Eco-Industrial Parks and the Rediscovery of Inter-Firm Recycling Linkages.

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Abstract

An eco-industrial park (EIP) is a community of firms in a region that exchange and make use of each other's byproducts, in the process improving their environmental and economic performance. The first EIP formally identified as such was "discovered" in the Danish coastal city of Kalundborg more than a decade ago, and similar cases in other parts of Europe and the United States have been documented since then. Nowhere, however, did a planning authority structure the development of these "localized industrial symbiosis." To the contrary, all of these cases were ultimately triggered by cost calculations. Could it be then that localized industrial symbiosis is a widespread, if neglected, type of industrial linkage? This is indeed the contention of this article, which examines the genesis of modern EIP before illustrating that urban areas have always exhibited widespread resource recovery between firms. It is then argued that regulatory reform would prove more effective than planning to replicate the Danish experience.

Introduction

An eco-industrial park (henceforth, EIP) is a community of firms in a region that exchange and make use of each other=s byproducts, in the process improving their environmental and economic performance. The argument is that by working together, this symbiotic community of businesses achieves a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only. EIP are an important component of eco-industrial development, a strategy that has been endorsed by the President's Council on Sustainable Development, the Department of Energy's Center for Excellence for Sustainable Development, and the Environmental Protection Agency. The concept has also gained momentum outside the United States, as numerous EIP have been planned in Canada, South America, Southeast Asia, Europe and South Africa (Ayres, 1996; Indigo Development, 1998; Gertler, 1995; Lowe, 1997).[1]

The first EIP formally identified as such was "discovered" in the Danish coastal city of Kalundborg more than a decade ago. Since then, similar cases have been documented in the Austrian province of Styria, the Ruhr region of Germany and the Houston Ship Channel. Nowhere, however, did a planning authority of any sort structure the development of these "localized industrial symbiosis." To the contrary, all of these cases were ultimately triggered by cost calculations. The most common argument given for supplying waste is the additional revenue earned as a result of the waste relationship and/or avoiding waste disposal costs or taxes. On the other hand, the substitution of primary materials brings a reduction of costs for the accepting companies (Gertler, 1995; Lowe et al., 1996; Schwarz and Steininger, 1997). Could it be then that localized industrial symbiosis is a widespread, if neglected, type of industrial linkage? This is indeed the contention of this article. The first section describes the contemporary EIP

[1] Although they sometimes come under different labels, such as industrial clusters, environmentally balanced industrial complexes and localized industrial ecosystems, they all refer to the concept described in this article as "eco-industrial parks" and "localized industrial symbiosis" (Lowe, 1997: 64). For an updated list of EIP, see the web page of the Cornell Center for the Environment (www.cfe.cornell.edu).

experience, while the second demonstrates that cities have always exhibited numerous resource recovery linkages between otherwise very different firms. The economic and technological rationales for these linkages are then discussed in more detail, while policy implications are derived from past experience in the last section. It is argued that removing barriers to reuse should be given greater priority than the planning of EIP.

1. The Genesis of Eco-Industrial Parks.

The concept behind EIP is industrial ecology, which, at its core, is the idea that modern industrial economies should be looked at as a system of raw material extraction, manufacturing processes, product use, and waste disposal that should ultimately mimic the cycling of materials in ecosystems. Industries are therefore seen as webs of producers, consumers and scavengers, while symbiotic relationships between companies and industries are encouraged. The ultimate goal of industrial ecologists is that products and byproducts should be reused, repaired, recovered, remanufactured or recycled on a very large scale.2

One of the applications of the concept of food webs between companies has been the idea of creating or retrofitting industrial zones where local industries would feed on each other's waste, in the process turning byproducts into raw materials. By marrying industrial ecology principles with pollution prevention and sustainable design, it has been argued that such EIP would provide one or more of the following benefits over traditional, non-linked operations: 1) reduction in the use of virgin materials as resource inputs; 2) reduction in pollution; 3) increased systemic energy efficiency leading to reduced systemic energy use; 4) reduction in the volume of waste products requiring disposal (with the added benefit of preventing disposal-related pollution); 5) increase in the amount and types of process outputs that have market value (Gertler, 1995).

