

# Eco-Industrial Parks

## The Case for Private Planning

Pierre Desrochers

### Introduction

An eco-industrial park (EIP) is a community of companies, located in a single region, that exchange and make use of each other's by-products or energy. Currently, EIPs are being promoted as a way of encouraging sustainable development. Proponents argue that such a symbiotic community of businesses produces more environmental benefits than each company can realize on its own. Numerous EIPs have been planned in North and South America, Southeast Asia, Europe and Southern Africa (Ayres 1996; Indigo Development 1998; Gertler 1995; Lowe 1997).<sup>1</sup>

---

*While the Kalundborg community developed entirely through market forces, many policy analysts argue that public planners can copy and even improve upon Kalundborg.*

---

Advocates of EIPs consider the Danish coastal city of Kalundborg a model. There, the main industries and the local government turn by-products into raw materials by trading and making use of their waste streams and energy resources. While the Kalundborg community and other similar cases<sup>2</sup> developed entirely through market forces (Garner and Keoleian 1995; Gertler 1995; Lowe, Moran, and Holmes 1996; Schwartz and Steininger 1997), many policy analysts argue that public planners can copy and even improve upon Kalundborg.

Thus, Hawken (1993, 63) speculates: "Imagine what a team of designers could come up with if they were to start from scratch, locating and specifying industries and factories that had potentially synergistic and symbiotic relationships." Similarly, van Der Ryn and Cowan (1996) suggest that the possibilities for planned industrial ecosystems are even greater than the industrial ecosystem that evolved in Kalundborg. Lowe (1997, 58) points out that "while industrial ecosystems must be largely self-organizing, there is a significant role for an organizing team in educating potential participants to the opportunities and in creating the conditions that support the development."

Despite such endorsements, the movement toward public planning of eco-industrial parks is misconceived. It rests on a misreading of the Kalundborg experience and reflects insufficient knowledge of how market forces have historically promoted resource recovery. This essay will show that Kalundborg is simply a contemporary illustration of how industrial loops have always worked. It will also compare private and public mechanisms in the development of industrial loops, and it will argue that greater reliance on market forces would be a more effective way of replicating the Danish experience.

## **The Rationale for Planning Eco-Industrial Parks**

While some people consider all waste as a hazard to health and the environment that must be destroyed or prevented, many others consider waste as an economic resource (Sinha 1993). Many who view waste as a resource label themselves “industrial ecologists,” drawing on an analogy with the natural world in which living organisms consume each other’s wastes. The premise of industrial ecology is that modern industrial economies should mimic the cycling of materials in ecosystems throughout the processes of raw material extraction, manufacturing, product use, and waste disposal. Industrial ecologists view industries as webs of producers, consumers, and scavengers, and they encourage symbiotic relationships between companies and industries. The ultimate goal of industrial ecology is to reuse, repair, recover, remanufacture, or recycle products and by-products on a very large scale (Allenby and Richards 1994; Ayres and Ayres 1996; Frosch and Gallopoulos 1989; Garner and Keoleian 1995; Graedel and Allenby 1995).

Some industrial ecologists and public planners envision eco-industrial parks as networks of companies and other organizations that exchange and make use of by-products. By integrating principles of industrial ecology with principles of pollution prevention and sustainable design, such regionally localized firms should, in the view of industrial ecologists, provide one or more of the following benefits over traditional, nonlinked operations:

- reduction in the use of virgin materials;
- reduction in pollution;
- increased energy efficiency;
- reduction in the volume of waste products requiring disposal;
- increase in the amount and types of process outputs that have market value (Gertler 1995).

## The Kalundborg Experience

Most industrial ecologists believe that Kalundborg, a small city on the island of Seeland, 75 miles west of Copenhagen, is the first recycling network in history (Garner and Keoleian 1995; Gertler 1995; Lowe, Moran, and Holmes 1996; Schwarz and Steininger 1997). In this city of 20,000, the four main industries—a coal-fired power plant (Asnæs), a refinery (Statoil), a pharmaceuticals and enzymes maker (Novo Nordisk), a plasterboard manufacturer (Gyproc), as well as the municipal government and a few smaller businesses—feed on each others' wastes, in the process turning them into useful inputs.

This local synergy began to form in the 1970s and now goes somewhat like this: The Asnæs power company supplies residual steam to Statoil refinery and, in exchange, receives refinery gas that used to be flared as waste. The power plant burns the refinery gas to generate electricity and steam. It sends excess steam to a fish farm that it operates, to a district heating system serving 3,500 homes, and to the Novo Nordisk plant.<sup>3</sup> Sludge from the fish farm and pharmaceutical processes becomes fertilizer for nearby farms. The power plant sends fly ash to a cement company, while gypsum produced by the power plant's desulfurization process goes to a company that produces gypsum wallboard. Finally, the Statoil refinery removes sulfur from its natural gas and sells it to Kemira, a sulfuric acid manufacturer.

### A Gradual Development

Consultants did not design, nor did Danish government officials finance, Kalundborg's industrial symbiosis. It was, rather, the result of many separate bilateral deals between companies that searched to reduce waste treatment and disposal costs, on the one hand, and, on the other, to gain access to cheaper materials and energy while generating income from production residue. Today, there is still no higher level of administration managing their interaction (Lowe 1997, 59). Jorgen Christensen, a spokesperson for Novo Nordisk, is explicit on that point: "I was asked to speak on 'how you designed Kalundborg.' We didn't design the whole thing. It wasn't designed at all. It happened over time" (Lowe 1995, 15).

Henning Grann, a Statoil employee, reinforces the point: "The symbiosis project is originally not the result of a careful environmental planning process. It is rather the result of a gradual development of co-operation between four neighboring industries and the Kalundborg municipality" (Garner and Keoleian 1995, 28). As Gertler (1995, n.p.) sums it up, the basis for the Kalundborg system is "creative business sense

and deep-seated environmental awareness,” and “while the participating companies herald the environmental benefits of the symbiosis, it is economics that drives or thwarts its development.” Much of Kalundborg’s “industrial metabolism” rests on the physical proximity of plants that are compatible in terms of their material flows, plus a few well-established and widespread industrial practices, including the cogeneration of electricity and heat, the hydro-desulfurization of gas, the heating of greenhouses from excess power plant heat, and standard transportation and purification technologies.

Using Kalundborg as the model, EIP advocates often argue that public planners, following a hierarchy of consciously chosen objectives, can outperform private agents whose priority is to maximize profit rather than promote sustainable development (Hawken 1993; van Der Ryn and Cowan 1996). The idea of planning EIPs has gathered momentum in academic, business, and political circles. Numerous EIP projects are now underway in North and South America, South Africa, Asia, and Europe. In the United States, the concept has won the support of the President’s Environmental Technology Initiative (ETI), the President’s Council on Sustainable Development (PCSD), and the Environmental Protection Agency, which created an Eco-Industrial Park Project in 1994. Several areas have been designated “demonstration sites” for EIP in the United States.<sup>4</sup>

### **Reading Too Much into Kalundborg**

EIP advocates fail to recognize that Kalundborg’s industrial symbiosis is not self-sufficient and is not limited to the industrial park. For example, Statoil (sulfur) and Asnæs (fly ash and clinker), both located in Kalundborg, sell some of their by-products to Kemira and the Aalborg Portland cement company, whose plants are located on the Jutland peninsula. Gyproc imports its supply of virgin gypsum, still a significant input, from 2,500 miles away in Germany and even from Spain, while in the early 1990s Asnæs fish farms mostly exported the 200 tons of trout and turbot they produced annually to the French market.

Furthermore, many of Kalundborg’s plants are subsidiaries of foreign-owned corporations (Statoil is a Norwegian firm, Gyproc is owned by a Dutch company, etc.) In short, Kalundborg is a typical industrial city, a nexus of trade whose firms import and export numerous components and products on a worldwide scale (Gertler 1995; Lowe, Moran, and Holmes 1996; Tibbs 1992).

No Kalundborg company ever acted on its own upon opportunities that did not fit within its core business, no matter how environmentally attractive they were. And when government intervention forced a linkage, the venture lost money.<sup>5</sup> Additionally, even though each company

considers the others when making decisions, it still evaluates its own agreements independently. There is no “Kalundborg-wide” assessment of performance because participating companies believe that this would be a complex and unrewarding standard (Lowe, Moran, and Holmes 1996, C7). A final point that EIP planners should note is that the development of Kalundborg’s “industrial ecosystem” required environmental regulatory flexibility.<sup>6</sup>

As interest in EIPs increases, so has research, which has brought other examples of industrial symbiosis to light. In a research project tracking industrial loops,<sup>7</sup> Schwarz and Steininger (1997) documented the same phenomenon in the Austrian province of Styria. The authors concluded that, as in Kalundborg, cost calculations triggered the development of the Styrian structure. These findings spurred further research in the Ruhr region of Germany, which resulted in qualitatively similar results (Schwarz and Steininger 1997, 50). Scholars of EIPs have also discovered that the same processes have been going on for a long time in major petrochemical complexes such as the Houston Ship Channel (Lowe, Moran, and Holmes 1996, A4). How unique then *is* Kalundborg? The Danish city’s experience is but a contemporary version of processes that are as old as cities.

