

Orchestrating Circularity within Industrial Ecosystems:

LESSONS FROM ICONIC CASES IN THREE DIFFERENT COUNTRIES

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SUMMARY

This article explores how to get companies engaged in value-creating cooperation regarding residual materials. Within different contexts, industrial ecology needs matchmakers who act as network orchestrators to facilitate new forms of interorganizational cooperation on what were previously perceived as “junk materials.” Three case studies of eco-industrial networks in Denmark (Kalundborg), Canada (the Québec region), and France (Dunkirk) demonstrate the various roles of the matchmakers to ensure the implementation of industrial ecology at the interorganizational level. This article highlights four strategic activities for matchmakers: revealing value in industrial ecology, generating trust, activating industrial ecology, and institutionalizing industrial ecology.

KEYWORDS: industrial ecology, circularity, industrial ecosystem, matchmaker

Is it really possible just to continue business as usual? The model of the circular economy proposes the replacement of the current, and mainly linear, “take-make-dispose” model.¹ At the theoretical level, this concept stems from the approach of industrial ecology popularized in the 1990s.² Taking a biological analogy, industrial ecology provides a new way of designing

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production processes, leading companies toward closed loops, reusing residues like in natural ecosystems.³

However, the implementation of industrial ecology at the interorganizational level remains complicated, especially because companies have difficulty seeing the potential value creation associated with this kind of cooperation. In this article, we show how to get companies engaged in value-creating cooperation regarding waste. We demonstrate that, within different contexts, industrial ecology needs matchmakers, that is, actors willing to facilitate the occurrence of closed loops within an ecosystem of organizations. These matchmakers act as networks orchestrators facilitating new forms of interorganizational cooperation on what were previously perceived as “junk materials.”⁴ We study three covered cases from Denmark (Kalundborg), Canada (the Québec region), and France (Dunkirk) where eco-industrial networks have been created. We observe that in these three iconic cases of industrial ecology, matchmakers are third parties,⁵ that is, actors that are external to the network of companies engaging in closed loops. Our empirical study explains how different matchmakers achieved getting companies engaged in value-creating cooperation regarding waste. We detail the various roles of these third-party matchmakers to ensure the implementation of industrial ecology at the interorganizational level.

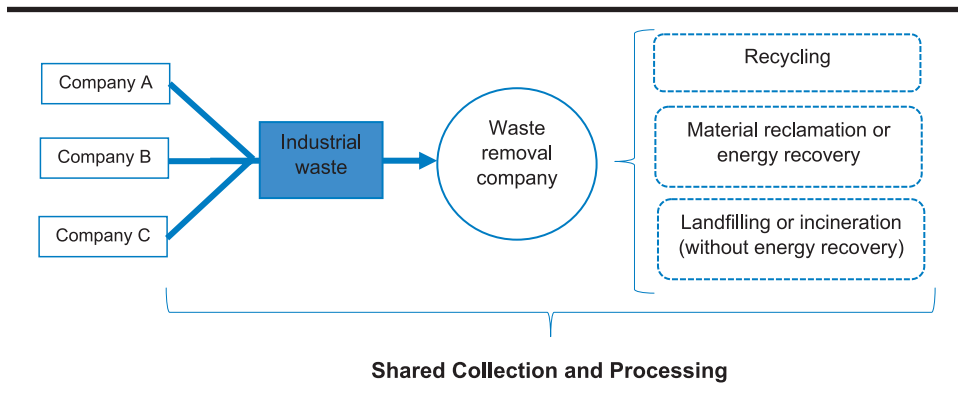
Issues in Implementing Industrial Ecology

Industrial ecology challenges the current “take-make-dispose” model⁶ that causes large environmental challenges. With the creation of eco-industrial networks⁷ inspired by natural ecosystems, industrial ecology may be an interesting approach to achieve circularity.

The Circularity of Natural Ecosystems: A Source of Inspiration for the Industrial World?

Criticizing the linearity of industrial systems, two American engineers from General Motors introduced in 1989 the idea that manufacturing activities should be reorganized like natural ecosystems.⁸ This “learning from nature” approach draws on the circular functioning of natural ecosystems to shape industrial processes to reduce their environmental impact⁹—that is, to increase resource efficiency upstream and reduce pollution downstream. Industrial ecology, thus, borrows ideas and concepts from the natural sciences to change industrial methods and practices within organizations.¹⁰

At the interorganizational level,¹¹ industrial ecology encourages the creation of industrial ecosystems¹² in which local organizations (companies, public bodies) form industrial symbioses.¹³ For instance, it implies shaping “industrial food chains”¹⁴ using natural food chains as a model.¹⁵ Recalling Lavoisier’s famous law: “Nothing is lost, nothing is created, all is transformed,” industrial ecology is

FIGURE 1. Shared waste-management service.