EIP promoters believe that the first significant localized case of industrial symbiosis emerged in the last three decades in the small Danish city of Kalundborg (pop. 20 000)

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2 See, among others, Allenby and Richards (1994), Ayres and Ayres (1996), Garner and Keoleian (1995), Graedel and Allenby (1995) .

on the island of Seeland, 75 miles west of Copenhagen. There, the four main industries, a coal-fired power plant (Asnæs), a refinery (Statoil), a pharmaceutical and enzyme maker (Novo Nordisk), a plasterboard manufacturer (Gyproc), as well as the municipality and a few smaller businesses feed on each other=s wastes, in the process turning them into valuable inputs. The local synergy began to form in the 1970's and now goes something 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, to a district heating system serving 3,500 homes and to the Novo Nordisk plant. Sludge from the fish farm and pharmaceutical processes becomes fertilizer for nearby farms. Surplus yeast from the biotechnology plant=s production of insulin is shipped to farmers for pig food. The fly ash from the power plant is sent 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 (Garner and Keoleian, 1995; Gertler, 1995; Lowe et al., 1996).

The Kalundborg Aindustrial symbiosis@ was not, however, designed by consultants or financed by Danish government officials. 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 gained access to cheaper materials and energy while generating income from production residue on the other. Today, there is still no higher level of organization managing their interaction (Lowe, 1997: 59). Jorgen Christensen, a spokesperson for Novo Nordisk, is explicit on this point: AI 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 this view: AThe 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, non-paginated document) sums it up, the Kalundborg system is based Aon creative business sense and deep-seated environmental awareness@

and Awhile the participating companies herald the environmental benefits of the symbiosis, it is economics that drives or thwarts its development.@

It must also be noted that the Kalundborg industrial symbiosis is neither self-sufficient nor limited to what would normally be labeled a local economy. For example, Statoil (sulfur) and Asnæs (fly ash and clinker), both located in Kalundborg, sell some of their byproducts to Kemira and the Aalborg Portland cement company whose plants are located on the Jutland peninsula, several hundred miles away from Kalundborg. Gyproc=s supply of virgin gypsum, still a significant input, is imported from 2500 miles away in Germany and from even further in Spain, while the 200 tons of trout and turbot produced annually in Asnæs fish farms were mostly exported to France in the early 1990's. Furthermore, many 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 in that it is a nexus of trade whose firms import and export numerous components and products on a much larger geographical scale (Gertler, 1995; Lowe et al., 1996; Tibbs, 1992).   How unique then is the Danish city? As will now be argued, it is but one contemporary version of processes that are probably as old as cities themselves.

2. Eco-industrial Parks in Historical Perspective

2.1 Industrial Symbiosis in Historical Perspective

Industrial symbiosis, i.e. the idea that the byproducts of one industry can become the valuable inputs of another, is nothing new. For thousands of such illustrations, one can look at the following books written long before the advent of modern environmental consciousness and regulation, each containing numerous and detailed illustrations of by-product reuse in many different industries:

* Waste Products and Undeveloped Substances: or, Hints for Enterprise in Neglected Fields (Simmonds, 1862);

* Descriptive Catalogue of the Collection Illustrating the Utilization of Waste Products (Bethnal Green Branch Museum, 1875),

* Waste Products and Undeveloped Substances: A Synopsis of Progress during the Last Quarter of a Century at Home and Abroad (Simmonds, 1876);

* The Utilization of Waste Products: A Treatise on the Rational Utilization, Recovery, and Treatment of Waste Products of All Kinds (Koller, 1918);

* Wealth from Waste (Spooner, 1918);

* Millions from Waste (Talbot, 1920);

* The Recovery and Use of Industrial and Other Waste (Kershaw, 1928).

Numerous other illustrations can also be found in "how-to" books dealing with specific kinds of waste, patent records, graduate dissertations and the serial *Waste Trade Directory* published, beginning in 1905, by the Atlas Publishing Company. Similarly, 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" (Lipsett, 1963: 407).

The practice of industrial symbiosis was clearly obvious to many commentators of the past. Simmonds (1862: 2) thus observed: "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 Museum (1875: 4) wrote that many ingenious persons were busily devising "means by which [the] 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."

Following the First World War, some English commentators marveled at the German's 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.” A few years later, Kershaw (1928: ix) replied to some criticisms of his attempt to cover in one volume the waste in all branches of manufacturing industry in the United Kingdom and the United States by pointing out: “It is a mistake to imagine that our industries can be carried on efficiently in water-tight compartments, for the waste material or by-product of one manufacture is quite often the starting-point or raw material of another.” This point was well understood by people familiar with industrial practices. Max Muspratt, past-president of the Federation of British Industries, thus wrote in the preface of Kershaw’s book:

> 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).