## Industrial Symbiosis in Historical Perspective

As we will see, industrial symbiosis—that is, exchanges between firms in which by-products of one industry become the valuable inputs of another—are probably as old as civilization. Certainly, long before the advent of modern environmental consciousness and regulation, documents and texts were published containing detailed illustrations of by-product reuse in different industries. Some examples include: *Waste Products and Undeveloped Substances: Or, Hints for Enterprise in Neglected Fields* (Simmonds 1862), and *The Recovery and Use of Industrial and Other Waste* (Kershaw 1928). (See Appendix for additional examples.) Other illustrations can also be found in patent records, graduate theses, and the serial *Waste Trade Directory*, which was published, beginning in 1905, by the Atlas Publishing Company. These periodicals were “revised every year to include vital, complete, up-to-the-minute listings of Dealers, Consumers, Associations, Consultants, Processes and Processors, Equipment... covering the Continent and all 50 states” (Lipsett 1963, 407). The same publisher’s *Waste Trade Journal* covered “every aspect of the giant Secondary Materials Industry . . . of the Free World,” while its monthly affiliate *Industrial Wastes and Salvage Journal* provided a “complete roundup of national and world markets in new and secondary materials”

(407).

The importance of industrial loops was obvious to many commentators of the past. In his classic *On the Economy of Machinery and Manufactures*, the English polymath Charles Babbage (1835, 217) wrote that preventing waste in industrial production often caused “the union of two trades in one factory, which otherwise might have been separated.” As Simmonds (1862, 2) observed a few decades later, “in every manufacturing process there is more or less waste of the raw material, which it is the province of others following after the original manufacturer to collect and utilize. This is done now, more or less, in almost every manufacture, but especially in the principal ones of the [United Kingdom]—cotton, wool, silk, leather, and iron.” Some years later, the authors of the *Descriptive Catalogue of the Collection Illustrating the Utilization of Waste Products* of the Bethnal Green Branch of the South Kensington Museum also noted that many ingenious persons were busily devising “means by which rubbish may be worked up into a useful product,” and that there were “few . . . great manufactures now which have not one or more of these dependent industries attached to them. These secondary products are all examples of one form of the utilization of waste” (Bethnal Green Branch Museum 1875, 4).

Following the First World War, some English commentators marveled at the Germans’ ability to turn waste products into resources (Spooner 1918; Talbot 1920). Talbot (1920, 19) thus wrote that “the German, when he encounters a waste, does not throw it away or allow it to remain an incubus. Saturated with the principle that the residue from one process merely represents so much raw material for another line of endeavor, he at once sets to work to attempt to discover some use for refuse.” What is now termed “industrial symbiosis” was therefore prevalent in advanced economies a century ago.

### **Cities as Industrial Loops**

Many authors have noted the important role that cities historically have played in resource recovery (Rathje and Murphy 1992; Sicular 1981; Sinha 1993). For example, nineteenth century Parisian writers such as Beaudelaire, Hugo, and Zola wrote moving tributes to the agricultural uses of the urban waste of the French capital (De Silguy 1989). The same processes were going on in all major European and North American cities (Bertolini 1990; De Silguy 1989; Sicular 1981). De Silguy (1989, 78) attributes the success of nineteenth century Flemish agriculture, whose yields were three to four times those of French agriculture, to a richer supply of urban products used as compost. Countless other illustrations of resource recovery can also be found in old texts.<sup>8</sup>

Jacobs (1970, 107–17) gives many similar examples from the second half of the twentieth century. She writes about one producer of book paper that refers to New York City as its “concrete forest,” but she argues that viewing cities as “waste-yielding mines” might be a more appropriate metaphor. Unlike typical mines, whose resources may be depleted over time, she notes that cities will become richer the more actively and longer they are exploited. This is because new veins, formerly overlooked, will be continually opened. She also adds: “The largest, most prosperous cities will be the richest, the most easily worked, and the most inexhaustible mines” (111).

Perceiving cities as mines has a history. For example, it was used in a more literal sense by Bernard Ostrolenk (1941, 21) in his classic economic geography textbook:

Even the sources of important raw commodities are changing. . . . The time is not far distant when New York, with its growing production of scrap iron and scrap copper from junked buildings, machinery, automobiles, etc., will be as important a source of raw material for metal industries as is the Mesabi Range or Anaconda.<sup>9</sup>

In the 1920s, Clemen cited the conditions necessary for commercially successful waste utilization. Historically, cities have fulfilled most of these stipulations: 1) a practical commercial process of manufacture; 2) actual or potential market outlets for the new proposed by-products; 3) adequate supplies of the waste used as raw material, gathered in one place or capable of being collected at a sufficiently low cost; 4) cheap and satisfactory storage; and 5) technically trained operatives (1927, 1).

Talbot’s comments in the conclusion of his book *Millions from Waste* provide evidence that cities fulfill Clemen’s third condition. Talbot (1920, 303) notes that “co-operative and individual methods [of resource recovery] . . . can only be conducted upon the requisite scale in the very largest cities where the volume of material to be handled is relatively heavy. Waste must be forthcoming in a steady stream of uniform volume to justify its exploitation, and the fashioning and maintenance of these streams is the supreme difficulty.” Cities typically facilitate cooperation among individuals by facilitating the communication of tacit knowledge, whether technical or commercial, and the development of trust relationships (Desrochers 1998).

The recovery of perishable industrial waste illustrates the historical function of the city in resource recovery. Some of the oldest urban archeological evidence of resource recovery comes from the late Stone Age city of Çatal Hüyük, in central Turkey. It appears that workers who

specialized in recovering bones made awls, punches, knives, scrapers, ladles, spoons, bows, scoops, spatulas, bodkins, belt hooks, antler toggles, pins and cosmetic sticks (Mellaart 1967, 214–15). Some texts written in the Roman era describe shops located near slaughterhouses that turned bones and ivory into items such as pins, tokens, buttons, components of hinges, and wall fittings (Chevalier 1993).

In the early history of eastern American cities, swine were frequently raised near liquor distilleries where they were fed on the mash (Bogart 1936, 300). One could observe the same phenomenon in Belgium, where beginning in the early nineteenth century, most distilleries relocated from the countryside to cities in order to secure markets for their by-products (Dechesne 1945, 51). In New York City most of the milk was produced in 260 city stables by cows living on the swill of local distilleries (Miller 1998, 78).<sup>10</sup>

In his classic study on “the economic basis of urban concentration” conducted in the early twentieth century, Haig explained why, despite the advent of artificial refrigeration, perishability remained an important factor in determining the location of certain fabricating functions.

Thus if articles which spoil quickly are to be preserved by drying or canning, these processes are usually best performed near the point of extraction. New York City’s canneries prove, upon analysis, to be, for the most part, salvage plants designed to preserve the surplus supplies of temporary glutted markets, supplies which would otherwise decay and be wasted. Perishability during some intermediate process of fabrication tends to bind processes together at one place. (Haig 1926, 191)

### **Trade and the Open Nature of Urban Industrial Loops**

So, cities have always exhibited a large number of industrial loops. While this history gives support to the idea of industrial ecology, proponents of EIPs often fail to consider that these industrial loops existed because of trade. That is, cities have never been closed or self-sufficient systems, but rather open systems where various inputs and by-products are imported and exported. For example, most of the raw materials used in Çatal Hüyük, with the exception of clay, reeds and wood, were not locally available (Mellaart 1967, 212).

That trade is an inherent characteristic of industrial loops is supported by other examples of urban recovery in the last two centuries. The United Kingdom imported more than 6000 tons of horns and hoofs and approximately 92,000 tons of bones from giraffe, elephant, horse, ox, buffalo, and whale each year in the 1870s for remanufacture (Simmonds



1875, 133–47). But this was in addition to a domestic production of bones thought to be between 70,000 and 80,000 tons (Bethnal Green Branch Museum 1875, 49).<sup>11</sup> Most of those imports went to London, Birmingham, and Sheffield (Simmonds 1875, 133–47). For example, every year in Sheffield about two million shank bones of oxen were turned into knife-handles, spoons, nail brushes, combs, fans, bone flats for button molds, and various other miscellaneous articles. This was, however, only part of their use.<sup>12</sup>

Much the same processes were going on in major cities around the world. In the middle of the nineteenth century, some 375,000 animals a year were slaughtered in New York’s “animal district,” located a few hundred feet from Times Square. Although the area was probably extremely unsanitary by today’s standards, it was yet another prototype of EIP, where no potential resource was wasted. Bones became handles, buttons, and inputs in textile coloration. Entrepreneurs converted marrow into tallow that chandlers, soap-makers, and the rapidly expanding chemical industry found valuable. Sugar refiners and fertilizer producers made use of residual blood. Hooves became gelatin and “Prussian Blue,” while hides and hair were valuable commodities, and whatever remained was hog food (Miller 1998, 82). Yet not only locally produced bones became valuable commodities; many railway cars freighted with buffalo bones arrived in the metropolis for transformation into button molds, knife handles, and other uses (Simmonds 1875, 98).<sup>13</sup>

With the advent of the Chicago stockyards the supply of animal by-products became so regular and important that chemistry techniques led to the creation of new and different products (Clemen 1927). The earliest innovative work of chemists focused on food products such as oleo-margarine and beef extract but eventually turned to more distant fields such as pharmaceuticals, explosives, lubrication oils, and cosmetics (Clemen 1923). Soon enough, “Packingtown” became a model EIP, as a number of separate satellite industries that bought unfinished by-products grew around the mammoth slaughtering plants. Large refineries took the non-uniform, steam-rendered lard of packers, refined and bleached it, and sold it on the open market. Soap factories bought various grades of tallow. Glue works made glue from bones, sinews, and various other packing-plant materials. Butterine manufacturers used neutral lard and oleo oil from packing plants to manufacture oleomargarine. Fertilizer plants carted off the pressed tankage and raw or pressed blood, dried and sold it as such, or manufactured mixed fertilizer (Talbot 1920; Clemen 1927).