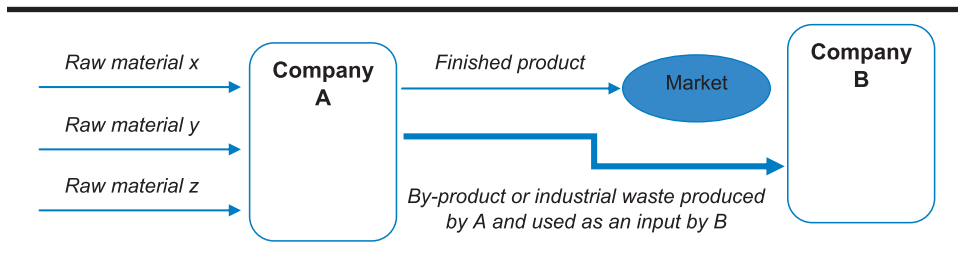
Source: Authors.

based on the principle that the residue of one organization may be another's raw material.¹⁶ In a global context of increasing scarcity of natural resources, unintentional outputs generated during a company's production process may become alternative and valuable inputs.

Thus, industrial symbioses reflect a collective effort of resource optimization through interorganizational relationships based on the sharing of utilities or ancillary services¹⁷ and/or the exchange of materials and energy¹⁸ among collocated companies.¹⁹

- *Sharing utility or ancillary services*—This kind of cooperation does not derive directly from the biological analogy, but the sharing of utilities or services may be an intermediary practice²⁰ that contributes to the establishment of industrial ecosystems. It relies on the pooling of participants' needs and resources, to attain more efficient solutions—for example, collective waste management (see Figure 1) and facilities sharing.
- *Exchanging materials and energy*—Inspired by the circular functioning of natural ecosystems, industrial ecology encourages interorganizational cooperation based on the reclamation of waste materials and energy²¹ according to the principle that a residue may be a resource (see Figure 2). These "output-input combinations" are a large constituent of a closed-loop economy.²² However, as they require a precise matching between the flows of the companies as well as a close cooperation between them, they remain intricate to implement.

These two kinds of industrial symbioses concretize into transactions with a built-in environmental effect²³ between the organizations involved in industrial ecosystems. Their potential benefits have been largely documented: additional revenue, reduced operating²⁴ and disposal²⁵ costs, and environmental impact.²⁶ However, as they constitute unintentional outputs that are closely regulated in

FIGURE 2. Output-input combination.

Source: Authors.

most countries, residues are not classical commodities.²⁷ The implementation of industrial symbioses often requires a reorganization of the production and logistical processes both at company and intercompany level. Indeed, not only regulatory²⁸ and technical²⁹ but also sociocultural³⁰ obstacles limit the possibilities of sharing or exchanging waste materials.

As waste management remains remote from the core business of most companies, it generally has a limited strategic dimension. Interorganizational cooperation regarding such materials is thus far from being perceived as a strategic priority.³¹ Furthermore, trade secrets and confidentiality relative to industrial processes can discourage companies from considering opportunities for cooperation.³² There is often a significant lack of trust³³ and communication about material and energy flows between companies, even if they are located in the same industrial area.³⁴ Indeed, companies that are identified for potential industrial symbiosis have generally little or no experience in working together.³⁵ Establishing eco-industrial transactions requires time and resources to analyze production processes, list inputs and outputs, search for matching opportunities among neighboring organizations, conclude partnerships, and so on. Perceived as time-consuming and remote from companies' core business, these practices are seen to imply considerable transaction costs.³⁶ As a consequence, opportunities of industrial symbioses do not often appear spontaneously, revealing a significant need of orchestration within industrial ecosystems.

The Need for Orchestration of Industrial Ecosystems

Industrial ecosystems involve diverse organizations establishing transactions that enable them to access new inputs and new value-added destinations for their residual outputs.³⁷ Even if reclamation and recovery practices existed for centuries,³⁸ waste is often seen as a source of costs. This antagonism between economic and environmental value remains common within the majority of companies.³⁹ As a consequence, the emergence of industrial ecosystems often requires more than pure market forces.⁴⁰

Thus, a major challenge arises: How to get companies engaged in value-creating cooperation regarding industrial ecology?

Networking and interorganizational cooperation are an important part of the implementation of industrial ecosystems,⁴¹ but the mere processes of implementation remain understudied.

Networks are interorganizational structures consisting of independent organizations involved in long-term relationships to achieve collective goals.⁴² They are complex entities⁴³ involving intricate relationships,⁴⁴ which are more than a set of dyadic ties.⁴⁵ Companies involved in networks are heterogeneous,⁴⁶ and their individual interests may be quite different and even contradictory. Moreover, networks may entail coordination problems.⁴⁷ As networks do not run themselves,⁴⁸ establishing effective and efficient networks⁴⁹ requires orchestration.⁵⁰

While matchmaking in networks has been studied, emphasis has been put on networks for technology development and innovation.⁵¹ Whether they are called brokers, matchmakers, or orchestrators, three main roles have been identified.⁵² First, the “Architect” creates and organizes the network. Second, the “Lead Operator” formally connects companies to actually make projects happen. Third, the “Caretaker” ensures that trust does exist in the network, allowing partners to collaborate.

However, we may wonder how matchmaking operates in the creation of ecosystems for industrial ecology? Indeed, industrial ecosystems are an unusual kind of interorganizational network⁵³ in which cooperation and transactions focus on waste and residual materials. Consequently, they may require specific orchestration.