The practice of industrial symbiosis was therefore prevalent in advanced economies more than a century ago. The phenomenon observed in Kalundborg and other places can therefore be interpreted as a modern day case of resource recovery linkages built up over time that accrue to a firm because it is located near other businesses with which it either exchanges or shares certain goods, services, and facilities. Linkage studies are a very old topic in economic and industrial geography, although resource recovery has been neglected by contemporary authors until very recently. This is not to say, however, that past authors did not realize the importance of agglomeration economies for converting byproducts into inputs, as will now be demonstrated.

2.2 Agglomeration Economies and Industrial Symbiosis in Historical Perspective

Whatever the time or location, the managers of a firm have only two ways to create value out of their byproducts: 1) they can add a new activity to their operation; 2) they can sell (or give away, in order to minimize disposal costs) their residuals. For obvious economic reasons, both options were often carried out in close proximity to the source plant. Simmonds (1876: 4) thus summarized the British experience:

> It may truly be said that there is scarcely any manufacture in which there does not remain, in the form of residue or waste, something which, though not suited for that special manufacture, has still a considerable economic value. And this may generally be usefully employed in some way or other. This is one of the characteristic and salient points of modern enterprise, not only to allow nothing to be wasted, but to recover and utilise with profits the residues from former workings. The diminution in price which results from utilising matters otherwise wasted, may easily be conceived. In this respect extensive works and factories are in a better position than small ones, in consequence of the larger quantity of residues at their command, and which necessitate special machinery for working up or utilising. In great industrial centres, too, the waste products of a large number of works may be easily collected.

Actually, the London Post-Office Directory of 1873 listed more than 2100 "Manufacturers, or Dealers, in Waste." According to Simmonds (1876: 29), this number was certainly far below the real total, for it only enumerated householders and excluded many manufacturers located in the suburbs. Industrial resource recovery was also widespread in American urban areas. According to the The Commercial Bulletin of Boston:

> The Collection and utilising of old material has become a very important business feature in all our large cities and manufacturing centres… In the New England States, over fifteen million dollars'… worth of old material is annually worked over; and at least five hundred thousand dollars' worth of this peculiar stock could at any time by thrown upon the market by the Boston dealers. The amounts consumed by our mills are astonishing, especially of shoddy. Woollen mills could be named that purchase each year from three to six thousand dollars' worth of shoddy, and this, too, in addition to flocks. Very many paper-mills have standing orders with the largest paper-dealers for thirty and fifty tons of stock per week. The Kingsley Iron and Machine Company receive and consume from sixty to seventy-five tons of scrap-iron each week, and the Old Colony and Ames Shovel Companies stand ready to take all the wrought-iron offered in the market. Nearly all the

> old lead sold in this vicinity is purchased by the Boston Lead Company, and one dealer, who makes it a specialty to supply them, turns in, on an average, one hundred tons per month (quoted by Simmonds, 1876: 5 and 7).

Two generations later, Talbot (1920: 303) wrote that in order to be successful "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" because "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."

Many other authors also alluded, although in less detail, to the importance of agglomeration economies for industrial resource recovery. Ross (1896: 256) wrote about "the cluster of side industries that grow up about packing establishments, refineries, or gas-works, engaged in turning refuse into byproducts." Devas (1901: 98) explained the concentration of industries by, among other factors, the "greater growth of subsidiary industries, such namely as supply materials and utilize refuse, to do which for a single factory would not be worth while." Interestingly enough, Alfred Marshall (1986 [1920]) wrote about byproduct recovery in his chapter on industrial districts.

An author that hinted even earlier at this issue is Charles Babbage. Even though he believed that large firms would prove more effective in recovering byproducts through "the union of two trades in one factory, which otherwise might have been separated," he readily saw that agglomeration economies were an alternative (Babbage, 1835: 217). Consider, for example, his illustration of the reuse of horn byproducts.

> The tanner who has purchased the raw hides, separates the horns, and sells them to the maker of combs and lanterns. The horn consists of two parts, an outward horny case, and an inward conical substance, somewhat intermediate between indurated hair and bone. The first process consists in separating these two parts, by means of a blow against a block of wood. The horny exterior is then cut into three portions with a frame-saw.
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> 1. The lowest of these, next the root of the horn, after undergoing several processes, by which it is flattened, is made into combs.