These by-product manufacturers, irrespective of whether or not they were formally affiliated with a giant meat-packing firm, bought their materials partly from packers and partly from outside concerns. For example, in the manufacture of compound lard, the purchase of vegetable

oils was necessary. The same was also true of the soap industry, which needed many materials that were not necessarily by-products of the meat-packing industry (Weld, Kearney, and Sidney 1925, 141). The livestock supply that went into the Chicago packing plants came from twenty-seven states (137) and the output was then marketed throughout America, either directly by the packers or through various brokers (169).

## Private Planning in the Creation of Eco-Industrial Parks

Even though all successful localized industrial parks developed through the normal course of business, many scholars and planners contend that public intervention is necessary to create EIPs (Hawken 1993; Indigo Development 1998; Lowe 1997; van Der Ryn and Cowan 1996). The American response largely has been to look to the Danish example as illustrative and to seek more proactive ways to model and imagine eco-industrial possibilities. However, public planning efforts are not likely to outperform market forces. To understand why, it is useful to compare the characteristic features of private and public planning.

Markets are spontaneous orders sustained by an institutional framework dominated by the pricing process and private property rights. Private planning through a market relies heavily on decentralized decision-making and a trial-and-error process of discovery and improvement. Unlike public planning, the market itself has no specific purpose and is essentially an arena of voluntary exchanges in which the private goals of individual actors tend to be coordinated (Ikeda 1995). The creation of localized industrial symbiosis is a fairly common outcome of those processes. The reasons can be summarized by examining the relationship of prices and technical innovation to industrial symbiosis.

### Prices and Industrial Loops

To understand how private planning leads spontaneously to the creation of industrial symbiosis, one must keep in mind that the ultimate goal of all market actions is to produce marketable goods and services using the least-cost combination of inputs. Firms cannot survive if they waste too many potentially valuable inputs. Thus, the history of resource recovery indicates that the goal of cheap production drove much of it. Babbage (1835, 217) observed that “the care which is taken to prevent the absolute waste of any part of the raw material” helped to reduce production costs and encouraged additional investment. A few decades later, the British authors of the *Descriptive Catalogue of the Collection Illustrating the Utilization of Waste Products* also noted that industries were paying

attention to the “utilization of waste materials.” They wrote, “As competition becomes sharper, manufacturers have to look more closely to those items which may make the slight difference between profit and loss, and convert useless products into those possessed of commercial value, which is the most apt illustration of Franklin’s motto that ‘a penny saved is twopence earned’” (Bethnal Green Branch Museum 1875, 4).

More than a generation later, the German engineer Koller (1918, vi) observed that “[c]ompetition is so keen that even with the most economical—and therefore the most rational—labour it is difficult to make manufacturing operations profitable, and it is therefore only by utilizing to the full every product which is handled that prosperity for all may be assured.”

Of course, the tendency of a company to reduce its manufacturing expense by creating new credits for products previously unmarketable is observed today in countless industries (Ayres, Ferrer, and Van Leynseele 1997; Florida 1996; Saunders and McGovern 1993). Market forces promote resource recovery because reused, remanufactured and recycled materials are generally cheaper than virgin materials. There are at least three reasons: 1) the value of some residuals can be close to nothing for their producers but of much greater value to somebody else; 2) a lot of processing has already been done in the production of residuals, thereby lowering further processing costs; 3) residuals are often produced much closer to their potential buyers than virgin materials, also lowering transportation costs.

So, the pricing process, in a context of properly enforced private property rights, is a powerful feedback mechanism to prevent the waste of valuable inputs and/or to find productive uses for by-products. Faced with competition from other producers, all entrepreneurs and managers have no choice but to cut down on waste and create industrial symbiosis either within their firms or with other businesses. As Max Muspratt, a past president of the Federation of British Industries, put it in 1928:

In the days of my childhood, “waste not, want not” was a lesson inculcated upon all young people. Whether there was at once a suitable response in the nursery I am now too old to remember, but the same wise saying has had the constant consideration of every progressive manufacturer for at least a century. . . . Every up-to-date factory has its experts who understand the problems of their particular processes and the character of the waste produced, but it may readily happen in the future, as in the past, that the waste of one industry has no interest for that particular industry and is neglected, but it may be capable of utilisation in some entirely different industry. (Kershaw 1928, vii)

### **Private Property Rights and Industrial Loops**

An owner must have reasonably secure expectations of continued ownership if he or she is going to improve or conserve resources. Private property rights are therefore essential to a free-market regime. What is less understood is that a private property rights regime, when backed by the common law, historically has been an efficient way of protecting the environment through legal actions for trespass and nuisance (Devlin and Grafton 1998; Meiners and Yandle 1999; Smith 1995). Thus, private owners can often achieve the environmental goals that EIP planners seek through public guidance, and they can do so without creating obstacles that come with regulation.

Liability makes a firm accountable for damages caused to others, including damages caused by pollution. This property-rights framework creates clear incentives for firms to find the best and cheapest way of reducing their level of discharge into the environment. For example, the early Chicago packers initially adopted the practice of dumping a significant portion of the non-edible portions of animals in the South Branch of the Chicago River, but the current did not prove strong enough to carry away the by-products. The packers were sued and eventually forbidden to dispose of their refuse that way. They therefore had to bring their load to a location sufficiently far from the city to be buried, an operation entailing considerable expense. In time, however, new uses were found for these by-products (Clemen 1923).

Of course, the common law is not flawless in terms of environmental protection. Multiple polluters, each inflicting low levels of damage, are unlikely to be held liable, especially when many share the damage. Injuries and harms that come after long gestation periods present another challenge. While parties who can show evidence of injury or imminent harm may have a common law cause of action, efforts to obtain injunctions for speculative harms such as future cancer are not generally successful. However, where common law does provide environmental protection, there is not an arbitrary distinction between a useful material and a waste, as there often is in regulatory schemes.

As Supreme Court Justice George Sutherland wrote in a famous case in 1926, “Nuisance may be merely a right thing in a wrong place like a pig in the parlor instead of the barnyard” (quoted in Meiners and Yandle 1999, 926). Similarly, in some instances “waste is merely raw material in the wrong place” (Talbot 1920, 11), and countless toxic wastes have become useful inputs within the institutional framework of prices and private property (Bethnal Green Branch Museum 1872 and 1875; Koller 1918; Simmonds 1862 and 1875; Talbot 1920).

### **Technical Innovation and Resource Recovery**

“Resources are not, they become” (De Gregori 1987, 1241); that is, they are created partly through technical innovation. The same is true of resource recovery. As Lipsett has stated, “Yesterday’s waste has become today’s new product or chemical or food, with its own waste which through research and development will become tomorrow’s new economic resource” (1963, 355). Because of technical innovation, the market process is in continual flux. Old products and markets disappear, while new ones emerge and make creative use of what were until then waste products.

Writing on the manufacturing applications of horns, Simmonds (1875, 138) noted that: “While many of the former uses of horns for glazing purposes, for drinking cups, for horn-books, and for the bugle of the bold forester, have passed away, other and more elegant and varied applications have been found for this plastic and durable substance.” In his 1939 address to the American branch of the Newcomen Society, Oscar G. Mayer, an industry executive and past president of the Institute of American Meat Packers, pointed out that in addition to familiar animal by-products, such as leather, wool, soap, and oleomargarine, new discoveries in the pharmaceutical field were made almost every year: “What is the value to humanity of such products as pepsin, adrenalin, pituitrin, ovarian extract, pineal extract, insulin and liver extract? . . . Many other compounds of incalculable value will be discovered, for the packer’s raw material is an inexhaustible biological well”(Mayer 1939, 18). New uses for waste products are more likely to be found in advanced economies, because the sheer diversity of the technical, managerial, and professional capacities of their individuals allows many different ways of turning residuals into resources, while at the same time providing many different potential markets.