First, “junk materials” are generally neglected by companies that consider them as negative in terms of value creation.⁵⁴ As industrial ecology brings junk materials back into fashion, a cognitive overlap seems necessary to disrupt the mental schemes of managers and bring a fresh perspective to these potential resources. Indeed, managers need to see residual materials as valuable resources.⁵⁵ The focus on residual materials as an object of interorganizational cooperation is a significant difference with the majority of networks that have been studied in management so far. Interorganizational networks generally focus more on innovation or research and development (where the potential role in value creation for the company is now obvious) than on potential collective solutions for waste management. Thus, waste and residual outputs are not a classical purpose of networking. Second, the role of matchmaker is often considered as varying according to the lifecycle of the network.⁵⁶ However, we do not know what the lifecycle of industrial ecosystems is. Third, interorganizational networks are often built on information systems, relying on virtualization of the organization and dispersion of partners.⁵⁷ However, in the case of industrial ecosystems, closed loops of residual materials are often organized in a limited geographical area.

Given these specific characteristics, it seems important to study the roles and actions of matchmakers in the context of industrial ecosystems. Indeed, even if companies start to realize the potential of circularity, they still need to learn how to incorporate it into their processes. Moreover, industrial ecology requires the presence of actors who are able to support and translate its disruptive logic.⁵⁸

Three Case Studies in Different Countries

Method

Sampling. We build our analysis of the contributions of a matchmaker to industrial ecology from three emblematic and international cases (Kalundborg in Denmark, the Québec region in Canada, and Dunkirk in France). In each of the three countries, these cases have been largely covered in media as successful cases. The industrial ecosystem of Kalundborg has already been studied in the academic literature,⁵⁹ but the two other cases are less well known. Enabling a comparative logic,⁶⁰ these cases provide three specific examples of the implementation of industrial ecology at an interorganizational level. If these industrial ecosystems are at different stages of advancement, all have resulted in the formation of eco-industrial transactions in the form of various output-input connections and shared services. While these projects emerged in different countries and at different times, sooner or later they all felt the need to resort to a matchmaker (see Table 1). We assume that a focus on the matchmakers' perspective may provide fruitful contributions in a managerial outlook.

Data Collection and Analysis. The three cases were first investigated through various sources of data. For each case, we have retrieved media coverage (and particularly articles from local and national press), scientific publications (particularly for the Danish case), website content (websites of local governments and third-party matchmakers for each case), waste diagnosis (particularly for the French case), essays and guides for practitioners (particularly for the Canadian and French cases), and reports on the industrial ecosystems (for each case). We have also led eight interviews (average duration of 110 min) with managers from four companies involved in the industrial ecosystem of Dunkirk in France, with managers from the Écopal matchmaker, and with the manager of a company who refused to become a member of the network. Moreover, participation in various events and conferences on the topic of industrial ecology has complemented our formal data with informal interactions and observation notes. The material constitutes thousands of pages that have been manually processed *via* multiple readings and interpreted through an iterative process⁶¹ using chronological and thematic analyses. The chronological analysis retraces the context—historical and institutional—in which each industrial ecosystem and its associated matchmaker has emerged, and their evolution over time. Then, a thematic analysis explores both primary and secondary data *via* systematic iterations between empirical materials, analyses, and the theoretical framework of this research (interorganizational cooperation and trust, network orchestration). The thematic analysis was used to produce inferences through the establishment of “patterns,” concepts and themes that were representative of the empirical material.⁶² A vertical analysis of each document (such as interviews, reports, and press) was associated to a horizontal analysis so as to identify emerging recurrences and differences, and to make comparisons between the cases. A set of codes was created to order and categorize the data, and then thematic trees were built to facilitate the conceptualization of the studied phenomenon. This analytical process has enabled a

TABLE I. Presentation of the Three Cases.

	Danish Case	Canadian Case	French Case
First output-input exchanges	1961	1993	1960
Geographical scale of cooperation	Kalundborg	Québec region (and Ontario) Eco-industrial projects have been developed in different areas: Bécancour, Lanaudière, Shawinigan, Rivière-du-Loup in Québec and Toronto in Ontario	Dunkirk
Nature of eco-industrial transactions	Output-input exchanges; energy, water, and waste materials		A portfolio of shared waste-management services, a barter system for the reuse of materials and objects and several output-input exchanges of by-products
Network members	Eight partners	Not available	101 members (mostly Small and Medium Enterprises)
Matchmakers			
Denomination	Kalundborg Symbiosis Centre	Technology Transfer Centre in Industrial Ecology (TTCIE)	Écopal
Creation	1996	1999	2001
Location	Kalundborg	Sorel-Tracy	Dunkirk
Founders	Industrial partners and the Kalundborg municipality	Public actors (the educational institution of Sorel-Tracy and a government agency)	Local companies (bottom-up logic) and local public institutions
Mission statement	To educate and build new partnerships (encouraging, facilitating, and managing eco-industrial interactions)	To educate companies and local governments in the Québec region about industrial ecology and enhance their performance through research and development and implementation of eco-industrial projects	To ensure local sustainable development by promoting the concept of industrial ecology through concrete and fruitful projects

Source: Authors.

better understanding of the contributions of each matchmaker and the processes of value creation for companies associated with its actions.

Results: The Contributions of Matchmakers to Industrial Ecology in Three Case Studies

The Danish Case

Genesis. Several decades ago, the port town of Kalundborg was the stage for the first experience of industrial ecology. In the 1960s, groundwater scarcity drove companies, especially the local refinery, to find alternative solutions for their water supply. This widely known,⁶³ advanced industrial ecosystem resulted from spontaneous and bilateral cooperation between six partners: an electricity-production plant, an oil refinery, a biotech company, a construction-product company, a waste-management company, and local government. Several factors fostered these exchanges: mutual economic gains (reduced costs and additional revenues), the presence of different but complementary industries (different types of production and needs, no direct competition), an open-management style, and a climate of trust.