> 2. The middle of the horn, after being flattened by heat, and having its transparency improved by oil, is split into thin layers, and forms a substitute for glass, in lanterns of the commonest kind.
> 3. The tip of the horn is used by the makers of knife-handles, and of the tops of whips, and for other similar purposes.
> 4. The interior, or core of the horn, is boiled down in water. A large quantity of fat rises to the surface; this is put aside, and sold to the makers of yellow soap.
> 5. The liquid itself is used as a kind of glue, and is purchased by cloth dressers for stiffening.
> 6. The insoluble substance, which remains behind, is then sent to the mill, and, being ground down, is sold to farmers for manure.
> 7. Besides these various purposes to which the different parts of the horn are applied, the clippings, which arise in comb-making, are sold to the farmer for manure... The shavings which form the refuse of the lantern-maker, are of a much thinner texture: some of them are cut into various figures and painted, and used as toys... But the greater part of these shavings also are sold for manure (Babbage, 1835: 217-18).

Other illustrations of the recovery of animal byproducts in the same time period also demonstrate the importance of agglomeration economies for resource recovery. Simmonds (1862: 345) thus argued that the most remarkable progress in the economical extract and preparation of pure gelatins and glues from the waste remnants of animals were made in France "where the well-organized and admirably arranged establishments for the slaughter of cattle, sheep, and horses in large towns, give great and valuable facilities for the economical application of all the waste parts of animal bodies." Meanwhile, Cincinnati entrepreneurs were creating a similar case of industrial symbiosis. As one journalist pointed out in 1845, "the facilities of turning to account in various manufactures, or as articles of food in a dense community, what cannot be disposed of to profit elsewhere, render hogs, to the Cincinnati packer, worth ten per cent more than they will command at other points in the Mississippi Valley" (Armour, 1895: 384). In the middle of the 19th 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 incredibly unsanitary by today's standards, it was yet another instance where no potential resource was wasted. There, as in many other large industrial cities, bones were turned into handles and buttons, used to refine sugar, in textile coloration and turned into fertilizers. Marrow was converted into tallow that was valuable to chandlers, soap-makers and the rapidly expanding chemical industry. Blood was used by sugar refiners and fertilizer producers. Hooves were turned into gelatin and "Prussian Blue," while hides and hair were valuable commodities. Whatever remained was hog food (Miller, 1998; Simmonds, 1875).

Meatpacking is, however, only one illustration of the past importance of agglomeration economies for industrial symbiosis. It can thus be pointed out that 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). The same phenomenon could be observed in Belgium, where beginning in the early 19th century most distilleries relocated from the countryside to cities in order to secure markets for their byproducts (Dechesne, 1945: 51) and in New York City where most of the milk was produced in 260 city stables by cows living on the swill of local distilleries (Miller, 1998: 78). In his classic study on "the economic basis of urban concentration" conducted in the early 20th 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).

The fact that cities have always facilitated industrial symbiosis is beyond question. Cities are not like anthills or termitariums, however, because humans alone engage in trade. It will now be illustrated that in matters of resource recovery, cities have never been closed or self-sufficient systems.

2.3 Cities as Open-Ended Systems

Cities have always been open systems where various inputs were imported and exported from outside their local economy. The same pattern has probably always been true for industrial byproducts. For example, in the middle of 19th century, the city of Dewsbury

(Yorkshire) became the world's center for the disposal of old clothes and woollen rags, for there converged "all the streams bearing abandoned flotsam and jetsam into the preparation of which wool has entered" (Talbot, 1920: 18). The same pattern could also be observed in many other cities. According to The Commercial Bulletin of Boston:

> Of the several kinds of junk, a large percentage of the paper stock of the South is accumulated at the seaports and shipped to Boston. The chief point of collection is New Orleans, whence comes to one firm in this city over three hundred thousand dollars' worth per month. The West bids fair to enter at New Orleans in sharp competition with New England in the purchase of old material. There are many things now that the West does not call for, and which are collected and sold to our dealers here as a sort of legitimate appendage to desirable stocks. Broken glass that contains lead, such as tumblers, decanters, &c.; old bones, scrap hides, refuse cotton, &c., that have in the South little market value, but which, when shipped North on an invoice that covers a good assortment of more valuable material, realize clever profits. This is the reason for still sending the bulk of the best selections to New England, notwithstanding the cost of transportation is more than to the Ohio or Upper Mississipi (quoted by Simmonds, 1876: 6).

Further illustrations of the urban recovery of animal byproducts in the last century can also illustrate this point. For example, many of the bones collected daily from the butchers and slaughter-houses of London were sent to France.