### **Public Planning and Industrial Symbiosis**

Most formal EIP development efforts are led by public agencies, non-governmental organizations, and university teams rather than businesses. These organizations have taken several approaches. One is to develop an EIP from scratch or build it around a few existing industries by providing a physical site where companies can be located near one another. Another is to create “virtual EIPs,” i.e., networks of firms within a region that can exchange by-products without having to relocate (Business Council for Sustainable Development 1997; Kincaid 1999).<sup>14</sup> In either case, unlike private agents, this governmental or bureaucratic management must ultimately rely on some form of “command-and-

control” mandates, because even though public planners operate in mixed economies, they do not use the profit-and-loss test to evaluate their performance.

Some authors contend that an EIP development team would be able to outperform market processes. Analysts and consultants have therefore identified various tasks to help create EIPs. These include, for example, recruiting companies to fill a void that may occur when key suppliers or customers move or go out of business; modeling the network of exchanges to reveal new opportunities; and researching technologies and markets for currently unmarketable by-products (Martin et al. 1996, 6–32).

To assess whether EIP developers can outperform private company employees, one must consider the outlook and incentives facing both public planners and private employees. The first difference between the two groups is the manner in which they view the activities of a firm. EIP planning team members typically look at private firms as producers of particular wastes or users of an established set of by-products (Martin et al. 1996).

Private company employees, on the other hand, are paid to create the most value out of a given set of inputs, not merely to produce a regular supply of waste products. As Henry Ford put it in 1926: “You must get the most out of the power, out of the material, and out of the time” (quoted in McDonough and Braungart 1998, 83). This means that we can typically expect firms, absent of regulatory constraints, to reduce their waste flows or find more productive uses for their waste. Attracting a power plant in a specific location does not ensure that its by-products will be used in the way that public planners imagine. The managers and designers of a power plant may find a more efficient way to extract energy and in the process reduce or eliminate by-products that an older plant might have found profitable to sell. Innovative substitute inputs might become available for a given production process, emitting fewer by-products. Entrepreneurs might develop new and more financially rewarding uses for by-products. The rise in a price of a given input or the lowering of the production costs of alternative producers may make the power unprofitable. Inevitably, the public planners will reflect past experience, not future possibilities. To plan localized waste flows as if they are intrinsically part of the internal structure of firms or not subject to change simply does not accord with historical evidence or with the logic of market processes.

Knowledge of by-products and production processes—that, is expertise—and how this affects resource recovery would also differ between a development team and private company employees. As I noted in the introduction, at least one author believes that a team of designers can come up with better symbiotic relationships if they start from scratch, locating and specifying industries and factories according to a grander

scheme (Hawken 1993). Others argue that an EIP development team can gain a better overview of the waste currently produced than private agents (Schwarz and Steininger 1997, 55). This belief in the superiority of central planning over decentralized decision making has been called by Nobel laureate F. A. Hayek (1980) the pretense of knowledge. According to Hayek, the most important knowledge in a market economy is that which is acquired by people under the particular circumstances of time and place. In a market economy, individuals confronted with specific problems can better tap into this decentralized knowledge because they always know more about the particularities of a given situation in which they are directly involved than does a distant planner.

Even though the EIP experiments are still in their infancy, there are reasons to believe that they cannot avoid certain pitfalls of central planning, especially if one considers that a fundamental reason for the success of the Kalundborg industrial symbiosis is the “knowledge of the local situation that was not available to staff at corporate headquarters” (Lowe, Moran, and Holmes 1996, C12).

The only kind of knowledge that EIP developers can acquire is a synthesis of what they learn from individuals working within firms about a very large set of by-products. They classify this information according to broad Standard Industrial Classification (SIC)<sup>15</sup> specifications and then look for possible localized matches by dwelling on the most well-known uses of these by-products. In contrast, in a private firm, employees who have to deal with by-products will typically look at a much smaller set of waste products. In so doing, they can explore more reuse possibilities and contact a larger number of potential customers. Consider, for example, some observations made by Kincaid (1999) in a recent by-products survey of producers located in and around North Carolina’s Research Triangle area.

Another means of increasing creative thinking about by-products was to foster interaction with people from outside individual facilities. When the interviewers sat down to review the survey booklet with facility representatives, the discussion usually resulted in the identification of promising items to add to survey responses. When the interviewer was able to take a tour of the plant, yet more reusables were usually identified. The creative process was further boosted by discussions between two or more potential partners.

Kincaid went on to identify two examples of excited brainstorming resulting from such meetings:

- Two representatives from a tool manufacturing company visited an amino acids manufacturing plant to discuss a

potential acids partnership. After they determined that an acids exchange might be feasible, the tool manufacturing company representatives asked, “What also do you have that we might be able to use?” This query resulted in a walk to where waste fiberboard drums were stored. These drums were lined with plastic bags, and they were originally packed with pouches of desiccant inside to keep the contents dry. The tool manufacturing representative thought his company might be able to use some of the drums, and the two men started enthusiastically brainstorming about who else might be able to use the plastic bags and desiccant pouches. The tool manufacturer suggested the Adopt-A-Highway program for the plastic bags and marinas for the desiccant.

- At a sawdust partnership meeting, a cabinetmaker and a hazardous waste management company representative determined that the latter’s company could use the cabinetmaker’s sawdust to pack hazardous waste bound for an incinerator. The two men went on to discuss how the sawdust might be used as a spill absorbent as well. This led to animated brainstorming about ways to make socks filled with sawdust for this purpose (Kincaid 1999, 93).

In short, the SIC, or formal and documented type of information acquired while conducting by-products surveys in one area, is no substitute for direct interaction between technical experts.

An EIP development team typically tries to recruit companies to fill by-product niches (Martin et al. 1996). Private company employees, on the other hand, must factor in many other variables, such as finding adequate labor, material, and energy supplies, proximity to markets, quality of life and amenities, business climate, capital availability, the need of frequent face-to-face interaction between producers and suppliers, etc. All these factors can never be known in their totality by central or EIP planners. By-products will only be crucial in location decisions if they are the most important inputs of a firm. In this case there would be no need for public planners to lure a waste-producing or receiving firm, economic incentives having been more than enough stimulus throughout history.

Another consideration when comparing an EIP development team to private company employees is performance evaluation. The effectiveness of EIP developers will have to be measured, one way or another, by their capacity to create *localized* industrial loops. A private firm bases evaluation of company employees on their capacity to create the most value out of their inputs, and they do not limit their attention to local markets. One



can therefore imagine a situation where two potential industrial loops are available, one that is local but less financially rewarding, another that is more lucrative but involves shipping by-products to a more distant location.<sup>16</sup> The private sector employees will send the by-products to the location that pays more, the place where it will be used more productively, thereby saving on the use of other resources. The course of action selected by an EIP development team may depend on how the team will be evaluated. If their performance evaluation is based on a demonstrated capacity to create localized loops, they will have little incentive to use the by-products in the most efficient way by sending them far away.

Ultimately, the justification for a public EIP development team rests on the tenet that private sector employees will not gather relevant information to create industrial loops. There may, indeed, be some situations in which this is the case. It may be that breaking with daily routine is not an easy endeavor, that most company employees have an inward-looking focus, and that they do not know what information is available, or where to find it, or simply do not have the time to get it (Côté and Smolenaars 1997, 72). However, if competition is allowed to reign, the most dynamic firms will get ahead, perhaps driving their less innovative competitors out of business. Besides, it is a mistake to think that only employees of a private firm will take care of the creation of industrial loops, as numerous brokers historically have been and are still today involved in resource recovery. The task of an EIP development team would, in all likelihood, be covered by both the insiders and outsiders of a firm.

An EIP development team can certainly spot a few business opportunities that have so far escaped the attention of market participants, but it is unlikely that such events would occur often in an industrial setting if employees who are currently paid to ensure regulatory compliance were instead working on finding creative uses for by-products. If “by-products” and “wastes” could be regarded as any other manufacturing outputs, i.e., for their chemical composition and potential uses, not their place in the industrial pecking order, the private sector would spend much more energy on the creation of industrial loops.

Some company employees and private brokers would automatically be in charge of finding markets for by-products, much as they find markets for other outputs. They would gather data on possible customers, arrange meetings, hire outside consultants, attend trade shows, subscribe to industry publications, etc. They would negotiate deals and sign contracts to transfer by-products, covering in the process standard issues such as quality of supplies, mode and timing of delivery, and legal recourse for failure to comply with previous agreements. Ultimately, market participants not only have more experience and knowledge about particular production processes and by-products than EIP planners, they

also have more financial incentives to seek out relevant information and to make correct decisions.

## Regulatory Obstacles

One of the major reasons that all the above actions may not occur in the private sector is not the unwillingness of the private sector, but the regulations imposed by the public sector in the name of environmental protection. Today's environmental regulations are fragmented and inconsistent. Firms collect copious amounts of technical information and data for regulators, who must enforce compliance with government-mandated standards. Such a framework typically leads to a rigid rule orientation inherently hostile to particular circumstances that unforeseen conditions or changes might occasion (Ikeda 1995; Wallace 1995). The bureaucratic officials involved in the process typically have no vision of the whole. They concern themselves almost exclusively with their specialty, resulting in a situation where complying with rules and requirements often offsets any economic benefits companies might derive by trading by-products.