The matchmaker. Over the years, the network has evolved to include new members and adapt industrial processes and exchanges to technology and regulatory changes. After several decades of relatively self-organizing cooperation, the collaborative dynamic was not easy to maintain, especially because of the turnover of staff within the different plants involved in the industrial ecosystem and the technical evolution of industrial processes. Even in the Kalundborg industrial ecosystem, a need for orchestration eventually appeared. As a result, the Kalundborg Symbiosis Centre was founded in 1996 to host academics and practitioners who wanted to learn from the Danish experience, as well as to continue the cooperative interactions within the network.

Educating people and disseminating circularity are the main goals of this matchmaker, which regularly offers educational tours. Moreover, the Kalundborg Symbiosis Centre is dedicated to encouraging eco-industrial cooperation and orchestrating the network by maintaining close contact between the current partners, as well as facilitating the integration of new ones.

In 2015, the creation of the Symbiosis Center Denmark, also in Kalundborg, demonstrates the political will to encourage industrial ecology at a wider scale. Founded “to make it easier for [companies] to become part of industrial [ecosystems],” this organization identifies and facilitates projects between potential partners. Its process of facilitation is composed of three steps: looking for potential cooperation *via* screening and assessment, then matching organizations, and finally anchoring partnerships and networks. This toolbox of methods supports the transformation of industrial processes toward circular and sustainable business models.

Current situation. The Kalundborg industrial ecosystem has enjoyed continuous growth for over 40 years. In 2015, 30 output-input exchanges were taking

place between eight main partners (seven private industrial companies and the local government of Kalundborg) linked by commercial agreements. These interactions are based on energy exchanges (e.g., steam, district heating, and warm condensate), water recycling (e.g., sewage, cooling water, deionized water, and sea water), and materials reclamation (e.g., gypsum, fly ash, slurry, bioethanol, sand, biomass, and lignin).

Transforming waste into valuable resources and reducing pollution and materials consumption generates annual economies that have been estimated as being of the order of €80 million. On the environmental side, 275,000 tons of CO₂ emissions are avoided every year; in 2010, three million cubic meters of water were saved thanks to recycling and reuse; desulfurization of flue gas produced 150,000 tons of gypsum that replaced natural gypsum; and biogas has been produced from yeast slurry generated during the production of insulin.

The Canadian Case

Genesis. The TTCIE (Technology Transfer Centre in Industrial Ecology) was created in 1999 to encourage the formation of industrial ecosystems in the Québec region.

The first one was launched in 2008 in the *Bécancour* industrial park following three steps: first, a year-long study to identify potential exchanges; second, the implementation of the identified exchanges; and third, starting in 2013, the continuation of detection and implementation of further materials and energy exchanges. In 2014, 29 exchanges were operational (e.g., water, metal, plastic, rubber, and oil), 53 were undergoing development, and 74 had been abandoned.⁶⁴

Between 2010 and 2012, the TTCIE continued to promote industrial ecology by contributing to the emergence of other industrial ecosystems (see Table 2).

The matchmaker. Since its creation in 1999, the TTCIE fosters cooperation to increase reuse and recycling. With its pivotal role, it promotes biomimetic thinking and contributes to industrial ecology through the creation of industrial ecosystems.

In 2005, the TTCIE launched the *Québec Industrial Waste Exchange Program*. This online marketplace supports companies' efforts in managing and reclaiming their residues. The TTCIE provides technical assistance to help them identify potential partners. More precisely, the exchanges address 19 types of secondary materials (e.g., acid, wood, oil, water, paper and cardboard, plastic, rubber, and glass) in 29 regions of Canada and the United States.

In 2013, the TTCIE published a guide providing a methodology and tools to initiate, implement, and perpetuate industrial ecosystems through five main steps: project definition, territorial diagnosis, participant recruitment and data collection, identification of potential exchanges, and, finally, implementation and monitoring. A set of economic, environmental, technical/logistical, and social indicators was also proposed for the assessment of the gains associated with eco-industrial

TABLE 2. Projects of Industrial Ecosystems Steered by the TTCIE.

Projects	Bécancour	Lanaudière	Shawinigan	Rivière-du-Loup	Toronto
Territory	Industrial park	Administrative region	Industrial parks	Town	Business park
Number of organizations	12	158	31	18	76
Project promoter	State-owned company (Société du Parc Industriel et Portuaire de Bécancour)	Economic development organizations	Economic development organizations	Town	Public-private partnership
Identified synergies	Step 1: 39 Step 2: 70 Step 3: 156	285	72	101	49

Source: TTCIE.

Note: TTCIE = Technology Transfer Centre in Industrial Ecology.

practices. In the same year, the TTCIE created *Synergie Québec* (synergiequebec.ca), an online platform facilitating information management and exchanges with regard to companies' residues with a program that automatically detects potential output-input combinations within each industrial ecosystem.