> The sorting of bones is a careful and very needful operation. Some of the larger and more perfect bones are laid aside, and boiled by themselves; these are the best bones. When they are dry, they are cut into convenient lengths, and sold mostly to France, where brush handles and other ornaments are made from them. It is a curious fact, that our own countrymen are unable to compete with our foreign neighbours in the purchase of and trade generally in, bones. The reason, however, is very simple. Our workers in bones know how to make a brush handle, or any other article, but are unable to utilize the chips and waste cuttings. These the French makers can convert into small toys, ornaments, &c., which are sold at a large profit. This additional source of gain enables them to outbid our buyers for 1,500 to 2,000 tons of these best prepared bones. The inferior pieces of bone are used for button making; the common bones, after drying and boiling, for manure making (Bethnal Green Museum, 1875: 35).

Despite the fact that some British manufacturers were not as efficient as their French competitors, more than 6,000 tons of horns and hoofs and approximately 92,000 tons of bones from giraffe, elephant, horse, ox, buffalo and whale were imported each year in the 1870's in the United Kingdom (Simmonds, 1875: 133-147) on top of a domestic production thought to be between 70,000 and 80,000 tons (Bethnal Green Museum, 1875: 49). Most of those imports went to London, Birmingham and Sheffield (Simmonds, 1875: 133-147).

There is thus little ground to believe that the Kalundborg experience is path-breaking in any way. To understand how industrial resource recovery emerged on such a large scale, however, one must look at the interaction of market incentives and technological innovation, a point that was also well understood by early authors.

3. Market Processes, Technological Innovation and Industrial Symbiosis

3.1 Market Processes and Industrial Symbiosis

The ultimate goal of all market actions is to produce valuable goods and services using the least-cost input combinations. In short, firms can't survive if they waste too many potentially valuable inputs. As Babbage (1835: 217) put it more than a century and a half ago: "Amongst the causes which tend to the cheap production of any article, and which are connected with the employment of additional capital, may be mentioned, the care which is taken to prevent the absolute waste of any part of the raw material." The same phenomenon was also described by other authors a few decades later.

> Few among the minor tendencies of industries are more worthy of note than that shown in the utilization of waste materials. 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:" our manufacturers have not been slow to appreciate this truth, as is shown in more than one branch of trade... Wherever we turn we find that the most trivial things may be converted into gold, the refuse and lumber of one manufacture or workshop, is the raw material of another (Bethnal Green Museum, 1875: 4).

More than a generation later, the German engineer Koller (1918 [1902]: vi) was to make similar comments based on his observation of the Reich's industries: "Competition 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." In the preface of his book Byproducts in the Packing Industry, the American economist Clemen (1927: vii) wrote that "the development of byproducts in industry is one of the most outstanding phenomena in our economic life" and that "from the viewpoint of individual business, this manufacture of byproducts has turned waste into such a source of revenue that in many cases the byproducts have proved more profitable per pound than the main product." He credited market forces entirely for this state of affairs by pointing out that the development of byproducts was done simply in order to avoid being overwhelmed by the competition of other industries, or of other corporations within the same industry.

> Modern conditions make it almost impossible materially to cut production and distribution of expense for the majority of commodities; hence one of the most important opportunities for gaining competitive advantage, or even for enabling an industry or individual business to maintain its position in this new competition, is to reduce its manufacturing expense by creating new credits for products previously unmarketable...
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> Indeed, the materials from which the byproducts in nearly all industries are manufactured today were formerly partially or wholly wasted, and the change to intensive utilization of these materials for by-product manufacture has been brought about by the ever-increasing force of competition in American business, both between individual concerns within a single industry and among different ones (Clemen, 1927: vii and 2).

Of course, the same phenomenon is observed today in countless industries (Ayres et al., 1997; Florida, 1996; Saunders and McGovern, 1993), although most present-day observers typically lack a historical perspective. In short, market forces promote resource recovery because reused, remanufactured and recycled materials are generally cheaper than virgin materials for 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, therefore lowering further processing costs; 3) residuals are often produced much closer to their potential buyers than virgin materials, therefore lowering transportation costs.