Many analysts now argue that some of these regulations are unenforced or unenforceable, inefficient, contradictory, and counter-productive, that others have instituted pervasive structural biases against new technology, and that, in the end, most have proven extraordinarily costly with little progress to show for them (Ayres and Ayres 1996; Crandall 1992; Frosch 1995; Heaton and Banks 1997; Landy and Cass 1997; Wallace 1995). Geffen and Marcus (1994) note that compliance problems tend to take up a great deal of the time of U.S. managers because regulations keep changing and that in the end so much effort goes into staying abreast of regulation that little time is left for pollution prevention. Heaton and Banks (1997, 24) write that "environmental innovators uniformly lament their treatment in the regulatory process, in which delay, uncertainty, red tape, and skepticism about new compliance techniques are widely acknowledged problems" and that "the most creative segments of the industrial community—new companies, small firms, entrepreneurs—are uniquely disadvantaged by an overall regulatory framework that erects entry barriers against new ideas."

### Regulatory Definitions as Barriers to Resource Recovery

By far the most glaring regulatory problems in the creation of industrial loops are the definitions of solid waste and hazardous waste<sup>17</sup> under the Resource Conservation and Recovery Act (RCRA), a 600-page-plus set of

complex and intricate regulations.<sup>18</sup> Under RCRA, a by-product can either be a solid waste, or be a hazardous (solid) waste, or avoid a solid waste label. As Gertler (1995) has pointed out, this legal approach has led to a circular definition.

Solid waste is a discarded material, a discarded material is anything inherently waste-like, such that a solid waste is anything inherently waste-like. (Since the three criteria for defining something as a “discarded material” are connected by “or” and not “and,” meeting any one of them results in the substance in question being “discarded.”) Perhaps more importantly, it is somewhat perplexing that recycled materials are defined as discarded, since to “discard” has the common meaning “to throw away.”<sup>19</sup> (Gertler 1995, n.p.)

RCRA considers a solid waste “hazardous” if it is ignitable (i.e., burns readily), corrosive, or reactive (e.g., explosive), or if it contains certain amounts of toxic chemicals (Gertler 1995). In addition to these characteristics, the EPA has developed a list of over 500 specific hazardous wastes. So the “hazardous” label refers not only to the inherent properties of a substance, but also to its history relative to its “discarded” status (Frosch 1995; Gertler 1995; Volokh 1995).

The ambiguity surrounding solid wastes, hazardous wastes, and secondary materials in the language of RCRA means that all waste or by-products falling under the statute’s definition of solid or hazardous waste are subject to RCRA requirements. Classification of a by-product as solid waste sets a costly permitting process into motion, and the label “hazardous waste” virtually prevents the reuse of the targeted substance, even though it might be chemically identical to or even less hazardous than a “virgin” product. For example, a manufacturer that produces waste containing cyanide, a toxic hydrocarbon, or a heavy metal will likely be controlled by strict environmental laws. Unless the firm’s managers are willing to invest a lot of resources in overcoming extremely long and complex bureaucratic barriers (getting permits, collecting data, writing timely reports, being subjected to increased liability, etc.), RCRA will most likely not allow the firm to process that material into a salable product or even to transport it, except to a disposal site.

The automotive industry’s anticorrosion measures to protect cars illustrate the negative effects of RCRA. The anticorrosion process typically creates a wastewater rich in zinc. In the past, producers of the sludge from this wastewater sent it to a smelter that recovered the zinc for reuse. But once government regulations designated this residual as “hazardous” in the mid-1980s, the regulatory requirements became so stiff that the smelter couldn’t accept it anymore. The zinc now ends up in a

landfill and is both an additional cost to its producers and a waste disposal problem for the rest of society (Frosch 1995, 181).

One can also look at a residual from aluminum production, the “potliner” (i.e., steel shells lined with insulation and carbon) used in the electrolytic process that converts alumina into aluminum. Such potliners are typically replaced after three to seven years and contain a mixture of carbon, aluminum, sodium, fluoride, silicon, calcium, and trace amounts of cyanide and iron. Historically, various industries recovered potliners. Mineral wool plants used them as a source of fluoride and as a fuel substitute for coke. Cement kilns used them as a fuel supplement to replace 2 to 5 percent of their coal. Steel plants used the carbon as a fuel source and the fluoride as a substitute for the fluxing agent fluorspar. All this, however, ended in 1988 when spent potliner was first classified a solid waste, and eventually a hazardous waste, despite lack of scientific evidence proving that these previous industrial practices posed any threat to human health (Volokh 1995, 19–20). As an EPA Assistant Administrator for the Office of Solid Waste and Emergency Response has put it, RCRA is “a regulatory cuckoo land of definition” where a substance that “wasn’t hazardous yesterday . . . is hazardous tomorrow, because we’ve changed the rule” (quoted in Volokh 1995, 3).

In short, the regulations governing hazardous waste management impose onerous burdens and responsibilities on those who generate, handle, treat, and dispose of such materials. It is therefore not surprising that very little hazardous waste is recovered. As Volokh (1995) has pointed out, about 100,000 to 1 million tons of hazardous waste are recycled in the United States each year, while another 13 million tons are dumped in hazardous waste landfills. Many analysts therefore view environmental regulation as the single greatest deterrent to the innovative use of by-products.

### **CERCLA (Superfund)**

While RCRA deals with the regulation of waste control practices at current manufacturing, transport, and disposal facilities, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), more commonly known as Superfund, was enacted in 1980 to deal with the cleanup of abandoned sites.<sup>20</sup> It has a critically detrimental impact on the development of EIPs in old industrial areas.

The enforcement of CERCLA often imposes the legal doctrine of “joint and several strict liability” on everyone having anything to do with the siting and storage of hazardous wastes on so-called “brownfields,” i.e., formerly used industrial sites. In practice, this means that the government can hold anyone who is even peripherally responsible for any portion of

the material at a Superfund site financially responsible for the entire cleanup. Restoring a Superfund site usually costs millions of dollars and may involve decades of litigation. As Devlin and Grafton (1998, 115) put it: “Technically speaking, all of these firms/individuals are liable to pay up to the full costs of clean-up or any costs stemming from damages to natural resources incurred by the federal or state governments from a hazardous waste site . . . irrespective of whether their actions actually caused the accident.”

As a number of difficulties arose from this practice, the 1986 Superfund Amendments Reauthorization Act gave the party that paid for the cleanup costs the right to collect from any others who might have contributed to the damages. Superfund therefore has a major impact on the decisions of firms regarding location and handling of by-products.

General Motors is a case in point. The firm is often reluctant to transfer regulated waste to brokers, waste exchanges, and potential users because it cannot get rid of the legal responsibility for the material and it is not sure it can trust downstream users (Gertler 1995). Besides, the cleanup standards associated with Superfund are generally acknowledged as unrealistically strict and therefore costly (Stroup 1996). Consequently, developers often fear that if they take on a cleanup effort, they will not only have to spend money to eradicate the last stray molecule of a given substance, but they will also be sued by a future user of the property to clean contamination that they did not cause. Because the liability scheme of CERCLA is so menacing, land near hazardous waste sites that has been or might be designated a Superfund site becomes virtually unsalable, despite some potential advantages such as location and existing amenities. Vast stretches of urban real estate have been written off for development because of Superfund, in the process starting a cycle of urban blight and promoting “green field” development in distant suburbs (Landy and Cass 1997, 207). Thus, many opportunities for the natural evolution of eco-industrial parks never see the light of day.

In sum, expensive and obtrusive government regulations that have minimal positive effects on public health make reuse of materials so difficult that a larger waste flow is de facto encouraged. Unlike the common law approach, environmental and other regulations have ended up erecting numerous barriers to resource recovery.

Had Superfund-like rules been in effect in Denmark, the Kalundborg industrial symbiosis would have been a very difficult, if not impossible, task. For example, the flue gas Statoil pipes to Gyproc and the liquid sulfur that Statoil sells to Kemira probably would not have been approved in the United States because both substances would be classified “hazardous waste,” and the new resources created out of these by-products would have been treated as hazardous as well under the “mixture and

derived from” rule (Gertler 1995, n.p.). Furthermore, the movement of sulfur from Statoil to Kemira and the movement of scrubber ash gypsum from Asnæs to Gyproc would break another rule, the ninety days storage rule, which would again in all likelihood prevent the profitable reuse of these by-products (Gertler 1995).

Of course, local, national, and international environmental regulations are only one type of public policy that affect the propensity of managers, engineers, and technicians to find creative new uses for their by-products. Antitrust statutes, too, can effectively bar the agglomeration of enterprises necessary to create EIPs, while consumer protection statutes relating to government procurement practices and safety regulations can prevent the use of by-products, and laws governing international trade may prevent their transportation. Zoning ordinances, subdivision regulations, permits for various construction phases, and growth management may prohibit certain activities. Subsidies targeted at the extraction and transportation of virgin materials may also discourage the use of by-products (Crandall 1992; Devlin and Grafton 1998; Graedel and Allenby 1995; Lowe, Moran, and Holmes 1996; Roodman 1998; Wernick and Ausubel 1997). It is beyond the scope of this essay to review in detail all governmental interventions that affect the creation of EIPs.