Current situation. Every year, the TTCIE supports about fifty projects of reuse and reclamation of residual materials: audits and sampling of residues, search of potential solutions for reclamation, and economic and technical feasibility tests. Since 2016, four new industrial areas⁶⁵ have requested its support in terms of training and technical assistance. All these initiatives, carried out at both different organizational (company and intercompany) and geographic (industrial or business park, town, or region) levels are facilitated by the TTCIE whose aim is to demonstrate the relevance of industrial ecology as an innovative model able to reorganize and sustain industrial activities.

The French Case

Genesis. Dunkirk is located in a highly industrialized area with metalworking, chemical/petrochemical activity, energy production, food processing, and logistics. This raft of heavy industries has generated high levels of pollution for decades (e.g., carbon and sulfur dioxide, nitrogen monoxide, volatile organic compounds, and particulates). These environmental stakes have nevertheless fostered partnerships to promote industrial ecology since the end of the 1990s. That is why Dunkirk is considered as the French cradle of the circular economy, whose principles have been propagated with the foundation of Écopal, an associative structure, in 2001. From this point onward, industrial ecology became a genuinely collective project under the auspices of this collaborative platform that orchestrates circularity among its members.

The matchmaker. From the beginning, Écopal has enabled its original members to meet each other and discuss their waste-management problems. As a “place” where companies could exchange business cards and information, this “waste club” prepared the ground for intercompany cooperation. Écopal members, especially Small and Medium Enterprises (SMEs), rapidly highlighted their difficulties in efficiently managing their waste in compliance with legal requirements, which included lack of time and information, unattractive pricing terms, and weak bargaining power compared with suppliers. As a result, they requested a collective solution. An initial shared collection was created in 2007 for paper and cardboard. Then, what might be termed as a “portfolio of shared waste-management services” was progressively built by Écopal for other types of waste: medical waste, hazardous waste, hydrocarbon separators, and so on. Here, Écopal plays a central role as it organizes this service by performing several key tasks: waste audit, specifications and invitations to tender, negotiations and selection of suppliers, and the drawing up of contractual documents. This service involves a tripartite structure, where the roles and the prerogatives of each partner are set out in a code of conduct (governing Écopal and supplier relations), a membership form (for relations between Écopal and network members), and an individual contract (between the supplier and network members).

From 2007 to 2009, 147 companies were also interviewed about their inputs and outputs. About 5,000 flows (raw materials, energy, waste, by-products, sludge and sewage, and unavoidable energy) were inventoried, and 30 opportunities for cooperation affecting 55 companies were identified; these included the sharing of services and exchanges of flows. Some of them have been concretized with the support of Écopal, such as exchanges of iron-ore or sulfuric acid. As a matchmaker, Écopal can rely on a diverse network of partners (e.g., research laboratories, environmental-services providers, and public authorities) helping it concretize the cooperation between its members (*via* technical, financial, logistical, and regulatory support). In parallel, Écopal participated in research projects to develop a methodology for the implementation of industrial ecology and to gain a better understanding of the contractual modes used by companies. Like its Canadian counterpart, Écopal has created in 2011 a system where “classified ads” related to circular economy are sent to its members. This barter platform enables them to reduce wastage by reusing some items and materials (e.g., pallets, straps, corrugated padding, plastic gloves, and wraps). Here again, Écopal positions itself as an intermediary that gathers, controls, and disseminates information within the industrial ecosystem.

More broadly, Écopal also supports the legitimization of industrial ecology at a regional scale. For instance, it co-organized (for three consecutive years) a dedicated event to promote industrial ecology with tours of companies considered as exemplars.

Current situation. In 2016, Écopal is steering a network of 101 members. The recruitment of new companies largely happens by word of mouth as a result of the climate of trust and the legitimacy that Écopal has built over the years. New

TABLE 3. The Portfolio of Shared Waste-Management Services of Écopal.

Type of Industrial Residues	Number of Participants per Collection	Collected Amount per Year	Frequency	Type of Treatment
Paper and cardboard	About 40 companies	67 tons	Twice a month	Local reclamation
Hazardous waste	Between five and eight companies	170 tons	Once a month	Local pooling and pretreatment Local and national reclamation
Archives	About seven companies	22 tons	Three per year	Local pooling Local pretreatment National reclamation
Ink cartridges	About seven companies	2000 ink cartridges	Six per year	Local pooling
Waste Electrical and Electronic Equipment	About five companies	8 tons	Four per year	Local dismantling Local reclamation as a priority
Batteries and accumulators	About two companies	0,50 tons	Once a month	Local pooling National reclamation
Hydrocarbon separators	About three companies	170 tons	Twice a year	Local reclamation

Source: Authors.

members represent a way to increase potential opportunities and redundancy,⁶⁶ which is critical in avoiding dependency problems between partners.

Every year, about 60 shared collections manage about 430 tons of industrial residues (see Table 3) enabling the sharing of transportation and processing costs, the sorting of residues in accordance with the regulation, and a local reclamation of the materials. These shared collections avoid the emission of 45 tons of CO₂ and generate a €210,000 of savings (which represents an average 20% saving on waste-management bills for each participant).