Furthermore, urban areas are especially likely to promote widespread resource recovery because they usually supply most of the requirements identified by Clemen (1927: 1) for the successful commercial utilization of industrial byproducts: 1) a practical commercial process of manufacture; 2) actual or potential market outlets for the new proposed byproducts; 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; 5) technologically trained operatives. Besides, as is well-known, by making it easier to communicate tacit knowledge and to establish long-term relationship, cities facilitate cooperation among individuals (Malmberg, 1996; 1997). A point that must be kept in mind, however, is that waste has always been turned into resources through technological innovation, as will now be illustrated.

3.2 Technological Innovation and Industrial Symbiosis

As many authors have long pointed out, "resources are not, they become" (DeGregori, 1987), usually through technological innovation. In this sense, "natural" things are no different than industrial byproducts. As Simmonds (1876: 5) wrote: "Modern science has pointed out the uses of many substances which were formerly regarded as offal, and thrown away; and the result is, that in England and on the Continent scarcely anything is entirely wasted." The Austro-Hungarian Archduke Regnier, the President of the Imperial Commission of the Vienna International Exhibition for 1873, concurred with this observation:

> Side by side with the increase and growth of wants, we see the quantity of useful material augment in a twofold manner. This is accomplished partly by making use of substances formerly useless, because their qualities were unknown; but still more by the use made of substances which, formerly considered to be as used up, appeared to be of no value, and were often incommodious and in many cases troublesome (quoted by Simmonds, 1876: 1).

Karl Marx, building on the work of Babbage, also argued that one of the general requirements for the re-employment of industrial "excretions" was "improved machinery whereby materials, formerly useless in their prevailing form are put into a state fit for new production: scientific progress, particularly chemistry, which reveals the useful properties of such waste" (quoted by Rosenberg, 1994: 104). In his The Evolution of Modern Capitalism, Hobson (1917: 75) made a similar observation a few decades later:

> New industrial arts owing their origin to scientific inventions and their practice to machinery arise for utilising waste products. Under "waste products" we may include (a) natural materials, the services of which were not recognised or could not be utilised without machinery...; (b) the refuse of manufacturing processes which figured as "waste" until some unsuspected use was found for it. Conspicuous examples of this economy are found in many trades. During the interval between great new inventions in machinery or in the application of power many of the principal improvements are of this order.

Alfred Marshall (1986 [1920]: 232) also wrote during the same period that "many of the most important advances of recent years have been due to the utilizing of what had been a waste product; but this has generally been due to a distinct invention, either chemical or mechanical." Marshall's contemporary, Frederick Talbot (1920: 13-14), was even more explicit.

> It is distinctly interesting, if not actually amusing, to follow what may be described as the utilitarian conjugation of waste. It remains an incubus, if not an unmitigated nuisance, until the chemist, or some other keenly observant individual possessed of a fertile mind, comes along to rake it over and to indulge in experiments. Such efforts are often followed with ill-conceaved amusement... In due course some definite conclusion is reached, and the fact becomes driven home that, if such-and-such a process be followed a particular spurned refuse can be utilized as raw material for the production of some specific article. Then scepticism and amusement give way to intense interest and speculative rumination. The new idea is submitted to the stern test of practical application upon a commercial basis, while the financial end of the proposal, which is the determining factor, is carefully weighed.

As numerous examples illustrate, this pattern was common to all industries (Bethnal Green Museum, 1875; Kershaw, 1928; Koller, 1918; Simmonds, 1862, 1876; Talbot, 1920). As Talbot (1920: 17-18) put it: "To relate all the fortunes which have been amassed from the commercialization of what was once rejected and valueless would require a volume. Yet it is a story of fascinating romance and one difficult to parallel in the whole realm of human activity."

There is thus compelling evidence that agglomeration economies have always been crucial in the development of industrial symbiosis. It will now be argued, however, that the rationale underlying present-day practices and policy proposals for the development of eco-industrial parks could benefit from a better understanding of past experience.

4. Learning from the Past for Today's Eco-Industrial Parks

Even though all successful localized cases of industrial symbiosis have been achieved in the normal course of business, much has been made about the necessity of public intervention to create EIP (Hawken, 1993; Indigo Development, 1998; Lowe, 1997; van Der Ryn and Cowan, 1996). It therefore comes as no surprise that the American response has largely been to look to the Danish example as illustrative, but to seek more proactive ways to model and imagine eco-industrial possibilities. Most EIP efforts have been led by public agencies, non-governmental organizations and university teams that have pursued two main strategies. The first is to develop an EIP from scratch or around a few existing industries by providing a physical site where companies can be located near one another. This strategy is also sometimes referred to as zero-emissions EIP, because the goal is to attract companies whose processes do not generate waste or by locating companies with specific input needs and byproduct generation in order to create a "closed loop" within the park. The second approach is to create "virtual EIPs," which are networks of regionally localized firms that can exchange by-products without having to relocate (Business Council for Sustainable Development, 1997; Kincaid, 1999).[3] In this writer's opinion, the first option is untenable, while the second requires more than public planning.