## Conclusion

Planning a regional community of companies that exchange and reuse by-products or energy has been advocated in academic, business, and political circles. The examples that are used to justify such an approach, however, such as Kalundborg, Denmark, were entirely the result of market forces. The claim that a more proactive approach would achieve better results than market processes rests on the claim that public agents are more likely to identify and achieve a goal such as the creation of an EIP than private agents whose priority is to maximize profit. This presupposes that public planners are capable of centrally planning and coordinating the activities of numerous public and private agents to conform with their specific objectives. Whether they can actually do this is doubtful.

Private agents working in competitive businesses tend to minimize the amount of waste they produce, whether by using their inputs more productively or by finding new uses for their by-products. The market process, unlike regulation, is a systematic error-correcting mechanism that encourages innovation. Within a market framework, trading by-products is not a good in itself if there is a more effective waste solution upstream. Where there is not, trade is likely to occur.

Ultimately, support for an EIP development team stems from perception of a market failure in developing industrial loops. This, however, presupposes that in a market economy firms have more incentive to cover the costs of by-product disposal than to eliminate them at the source or find new markets for them. This belief also requires that firms' employees would not be able to gather as useful information as an EIP development team would. Both postulates are manifestly false, on logical as well as empirical grounds. Furthermore, current attempts to create EIPs are too narrowly focused and fail to consider that firms are in business to create products that consumers want using the least-cost input combination and therefore that their locational choice will evaluate many more factors than proximate reuse of by-products.

Promoting resource recovery where economically feasible and environmentally sound is simple common sense, but the current focus on planning and creating EIP is largely erroneous. Greater priority should be placed on removing barriers to reuse. Unless these are changed, EIP will remain an academic or public relations exercise.

## Notes

1. Although they sometimes come under different labels, such as industrial symbiosis, industrial clusters, environmentally balanced industrial complexes and localized industrial ecosystems, they all refer to the concept described in this article as "eco-industrial parks" (Lowe 1997, 64).

2. Other examples are located in the Austrian province of Styria, the Ruhr region of Germany, and the Houston Ship Channel (Garner and Keoleian 1995; Gertler 1995; Lowe, Moran, and Holmes 1996; Schwartz and Steigner 1997).

3. Some residual steam was also sent to greenhouses that belonged to Asnæs, but this practice was abandoned after growers elsewhere in Denmark complained of unfair competition because the greenhouses in Kalundborg enjoyed especially low heating costs (Lowe, Moran, and Holmes 1996, C12).

4. Designated sites include the Cabazon Resource Recovery Park (CA), Cape Charles (VA), Chattanooga (TN), Civano (Tucson, AZ), East San Francisco Bay (CA), Fairfield Park (Baltimore, MD), the Green Gold Initiative (Buffalo, NY), the Green Institute (Minneapolis, MN), Londonderry (NH), Mesa del Sol (Albuquerque, NM), Plattsburgh (NY), Riverside Eco-Park (Burlington, VT), Trenton (NJ) and Triangle J Council of Governments (NC) (Indigo Development 1998).

5. Asnæs was required by the Danish government to initiate a fish-farming operation as a way to consume excess sludge. The operation was a money-loser until the government allowed sale of the fish farm to an independent operator who was able to convert it into a profitable venture. As some observers noted, fish farming “just didn’t fit” into Asnæs’s line of business (Lowe, Moran, and Holmes 1996, C12).

6. Danish authorities approach environmental protection by requiring firms to submit plans detailing their efforts to continually reduce their environmental impact. According to Gertler (1995, n.p.), the flexibility of this approach, coupled with the fact that the Danish Environment Ministry encourages attempts to find uses for all waste streams on a case-by-case basis, allows firms “to focus their energies on finding creative ways to become more environmentally benign instead of fighting the regulators.” Also, the stricter environmental regulations that have been the driving force for some linkages have been performance rather than technology standards. This allowed firms to choose technologies that rendered their waste streams usable as feedstock elsewhere. For a more detailed description of Danish environmental policy making, and especially of its flexible and personal approach compared to the formulaic and procedure-driven American approach, see Wallace (1995).

7. “The initial procedure was to choose a basic goods company since this could be expected to represent a supplier and recipient of various kinds of waste. Starting here, the waste streams coming into the plant site as well as originating from it were then followed. For each new supplier and recipient thus identified the procedure was repeated until the geographic system boundary was reached” (Schwarz and Steininger 1997, 50).

8. “The worn-out saucepans and tin ware of our kitchens, when beyond the reach of the tinker’s art, are not utterly worthless. We sometimes meet carts loaded with old tin kettles and worn-out iron coal-skuttles traversing our streets. These have not yet completed their useful course; the less corroded parts are cut into strips, punched with small holes, and varnished with a coarse black varnish for the use of the trunk-maker, who protects the edges and angles of his boxes with them; the remainder are conveyed to the manufacturing chemists in the outskirts of the town, who employ them in combination with pyroligneous acid, in making a black die for the use of calico printer” (Babbage 1835, 11–12).

9. According to a personal communication from an industry specialist, New York City also became the premier copper mine in the world, as the advent of fiber optics made the old copper lines useless.

10. Of course, scholars still observe the same phenomenon today: “Brewing is an example of recycling. Grains are malted and fermented and the extract made into beer. The spent grains from the breweries in our large cities are transported to central plants where they are dewatered,



dried, and prepared for animal feed, particularly for milk farms not too far distant, serving the same central population. The grains after drying are high-protein feed” (Mantell 1975, 753).

11. Actually, the demand for bones was so important in the nineteenth century that some merchants had the bones on the battlefields of Waterloo and Crimea picked up and sent to England to be turned into fertilizers (De Silguy 1989, 78).

12. See also Simmonds (1862, 352–60).

13. It must be pointed out, however, that St. Louis was probably the major hub in the buffalo bones trades (from an exhibit at the Museum of the Rockies, Bozeman, Montana, July 1999).

14. These are said to be different from traditional waste exchanges such as Recycler’s World, the National Materials Exchange Network, and the Global Recycling Network or from commodity-specific financial exchanges such as the Chicago Board of Trade’s market for scrap materials because they are much more proactive in identifying by-products and creating connections (Kincaid 1999).

15. The traditional SIC is currently being replaced by the new North American Industrial Classification System (NAICS).

16. I am assuming that transportation does not add significant pollution; in a world of strictly enforced private property rights, it would not.

17. RCRA defines a solid waste as “any garbage, refuse, sludge from a waste treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities.” EPA officials have encountered difficulty in establishing when a material is “discarded” and have consequently redefined solid waste as “any discarded material not otherwise excluded by regulation or variance”; a discarded material is then any material that is “abandoned,” “recycled,” or “inherently waste-like.”

RCRA defines hazardous waste as a “solid waste, or combination of solid wastes which because of its quantity, concentration, or physical, chemical, or infectious characteristics may [a] cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or [b] pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed” (42 U.S.C., Sec. 1004[27]).

18. For a much more detailed treatment of this issue, see Dower (1995), Frosch (1995), Gertler (1995), Landy and Cass (1997), Lowe, Moran, and Holmes (1996), Martin et al. (1996), Powers and Chertow (1995) and Volokh (1995). It must also be noted that in addition to RCRA,

statutes such as the Toxic Substances Control Act (TSCA), the Clean Air Act (CAA), the Asbestos Hazard Emergency Response Act (AHERA), and the Clean Water Act (CWA) also affect the management of solid and hazardous waste (Martin et al. 1996, 5-5).

19. Gertler (1995, n.p.) also adds that the “reason for all this intrigue is apparently that recycling status exempts a process from the bulk of RCRA regulation, making attaining such a status very attractive to those generating waste. EPA has thus endeavored to separate ‘sham recycling,’ which is essentially a show at recycling made by generators of hazardous waste in order to avoid the costs of mandated disposal, from ‘true recycling.’” Needless to say, such an approach ultimately works against resource recovery.

20. For a much more detailed treatment of this issue, see Dower (1995); Gertler (1995); Landy and Cass (1997); Lowe, Moran, and Holmes (1996, Appendix D); Segerson (1995); Stroup (1996); Viscusi (1996); Viscusi and Hamilton (1996); and Volokh (1995).