Synthesis

These compelling cases show how three different matchmakers proceeded to implement industrial ecology among local companies and motivate them to adopt new behaviors with regard to their waste. However, these experiences from three different countries differ in some of their characteristics (e.g., history, scope of the network, and types of partners). For instance, in Kalundborg, the first exchanges appeared spontaneously due to the local context, which was very favorable (geographical and cultural proximity). Kalundborg is indeed a small

town, and the managers of the main industrial companies belonged to the same circles, in which the first discussions were initiated. Oral exchanges and collective reflections were taking place even before a dedicated organization was established to facilitate the industrial ecosystem. This is a major difference with the two other cases, which involved more planning; this was especially true for the Canadian case where the official launch of eco-industrial projects occurred following the foundation of the TTCIE. However, even where there are a few spontaneous eco-industrial transactions, a matchmaker may rapidly become key to spreading circularity and expanding the network by integrating new partners. In Kalundborg and Dunkirk, there are many large industrial companies, but in the Écopal case, it is SMEs that are mainly targeted. In fact, materials and energy exchanges are already taking place between large companies without the support of Écopal. Conversely, small businesses require momentum and support to implement industrial ecology. Moreover, the initial motivation was not identical in each case. For instance, in Kalundborg, it was a chronic shortage of water that pushed local businesses to initially cooperate. In Dunkirk, it was pollution and the proximity between a large number of industrial companies and residential areas that led to collective and concerted action and, later, to the creation of Écopal. The Danish regulatory framework also played a key role in the development of industrial ecology by driving companies to find solutions to reduce their pollution,⁶⁷ whereas in France, current regulation remains very strict regarding waste reuse, which limits the numerous opportunities identified by Écopal. However, in the three cases, the dense industrial base has increased possibilities in terms of materials and energy exchanges, and a third-party matchmaker has accelerated and institutionalized eco-industrial transactions between local companies.

Implementing Industrial Ecology: Four Strategic Contributions for the Matchmaker

Industrial ecology is far from being easy to implement as it remains an unconventional field of interorganizational cooperation. For instance, companies have to learn how to rethink their processes and see their junk materials⁶⁸ as potential resources. Moreover, technical and chemical aspects are not sufficient to reorganize industrial processes. Industrial ecology indeed requires new standards and new behaviors based on mutual trust and openness, a spirit of cooperation, and a focus on collective responses to environmental challenges. Social and cultural aspects are then important to change the mindsets regarding waste.

Following are four strategic contributions for the matchmaker.

Revealing Value in Industrial Ecology

The use of residual materials as resources is not mainstream as it still has a persistent negative image among companies. Individual and collective mind-sets must evolve to enable industrial ecology to pervade organizational behaviors.

The matchmaker must affect the cognitive dimension of the managers so as to encourage eco-industrial cooperation at the interorganizational level. Raising environmental awareness and promoting the use of residual materials as potential and valuable resources are indeed prerequisites. Put another way, the matchmaker helps managers make sense of industrial ecology. It must then develop a specific rhetoric considering the constraints and specifics of local companies. This “speech” used to convince managers regarding the potential of industrial ecology must particularly highlight its economic stakes.⁶⁹ Indeed, most managers are first interested in the economic value—especially in SMEs, which have limited resources and lack of efficient alternatives regarding their residues.

Some of the arguments that help matchmakers reveal the potential benefits of industrial ecology for companies are as follows. Economically, using residues as inputs provides companies an access to local suppliers, which represents a way to save money⁷⁰—especially on transportation—while obtaining cheaper resources. Sharing services increases companies bargaining power through the pooling of their needs.⁷¹ Increased resource efficiency, reduced waste disposal costs, cheaper raw materials, additional revenues, shared investments, and reduced dependency on classical raw material channels are the main sources of economic value resulting from industrial ecology. On the environmental side, real progress is also possible in terms of reduction of CO₂ emissions and other sources of pollution as industrial ecology stimulates partnerships with industries and suppliers that locally reclaim the residual materials.

By explaining that potential economic and environmental value may result from the practice of industrial ecology, the matchmaker shows that residues are not always destructive of value. Through its discourses, it contributes to give meaning to industrial ecology and favors the social acceptability of such projects. Progressively, managers add industrial ecology to their cognitive repertoire and benefit from a range of concepts and tools enabling them to conduct their business more virtuously.

Regarding the cognitive dimension, changing individuals’ perception regarding waste materials is not sufficient. A collective awareness and sense of action are necessary. Without dialogue and mutual trust, managers cannot activate the potential opportunities for eco-industrial cooperation at the interorganizational level.

Generating Trust

As many authors have already shown, intermediaries are crucial within networks to generate communication and trust between companies and their members.⁷² The matchmaker provides a “neutral” platform where managers meet, share their problems,⁷³ and develop a collective consciousness and common interests. Under its leadership, they can understand their respective constraints and needs, and learn to cooperate. By breaking down cognitive barriers and giving them the opportunity to interact, the matchmaker progressively reduces mental distance.⁷⁴ Codes of conduct, confidentiality charters, partnership

agreements, and other artifacts help the matchmaker overcome some obstacles such as trade secrets and the fear of becoming dependent on others. The matchmaker partially assumes the costs of trust creation⁷⁵ as it invests time and resources⁷⁶ to develop a cooperative climate among companies. Thus, by taking deliberate actions,⁷⁷ it stimulates interpersonal and interorganizational trust,⁷⁸ which, in turn, reduces transaction costs.⁷⁹ As a guarantor of other members' behavior and a safeguard against opportunism,⁸⁰ the matchmaker is an architect of trust.⁸¹ However, industrial ecosystems characterized by a high level of trust take several years to construct. Thus, patience, commitment, and perseverance are the keywords for the matchmaker's employees. Furthermore, the matchmaker also has a role to play in maintaining the commitment and involvement of network members over time⁸² by using diverse modes of communication and coordination.