4.1 Market Processes and the Planning of EIP

In view of past experience, the concept of zero-emissions EIP must be rejected out-of-hand. There has probably never been such a case in the annals of urban history. The fundamental mistake with this approach is the static view that underlies it, whereas economic development has always been in a continual flux. In short, old products and

[3] 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 exchange such as the Chicago Board of Trade financial exchange for trading scrap materials, because they are much more pro-active in identifying by-products and creating connections (Kincaid, 1999).

markets disappear, while new ones emerge and make creative use of what were until then waste products. Simmonds (1875: 138) made this point more than a century ago using as an example the manufacturing applications of horns: "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."

The main problem here is that EIP planning team members typically look at private firms as producers or users of certain byproducts. Private company employees, on the other hand, are paid to create the most value out of a given set of inputs, not to produce a regular supply of waste products. This means that firms can always be expected, absent from regulatory constraints, to reduce their waste flow and/or to find more productive uses for it. Attracting a power plant in a specific location does not ensure that its byproducts will be used in the way originally envisioned by public planners, which is usually the way of past experience, not future possibilities. Thus the managers and designers of a power plant may find a more efficient way to extract energy out of their input and in the process reduce or eliminate by-products that a plant with an older technology might have found profitable to sell to other companies. Innovative substitute inputs might become available for a given production process, emitting less and/or different by-products. New and more financially rewarding uses for by-products might be developed. The rise in a price of a given input or the lowering of the production costs of alternative producers may make the power plant unprofitable.

Planning localized waste flows as if they were not subject to change simply does not accord with historical evidence and the logic of market processes. It is also doubtful that close byproduct reuse plays a more important role in the location decision of a firm than a host of other factors, such as finding adequate labor, materials and energy supplies, proximity to markets, quality of life and amenities, business climate, sunk costs, capital availability, the need for frequent face-to-face interactions with suppliers and customers, etc. By-products will only be crucial in location decisions if they are the most important inputs of a firm, in which case there is no need for public planners to lure a waste producing or receiving firm, economic incentives having been more than sufficient throughout history.

Virtual EIP are obviously a more realistic approach to achieve industrial symbiosis. It is not clear, however, how outside observers could gain a better understanding of he specific nature of a firm's byproducts than its employees. The regional focus of EIP planners might also create other problems. Although this is not clear at the moment, EIP developers' performance would ultimately have to be measured, one way or another, by their capacity to create *localized* industrial loops. Private sector employees' evaluation, on the other hand, is based on their capacity to create the most value out of their inputs. Their attention is not limited to local markets. A problem might therefore arise when two potential industrial loops can be developed, one that is local but less financially rewarding, and another that is more lucrative but involves shipping byproducts to a more distant location. The behavior of private sector employees will obviously be to send the byproducts to the location that is paying more, which is probably 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, on the other hand, is less obvious. If their performance evaluation is based on their demonstrated capacity to create localized loops, then what is their incentive to use the by-products in the most efficient way by sending it outside their assigned territory?

Ultimately, the belief in the need of an EIP development team is that private sector employees will not gather relevant information to create industrial symbiosis. It might 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, where to find it or simply do not have the time to get it (Côté and Smolenaars, 1997). Historical evidence does not, however, support that view. Besides, it may be that the role of private brokers is underestimated in the literature on EIP, despite the fact that they have been very active in resource recovery for more than a century (Simmonds, 1862). Thus according to The Commercial Bulletin of Boston :

> The collection, sorting, and distribution of old material have settled into a regular system. Mills and manufacturers have, of late years, turned their attention to the production of specialties, and, as a consequence, are calling for particular and carefully-selected stocks. This policy has driven the dealers in "old junk" into a regular routine for the sale and delivery of their old stuff; and, while the market is constantly affected by supply and demand, the stock is all worked off into the hands of large dealers, who, in turn, re-sort and classify according to the specialties desired, and then stand ready to job off their grades and sorts in large amounts to the manufacturer (quoted by Simmonds, 1876: 5).