## Bibliography

- Allenby, Braden R., and Deanna J. Richards. 1994. *The Greening of Industrial Ecosystems*. Washington (D.C.): National Academy of Engineering.
- Ayres, Robert U. 1996. Creating Industrial Ecosystems: A Viable Management Strategy. *International Journal of Technology Management, Special Issue on Changing Technological Determinants* 12(5/6): 608–24.
- Ayres, Robert U., and Lesli W. Ayres 1996. *Industrial Ecology: Towards Closing the Materials Cycle*. Cheltenham, UK: Edward Elgar.
- Ayres, Robert U., Geraldo Ferrer, and Tania Van Leynseele. 1997. Eco-Efficiency, Asset Recovery and Remanufacturing. *INSEAD Working Paper 97/35/EPS/TM*. Fontenavleau, France: INSEAD and the Center for the Management of Environmental Resources.
- Babbage, Charles. 1835 [1832]. *On the Economy of Machinery and Manufactures*, 4th ed. enlarged. London: Charles Knight. Reprinted by Augustus M. Kelley Publishers, 1986.
- Bertolini, Gérard. 1990. *The Market For Waste: Economics and Management of Trash*. Paris, France: Éditions L’Harmattan.
- Bethnal Green Branch Museum. 1872. *A Brief Guide to the Animal Products Collection*. London: George E. Eyre and William Spottiswoode for Her Majesty’s Stationery Office.
- . 1875. *Descriptive Catalogue of the Collection Illustrating the Utilization of Waste Products*. London: George E. Eyre and

- William Spottiswoode for Her Majesty's Stationery Office.
- Bogart, Ernest Ludlow. 1936. *Economic History of the American People*, 2d ed. New York: Longmans, Green and Co.
- Brannt, William Theodore. 1908. *The Metallic Alloys: A Practical Guide for the Manufacture of All Kinds of Alloys, Amalgams, and Solders, used by Metal-Workers . . . with an Appendix on the Coloring of Alloys and the Recovery of Waste Metals*, 3d ed. revised and enlarged. Philadelphia: H. C. Baird & Co.
- Business Council for Sustainable Development-Gulf of Mexico. 1997. *By-Product Synergy: A Strategy for Sustainable Development*. Austin, TX, April. Available: <http://www.bcsdgm.org/primer.pdf>
- Chevalier, Raymond. 1993. *Science and Technology in Rome*. Paris: Presses Universitaires de France.
- Clemen, Rudolf A. 1923. *The American Livestock and Meat Industry*. New York: Ronald Press Company.
- . 1927. *By-Products in the Packing Industry*. Chicago: University of Chicago Press.
- Côté, Raymond P., and Theresa Smolenaars. 1997. Supporting Pillars for Industrial Ecosystems. *Journal of Cleaner Production* 5(½): 67–74.
- Crandall, Robert. 1992. *Why is the Cost of Environmental Regulation So High?* Washington University (Saint-Louis): Center for the Study of American Business.
- Cruess, William Vere. 1914. *Utilization of Waste Oranges*. Berkeley: Agricultural Experiment Station.
- Dechesne, Laurent. 1945. *The Location of Various Manufacturing Activities*. Bruxelles: Les éditions comptables, commerciales et financières.
- De Gregori, Thomas R. 1987. Resources are Not; They Become: An Institutional Theory. *Journal of Economic Issues* 21(3): 1241–63.
- De Silguy, Catherine. 1989. *The Saga of Trash From the Middle Ages to Today*. Paris: L'instant.
- Desrochers, Pierre. 1998. A Geographical Perspective on Austrian Economics. *Quarterly Journal of Austrian Economics* 1(2): 63–83.
- Devlin, Rose Anne, and R. Quentin Grafton. 1998. *Economic Rights and Environmental Wrongs. Property Rights for the Common Goods*. Northampton, UK: Edward Elgar.
- Dower, Roger W. 1995 [1990]. Hazardous Waste. In *Public Policies for Environmental Protection*, Paul R. Portney, ed. Washington, DC: Resources for the Future.
- Florida, Richard. 1996. Lean and Green: The Move to Environmentally Conscious Manufacturing. *California Management Review* 39(1): 80–105.

- Frosch, Robert A. 1995. The Industrial Ecology of the 21<sup>st</sup> Century. *Scientific American* 273(3): 178–81.
- Frosch, Robert A., and Nicholas E. Gallopoulos. 1989. Strategies for Manufacturing. *Scientific American* 261(3): 144–52.
- Garner, Andy, and Gregory A. Keoleian. 1995. *Industrial Ecology: An Introduction*. Ann Arbor: University of Michigan, National Pollution Prevention Center for Higher Education. Available: <http://www.umich.edu/~nppcpub/resources/compendia/ind.ecol.html>.
- Gee, George Edward. 1920. *Recovering Precious Metals from Waste Liquid Residues: A Complete Workshop Treatise Containing Practical Working Directions for the Recovery of Gold, Silver, and Platinum from Every Description of Waste Liquids in the Jewelry, Photographic, Process Workers, and Electroplating Trade*. New York: Spon & Chamberlain.
- Geffen, Donald A., and Alfred A. Marcus. 1994. *Pollution Prevention—Overcoming Barriers to Further Progress*. Advanced Management Practices Paper #12. Minneapolis: University of Minnesota, Strategic Management Research Center.
- Gertler, Nicholas. 1995. *Industrial Ecosystems: Developing Sustainable Industrial Structures*. M.S. Thesis (Technology and Policy), Massachusetts Institute of Technology. Available: <http://www.sustainable.doe.gov/business/gertler2.html>.
- Graedel, Thomas E., and Braden R. Allenby. 1995. *Industrial Ecology*. Englewood Cliffs, NJ: Prentice Hall.
- Haig, Robert M. 1926. Toward an Understanding of the Metropolis. 1. Some Speculation Regarding the Economic Basis of Urban Concentration. *Quarterly Journal of Economics* 40(1): 179–208.
- Harper, Walter Benjamin. 1907. *The Utilization of Wood Waste by Distillation: A General Consideration of the Industry of Wood Distilling, Including a Description of the Apparatus Used and the Principles Involved, also Methods of Chemical Control and Disposal of the Products*. Saint-Louis: Journal of Commerce Company.
- Hawken, Paul. 1993. *The Ecology of Commerce*. New York: Harper Business.
- Hayek, Friedrich A. 1980 [1948]. *Individualism and Economic Order*. Chicago: University of Chicago Press.
- Heaton, George R. and R. Darryl Banks. 1997. Toward a New Generation of Environmental Policy. *Journal of Industrial Ecology* 1(2): 23–32.
- Hubbard, Ernst. 1920. *The Utilisation of Wood-Waste*, 3d ed. revised and enlarged. London: Scott, Greenwood & Son.
- Ikeda, Sanford. 1995. The Use of Knowledge in Government and Market.

- Advances in Austrian Economics* 2: 211–40.
- Indigo Development. 1998. *Strategic Reviews of Eco-Industrial Park Projects*. Oakland, CA: Indigo Development. Available: <http://www.indigodev.com/Streview.html>.
- Jacobs, Jane. 1970 [1969]. *The Economy of Cities*. New York: Random House.
- Johnsen, Bjarne. 1919. *Utilization of Waste Sulphate Liquor: A Review of the Literature*. Ottawa, Ontario: J de L. Taché.
- Kershaw, John B. C. 1928. *The Recovery and Use of Industrial and Other Waste*. London: Ernest Benn Limited.
- Kincaid, Judy. 1999. *Industrial Ecosystem Development Project Report*. Research Triangle Park, NC: Triangle J Council of Government.
- Koller, Theodor. 1918 [1902]. *The Utilization of Waste Products: A Treatise on the Rational Utilization, Recovery, and Treatment of Waste Products of all Kinds*, 3d revised ed. translated from the 2d revised German ed. New York: D. Van Nostrand Company.
- Landy, Marc, and Loren Cass. 1997. U.S. Environmental Regulation in a More Competitive World. In *Comparative Disadvantages? Social Regulations and the Global Economy*, Pietro S. Nivola, ed. Washington, DC: Brookings Institution Press, 203–41.
- Lipsett, Charles H. 1963 [1951]. *Industrial Wastes and Salvage: Conservation and Utilization*, 2d ed. New York: Atlas Publishing.
- Lowe, Ernest A. 1995. The Eco-Industrial Park: A Business Environment for a Sustainable Future. Paper presented at conference on “Designing, Financing and Building the Industrial Park of the Future,” sponsored by the U.S. EPA, Research Triangle Institute, and the University of California at San Diego, held in San Diego, May 4–5.
- . 1997. Creating By-Product Resource Exchanges: Strategies for Eco-Industrial Parks. *Journal of Cleaner Production* 5(½): 57–65.
- Lowe, Ernest A., Stephen R. Moran, and Douglas B. Holmes. 1996. *Fieldbook for the Development of Eco-Industrial Parks: Final Report*. Research Triangle Park, NC: Research Triangle Institute.
- Mantell, C. L., ed. 1975. *Solid Wastes: Origin, Collection, Processing, and Disposal*. New York: John Wiley & Sons.
- Martin, Sheila A., Keith A. Weitz, Robert A. Cushman, Aarti Sharma, Richard C. Lindrooth, and Stephen R. Moran. 1996. *Eco-Industrial Parks: A Case Study and Analysis of Economic, Environmental, Technical, and Regulatory Issues: Final Report*. Research Triangle Park, NC: Research Triangle Institute.
- Mayer, Oscar G. 1939. *America’s Meat Packing Industry*. Princeton: Princeton University Press for the New comen Society.
- McDonough, William, and Michael Braungart. 1998. The Next Industrial