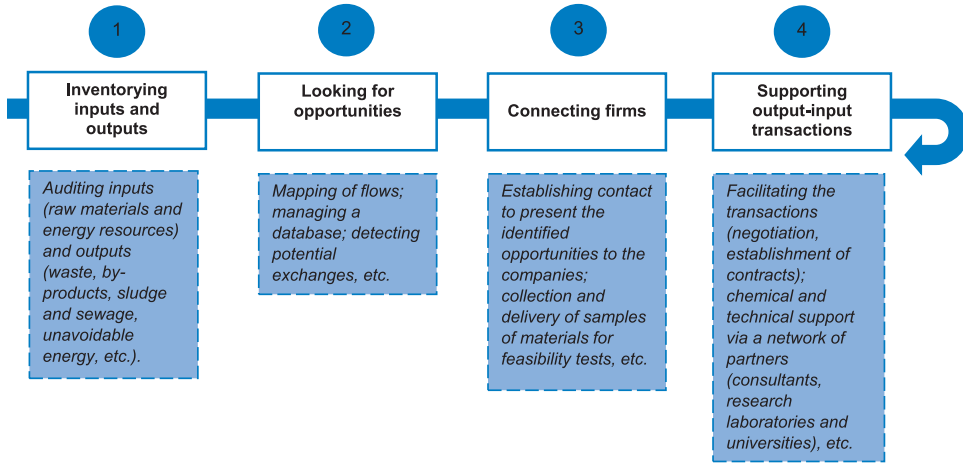
Changing the perception of residues and generating trust between companies are significant milestones during the development of an industrial ecosystem. However, implementing industrial ecology also requires concrete transactions between the participants. To this end, several tasks remain essential before latent opportunities can become real eco-industrial transactions.

Activating Industrial Ecology

Generally, managers only have few options available in mind for managing their residues, especially because of their bounded rationality⁸³ and also because residues are not a strategic concern in most companies.⁸⁴ Interorganizational cooperation does not usually come to mind among managers to increase the efficiency of the management of their residual materials.⁸⁵ At that point, the matchmaker shows the alternatives and possibilities in terms of industrial ecology. It then will activate them to transform latent opportunities into real eco-industrial transactions.

However, several tasks are essential to develop transactions integrating junk materials,⁸⁶ and companies often must reorganize their processes. Indeed, even if industrial ecology generates new complementarities, such practices remain time-consuming and entail significant transaction costs.⁸⁷

The implementation of industrial ecology may be facilitated by a gradual approach⁸⁸ through intermediate steps such as the institution of a range of shared services.⁸⁹ As output-input exchanges may be quite difficult to build from scratch, shared waste-management services, for instance, can constitute a first and less risky step for the companies. In this case, they only pool their waste to increase their bargaining power⁹⁰ while the matchmaker supports the creation of a portfolio of shared services by auditing their needs, inviting suppliers to tender, establishing a contractual framework, and coordinating operations. Shared services represent a first way to create economic and environmental value for the participants. Concerning waste management, for instance, companies can save time and money on waste disposal: storage, transportation, and treatment costs through the matchmaker negotiations (e.g., free services, preferential rates, costs sharing,

FIGURE 3. How to close loops? The matchmaker's contributions.

Source: Authors.

and recourse to local suppliers). The pooling of residues that were previously disseminated (and separately collected) also enables the creation and the perpetuation of local recycling channels. However, such practices require constant efforts of organization and monitoring from the matchmaker. Nevertheless, these “quick wins”⁹¹ may represent a considerable lever for industrial ecology by demonstrating the potential value creation resulting from junk materials.⁹² They are thus useful to convince companies to go further.⁹³

Identifying potential partners for output-input combinations is crucial for the implementation of industrial ecology. Yet it remains intricate as eco-industrial networking focuses on materials strictly regulated and usually neglected by the companies. Our results confirm that matchmakers have a significant role during this “matching phase.”⁹⁴ From the audits enabling the identification of companies’ inputs and outputs (e.g., nature, quantities, and frequencies, which are then listed in a database used to search for potential connections) to the support provided to concretize the transactions, the matchmaker may intervene throughout the process (see Figure 3).

As a broker,⁹⁵ the matchmaker looks for opportunities and connects the companies according to their residual flows.⁹⁶ Because of its overview of the industrial area it operates in, the matchmaker is particularly useful for recognizing unusual interdependencies and thus activating the opportunities. It centralizes information, steers collective actions, and, at the same time, absorbs transaction costs⁹⁷ resulting from search, information, and bargaining activities, and thereby it reduces opportunism.⁹⁸ For instance, managing an industrial-residues marketplace or a barter system provides companies with a platform that organizes information and facilitates the creation of exchanges of materials and residues. Thus, companies have access to more efficient solutions while reducing their environmental impact, and they learn to transform junk materials into valuable inputs.

As our results confirm, numerous opportunities fail because of economic, technical, or regulatory obstacles.⁹⁹ There is not a one best way to achieve industrial ecology, as the transactions developed in a given context cannot be automatically duplicated elsewhere. Thus, matchmakers should take into account the constraints and specifics of companies that differ greatly from one industrial area to another so that they can develop customized solutions.¹⁰⁰

Once the industrial ecosystem has appeared and transactions occur between its participants, the results should be disseminated to institutionalize industrial ecology and its circular logic at a larger scale.

