2002; 2007) has argued that the field of Industrial Ecology (and specifically Industrial Symbiosis) has been pursued too narrowly geographically, that it has overemphasized public planning over private sector initiatives, and that Industrial Ecology type interactions have been present in industry for far longer than the field typically acknowledges. Other authors have argued that the current Industrial Ecology framework fails to adequately incorporate issues raised by parallel discourses concerning scale and business ethics (Randles 2007), that industrial ecology has been selective in its use of ecological metaphors and that this has created a theoretical and empirical bias in the field (Wells 2006), and that slow progress in implementing Industrial Ecology results from underdeveloped analysis of social factors and social processes (Vermeulen 2006).

Although these criticisms are noteworthy, O'Rourke et al (1996) also acknowledged the importance of the field and the ongoing efforts to address these theoretical and practical shortcomings. In recent years the work of Chertow (2000) and others have helped to more tightly define the field and its concepts.

Industrial Ecology in Canada: An Example from the Mining Industry

As mentioned earlier, there has been relatively little application of Industrial Ecology research tools within Canada and few Industrial Ecology case studies exist compared to other regions. This is evidenced by the sparse availability of Industrial Ecology studies in the mining sector, despite the fact that this sector is a major part of the Canadian economy and one of Canada's largest heavy industries. This researcher could find only two studies that incorporated a detailed application of the Industrial Ecology framework in the Canadian mining sector, these include Hilson and Murck (2001) and Lang et al (2006). However, preliminary investigations indicate that the Canadian mining industry is rich with examples of Industrial Ecology type linkages. This is evidenced by the activities of two of Canada's largest mining companies; Falconbridge and Noranda.

Both Falconbridge and Noranda are major copper, nickel, zinc, and aluminum producers managing a diverse set of Canadian and international sites. While the primary business of these companies is mining they also control significant smelting and processing facilities, and quite surprisingly, they have extensive recycling and reprocessing capacity. This is evidenced by the fact that after Falconbridge's acquisition of Noranda in 2005, Falconbridge-Noranda became the world's largest recycler of electronic waste[8] and one of the world's largest recyclers of batteries and copper. This is an interesting fact, especially given that Falconbridge and Noranda had independently entered the recycling sector prior to their merger and both firms have been developing their recycling capabilities since the early 1970s (Falconbridge-Noranda 2002; Falconbridge 2006). This aspect of the companies' activities have grown substantially and prior to the merger announcement in 2001 recycling accounted for 29% of Noranda's annual revenues at a gross value of $328 million dollars (Falconbridge-Noranada 2002). Currently Falconbridge-Noranda process over 100 million pounds of electronic waste annually (Falconbridge 2006).

The growth of Falconbridge-Noranda's recycling capacity has emerged as a result of several processes that would be particularly interesting to industrial ecologists:

- Shortage of Smelting Inputs: Declining mine outputs in the 1970s and 1980s left Falconbridge and Noranda smelters operating below optimum capacity. In order to operate at full capacity these firms sought recyclable material. By 2001 recycled material accounted for 15% of Noranda's smelter inputs (Falconbridge-Noranda 2002).
- Smelting Facilities: It became clear early on that smelting facilities built originally for primary processing could be retrofitted for recycling at relatively low cost. Smelting facilities are now designed with eventual use for recycling in mind (Hatch Engineering 2007; Falconbridge 2008).
- Loop Closing Networks: Falconbridge has made extensive efforts to form recycling partnerships with companies that buy its primary outputs. These partnerships involve the creation of waste disposal agreements whereby Falconbridge takes a partner's electronic and other recyclable wastes, reprocesses them, and then sells the recycled metal products back to that partner so that it may be added back into their production cycle (Falconbridge 2006).

Falconbridge-Noranda continues to expand their recycling activities and increase the complexity of their Industrial Ecology activities. This is evidenced by the recent opening of the Horne Smelter – Recycling Plant which was built by retrofitting the smelter that had originally serviced the Horne mine located in Rouyn-Noranda, Québec. This particular facility boasts a specially designed reactor that captures SO_2 emissions as a byproduct of the copper recycling process and converts them into valuable sulfuric acid, which is later resold for a variety of industrial purposes (Hatch Engineering 2007). This facility is now the largest and most technically advanced of its kind in North America and it is capable of processes complex feeds of recyclable material, processing up to 800,000 tones of copper and precious metal bearing material annually, yielding approximately

8. Falconbridge was recently acquired by the Swiss mining firm Xstrata and so both firms are now subsidiaries of that parent company.

180,000 tones of anode copper and 600,000 tones of sulfuric acid (Falconbridge 2008).

The examples presented here have not, to this author's knowledge, been addressed by the Industrial Ecology literature. An industrial ecologist will recognize that the recycling, waste reduction, and pollution control linkages that these companies have formed represent very large scale examples of Industrial Ecology activity within Canada and yet very little detail is known regarding the process by which these linkages formed, how they have affected other industries and businesses, and how such linkages can be formed in other industries. Other significant mining sites in Canada offer similar opportunities for study, including the gold mining complexes of the Northwest Territories, Ontario's gigantic Sudbury basin complex, and other large industrial sites. Studying such sites could offer valuable insights for Canadian industrial ecologists and geographers.

Conclusion

In this paper Industrial Ecology has been reviewed through a detailed examination of the literature in an attempt to define the field, examine its genealogy, summarize popular critiques, and situate this area of thought in relation to the closely related fields of Industrial Symbiosis, Industrial Metabolism, and Corporate Social Responsibility. The potential for meaningful Industrial Ecology fieldwork to be conducted in Canada was illustrated by a brief example of Industrial Ecology type phenomenon in the Canadian mining industry, as exemplified by the recycling activities of two of Canada's largest mining firms; Falconbridge and Noranda. It has been argued that these examples are worthy of future study, that Canadian Industrial Ecology case studies are underrepresented in this field's literature, and that large scale and potentially meaningful examples of innovative Industrial Ecology type behavior exists in Canada. Bringing these studies to the attention of the wider academic community could provide valuable insights to industrial ecologists and geographers alike.

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