- Revolution. *Atlantic Monthly* 282(4): 82–92.
- Meiners, Roger E., and Bruce Yandle. 1999. Common Law and the Conceit of Modern Environmental Policy. *George Mason Law Review* 7(4): 923–63.
- Mellaart, James. 1967. *Çatal Hüyük. A Neolithic Town in Anatolia*. New York: McGraw-Hill Book Company.
- Miller, Benjamin. 1998. Fat of the Land: New York's Waste. *Social Research* 65(1): 75–100.
- Ostrolensk, Bernhard. 1941. *Economic Geography*. Chicago: Richard D. Irwin.
- Powers, Charles S., and Marian R. Chertow. 1995. Industrial Ecology: Overcoming Policy Fragmentation. In *Thinking Ecologically: The Next Generation of Environmental Policy*, Marian R. Chertow and Daniel C. Esty, eds. New Haven, CT: Yale University Press, 19–36.
- Rabak, Frank. 1917. *The Utilization of Waste Tomato Seeds and Skins*. Washington, DC: U.S. Department of Agriculture.
- Rathje, William, and Cullen Murphy. 1992. *Rubbish! The Archeology of Garbage*. New York: Harper Collins Publishers.
- Rayner, Hollins. 1903. *Silk Throwing and Waste Silk Spinning*. London: Scott & Greenwood.
- Riley, Walter A. 1913. *Brewery By-Products*. London: Brewing Trade Review.
- Roodman, David Malin. 1998. *The Natural Wealth of Nations*. New York: W. W. Norton & Company.
- Saunders, Tedd, and Loretta McGovern. 1993. *The Bottom Line of Green is Black*. New York: Harper Collins.
- Schwarz, Erich J., and Karl W. Steininger. 1997. Implementing Nature's Lesson: The Industrial Recycling Network Enhancing Regional Development. *Journal of Cleaner Production* 5(½): 47–56.
- Segerson, Kathleen. 1995. Redesigning CERCLA Liability: An Analysis of the Issues. *Policy Study*, #187. Los Angeles: Reason Foundation.
- Sicular, Daniel D. 1981. *Currents in the Waste Stream: A History of Refuse Management and Resources Recovery in America*. Master's thesis (Geography), University of California, Berkeley.
- Silver, L. B. 1876. *A Great Problem Solved: How to Utilize Waste Heat from Chimneys and Establish a System of Warming and Ventilation Based Upon Sound Philosophy and Economy*. Cleveland, OH: S. Barker.
- Simmonds, Peter Lund. 1862. *Waste Products and Undeveloped Substances: Or, Hints for Enterprise in Neglected Fields*. London: Robert Hardwicke.
- . 1875. *Animal Products: Their Preparation, Commercial Uses,*

- and Value*. New York: Scribner, Welford, and Armstrong.
- Sinha, Abu Hasnat Md. Maqsood. 1993. *The Formal and Informal Sector Linkages in Waste Recycling: A Case Study of Solid Waste Management in Dhaka*. Master of Science Degree, Asian Institute of Technology, Bangkok, Thailand.
- Smith, Fred L. 1995. Markets and the Environment: A Critical Reappraisal. *Contemporary Economic Policy* 13(1): 62–73.
- Spooner, Henry J. 1918. *Wealth from Waste*. London: G. Routledge. Reprinted by Hive Publishing Company, 1974.
- Strachan, James. 1918. *The Recovery and Re-Manufacture of Waste-Paper: A Practical Treatise Printed on Paper Made Entirely from Regenerated Waste-Paper*. Alberdeen, Scotland: Albany Press.
- Stroup, Richard L. 1996. Superfund: The Shortcut that Failed. *PERC Policy Series*, PS-5. Bozeman, MT: Political Economy Research Center. Available: <http://www.perc.org/ps5.htm>.
- Talbot, Frederick A. 1920. *Millions from Waste*. Philadelphia: J. B. Lippincott Company.
- Thornley, Thomas. 1912. *Cotton Waste: Its Production, Manipulation and Uses*. London: Scott & Greenwood.
- Tibbs, Hardin C. 1992. *Industrial Ecology: An Environmental Agenda for Industry*. U.S. Department of Energy, Center of Excellence for Sustainable Development. Available: <http://www.sustainable.doe.gov/articles/indecol.htm>.
- Turrentine, John William. 1915. *Utilization of the Fish Waste of the Pacific Coast for the Manufacture of Fertilizer*. Washington, DC: U.S. Department of Agriculture.
- Van Der Ryn, Sim, and Stuart Cowan. 1996. *Ecological Design*. Washington, DC: Island Press.
- Veitch, Fletcher Pearre. 1913. *Pulp and Paper and Other Waste Products from Waste Resinous Woods*. Washington, DC: Government Printing Office.
- Viscusi, W. Kip. 1996. Economic Foundations of the Current Regulatory Reform Efforts. *Journal of Economic Perspectives* 10(3): 119–34.
- Viscusi, W. Kip, and James T. Hamilton. 1996. Cleaning Up Superfund. *Public Interest* 124: 52–60.
- Volokh, Alexander. 1995. Recycling Hazardous Waste: How RCRA Has Recyclers Running Around in CERCLAs. *Policy Study*, #197. Los Angeles: Reason Foundation.
- Wallace, David. 1995. *Environmental Policy and Industrial Innovation: Strategies in Europe, the USA and Japan*. London: Earthscan Publications Ltd.
- Weld, L. D. H., A. T. Kearney, and F. H. Sidney. 1925. *Economics of the*

- Packing Industry. Part I. History and Organization.* Chicago: University of Chicago and the Institute of American Meat Packers.
- Wernick, Iddo K., and Jesse Ausubel. 1997. *Industrial Ecology: Some Directions for Research.* Paper prepared for the Office of Energy and Environmental Systems, Lawrence Livermore National Laboratory. Prepublication draft, May. Available: <http://phe.rockefeller.edu>.
- Whitin Machine Works. 1914. *Illustrated and Descriptive Catalog of Whitin Cotton Waste Machinery and of Various Systems of Working Cotton Waste.* Whitinsville, MA: Whitin Machine Works.



# Appendix

## Some Historical Texts Documenting Resource Recovery

---

### Chemical Wastes

- A Great Problem Solved: How to Utilize Waste Heat from Chimneys* (Silver 1876)  
*Millions from Waste* (Talbot 1920)  
*The Recovery and Use of Industrial and Other Waste* (Kershaw 1928)  
*The Utilization of Waste Products* (Koller 1918)  
*Utilization of Waste Sulphate Liquor* (Johnsen 1919)  
*Waste Products and Undeveloped Substances or Hints for Enterprise in Neglected Fields* (Simmonds 1862)  
*Wealth from Waste* (Spooner 1918)

### Food and Animal Wastes

- Animal Products: Their Preparation, Commercial Uses, and Value* (Simmonds 1875)  
*Brewery By-Products* (Riley 1913)  
*Millions from Waste* (Talbot 1920)  
*The Recovery and Use of Industrial and Other Waste* (Kershaw 1928)  
*Utilization of the Fish Waste of the Pacific Coast for the Manufacture of Fertilizer* (Turrentine 1915)  
*Utilization of Waste Oranges* (Cruess 1914)  
*The Utilization of Waste Products* (Koller 1918)  
*The Utilization of Waste Tomato Seeds and Skins* (Rabak 1917)  
*Waste Products and Undeveloped Substances or Hints for Enterprise in Neglected Fields* (Simmonds 1862)  
*Wealth from Waste* (Spooner 1918)

### Manufacturing and Mining Wastes

- The Metallic Alloys* (Brannt 1908)  
*Recovering Precious Metals from Waste Liquid Residues* (Gee 1920)  
*The Recovery and Use of Industrial and Other Waste* (Kershaw 1928)  
*The Utilization of Waste Products* (Koller 1918)  
*Waste Products and Undeveloped Substances or Hints for Enterprise in Neglected Fields* (Simmonds 1862)

## Vegetable and Organic Wastes

- Pulp and Paper and Other Products from Waste Resinous Woods* (Veitch 1913)  
*The Recovery and Re-Manufacture of Waste-Paper* (Strachan 1918)  
*The Recovery and Use of Industrial and Other Waste* (Kershaw 1928)  
*The Utilization of Waste Products* (Koller 1918)  
*The Utilization of Wood-Waste* (Hubbard 1920)  
*The Utilization of Wood Waste by Distillation* (Harper 1907)

## Textile Wastes

- Cotton Waste: Its Production, Manipulation, and Uses* (Thornley 1912)  
*Illustrated and Descriptive Catalog of Whitin Cotton Waste Machinery and of Various Systems of Working Cotton Waste* (Whitin Machine Works 1914)  
*Millions from Waste* (Talbot 1920)  
*The Recovery and Use of Industrial and Other Waste* (Kershaw 1928)  
*Silk Throwing and Waste Silk Spinning* (Rayner 1903)  
*The Utilization of Waste Products* (Koller 1918)  
*Wealth from Waste* (Spooner 1918)

---

*Note:* Since these scholars wrote before the advent of modern classification systems, the manner of categorizing waste varies from author to author. For example, Kershaw (1928) has a chapter on “tannery and leather wastes” and another on “food and stockyard wastes,” while Koller (1918) has chapters on “blood and slaughter-house refuse,” “fat from waste,” “tannery waste,” “leather waste,” “fur and feather waste,” “waste horn” and “fish waste.” In this appendix, all were grouped under food and stockyard wastes.