Institutionalizing Industrial Ecology

Where there is no will on the part of companies themselves, a matchmaker is essential from the beginning to bring companies together and trigger cooperation. In serendipitous networks¹⁰¹ that have spontaneously appeared, like that in Kalundborg, a matchmaker is not necessary as long as the participants are able to interact and coordinate activities with each other. However, industrial ecosystems imply a dynamic process,¹⁰² with the appearance of new transactions between the partners and disappearance of others. Over time, this collaborative dynamic may be difficult to maintain, especially when there is a high turnover within the companies. The institution of a matchmaker may become vital in the long term to perpetuate the network¹⁰³ as well as integrate new partners.

The emergence of such structures also generally marks the beginning of the institutionalization of industrial ecology as a genuine strategy for the participants and, more broadly, for the industrial area. The matchmaker can thus contribute to the institutionalization of industrial ecology, especially by sharing information and feedbacks beyond the industrial ecosystem boundaries. By facilitating and orchestrating eco-industrial transactions inside the network, it generally has a central and legitimate position from which to highlight the achievements of the network. Here, the matchmaker may act as an ambassador to communicate the “success stories” and promote the cause of industrial ecology. Attending academic and professional conferences and workshops, publishing articles and books dedicated to practitioners and researchers, administering a website or online platform, and organizing tours and themed events—these are some of the many ways that a matchmaker can share its experience and help other organizations, other industrial areas, and even other countries to discover industrial ecology and its “share-reuse-prolong” model.¹⁰⁴

Nevertheless, the economic and environmental benefits of industrial ecology often remain unknown and poorly documented. One of the main reasons for this is a lack of indicators. Where indicators exist, they tend to be underused, either due to lack of time or because companies are reluctant to communicate the results. Here again, the matchmaker has a relevant position in developing a range of indicators (as the TTCIE in Canada began to do). A better appreciation of potential benefits associated with industrial ecology will ensure more appropriate and meaningful communication, and will lead to more tangible results. Finally, the presence

TABLE 4. Implementing Industrial Ecology: Four Strategic Roles for the Matchmaker.

Strategic Contribution	Associated Actions
Revealing value in industrial ecology	<p>The matchmaker contributes to change individual and collective mind-sets regarding residual materials by:</p> <ul style="list-style-type: none"> • Raising environmental awareness within companies; • Promoting the use of residual materials as valuable resources; • Highlighting the potential economic and environmental value resulting from industrial ecology.
Generating trust	<p>The matchmaker generates interpersonal and interorganizational trust to ensure a collective awareness and sense of action by:</p> <ul style="list-style-type: none"> • Activating communication and reducing mental distance between the companies via a neutral platform; • Creating artifacts like codes of conduct, confidentiality charters, partnership agreements as safeguards against opportunism.
Activating industrial ecology	<p>The matchmaker supports the creation of eco-industrial transactions by:</p> <ul style="list-style-type: none"> • Identifying and implementing potential transactions in the forms of shared services, input-output exchanges, barter system...; • Absorbing and reducing the associated transaction costs through the carrying out of several tasks.
Institutionalizing industrial ecology	<p>The matchmaker contributes to the institutionalization of industrial ecology by:</p> <ul style="list-style-type: none"> • Sharing feedbacks and success stories of its industrial ecosystem; • Building indicators for the assessment of the economic and environmental value resulting from eco-industrial transactions.

Source: Authors.

of the matchmaker ensures better understanding of the process of implementing industrial ecology. If documenting successes is important, then failures, which are numerous, are just as interesting. Therefore, reasons for failure need to be more thoroughly investigated to understand the technical, regulatory (e.g., the legal status of waste), and economic obstacles that still hamper industrial ecology.

Conclusion

Drawing on the circular functioning of natural ecosystems, industrial ecology suggests the reuse of industrial residues to create material loops and reduce the environmental footprint of companies. Matchmakers represent a significant lever to implement industrial ecology at the interorganizational level. Table 4 summarizes the activities associated with the implementation of industrial ecology and the four strategic roles of a matchmaker in an industrial ecosystem.

Through industrial ecology, companies discover new areas for inter-organizational cooperation involving industrial residues. First, the support of

a matchmaker can be very important as residues are rarely a strategic concern for companies. Indeed, this focus on materials that are usually devaluated challenges the cognitive schemes of managers and existing businesses' habits and practices. Second, as industrial ecology also requires a collective awareness and sense of action, the matchmaker can also serve as a trigger of inter-organizational trust. Third, managing residues is not naturally an important concern for companies, and the matchmaker can be useful for the detection and establishment of potential eco-industrial transactions. Fourth, it contributes to the institutionalization of industrial ecology by sharing feedback and success stories.

The strategic contributions of the matchmaker are important to build and sustain successful processes for industrial ecology. While some roles may look quite similar to those identified in the literature on innovation networks, it appears that network orchestration in industrial ecosystems also supposes specific contributions as companies may not be aware of the potential value creation associated with closing loops and exploiting residues. Moreover, the fact that the matchmaker is a third party militating for industrial ecology leads it to promote best practices and try to institutionalize some aspects of circular economy beyond the initial network of partners.

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