The most crucial problem in the development of EIP at this point is, however, the numerous regulatory barriers to resource recovery that have been put in place in recent decades. This issue will now be looked at more closely.

4.2 Regulatory Barriers to the Creation of EIP

As many industrial ecologists and other authors have pointed out in recent years, many regulations that were often adopted with the best of intentions have turned out to be serious obstacles to resource recovery. For example, most environmental regulations are totally fragmented while exhibiting a single-media, single-species, single-substance, single source control and a single-life-cycle-stage focus. The policy makers involved in the process have typically had no vision of the whole and concern themselves almost exclusively with their specialty, resulting in a situation where compliance with rules and requirements often offsets any economic benefits companies might derive by trading by-products.

It is beyond the scope of this essay to review the details of the regulatory obstacles to industrial symbiosis. A few examples will nonetheless be provided to illustrate the magnitude of the problem. By far the most problematic regulatory problem for the creation of industrial symbiosis are the definitions of *solid waste* and *hazardous waste* under the *Resource Conservation and Recovery Act (RCRA).* [4] The main problem with

[4] For a much more detailed treatment of this issue, see Dower (1995), Frosch (1995), Gertler (1995), Landy and Cass (1997), Lowe et al. (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

this approach is that once a byproduct is classified "solid waste", a costly permitting process is set into motion, while the label "hazardous waste" virtually prevents the reuse of the targeted substance, even though it might be chemically identical 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 to overcome extremely long and complex bureaucratic barriers (getting permits, collecting data, writing timely reports, being subjected to increased liability, etc.), it will most likely not be allowed to process that material into a salable product or even to transport it, except to a disposal site. On the other hand, anyone can easily go to a chemical manufacturer and buy cyanide, hydrocarbon solvents or heavy metal compounds that have been newly produced, however, because their manufacturer generally has a standing permit for packaging, transporting and selling these "virgin" materials used as commercial products (Frosch, 1995: 180). As an EPA Assistant Administrator for their 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 by Volokh, 1995: 3).

RCRA also creates other problems. For example, permits to reuse hazardous waste typically require 18 to 24 months for approval (Heaton and Banks, 1997: 29). Also, a generator of hazardous waste may store that material in RCRA-approved containers for no more than 90 days on-site without having to obtain a permit as a Treatment, Storage, and Disposal Facility. According to Gertler (1995), given the cost, complexity, time, and stigma required to obtain such a permit, "it is a foregone conclusion that no firm will seek licensing as a TSD facility solely for the purpose of participating in a symbiotic byproduct-to-feedstock linkage." Actually, the ninety days rule has often been pointed out as a great impediment to recycling because in many cases it does not allow the accumulation of byproducts in sufficient quantity to make transportation to site of reuse

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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).

economically viable. Another problem is that while the generator of a hazardous waste may store on-site for up to ninety days, any storage by the facility that is to recycle or reuse that waste requires a RCRA permit. The lack of on-site storage forces a facility either to transfer directly hazardous waste from a truck to the recycling process, or not to recycle. Yet another problem is the "mixture and derived from rule," which establishes that once a substance is tagged as a listed hazardous waste, any substance derived from treating it is also a hazardous waste, a stipulation that makes difficult or impossible the use of residues of pollution control technologies as feedstock (Gertler, 1995). Landy and Cass have summarized the typical outcome of this regulatory process.

> Because [EPA invading] action is triggered by the application for a RCRA permit, the trick is to keep from having a facility defined as needing a permit. The easiest way to keep something from being declared a hazardous waste is to avoid reusing it and therefore avoid being defined as a "treater or storer" of such material. Instead one simply ships the material off to a licensed hazardous waste disposer who either incinerates it or places it in a landfill. In the process a valuable opportunity to recycle is lost, a high disposal fee is paid, and more hazardous waste is either emitted into the atmosphere via incineration or dumped into the ground (Landy and Cass, 1997: 218).

RCRA deals with the regulation of waste control practices at current manufacturing, transport and disposal facilities. Another legislation, the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA),[5] more commonly known as Superfund, was deemed necessary to deal with abandoned site cleanup and is therefore of crucial importance for the development of EIP in old industrial areas. One of the main features of CERCLA is that it is often enforced with the imposition of "joint and several strict liability" (JSSL) on everyone having anything to do with the siting and storage of hazardous waste on so-called "brownfields." In practice, JSSL means that anyone even peripherally responsible for any portion of the material at a Superfund site can be held financially responsible for the entire cleanup, which commonly have multimillion dollar price tags and usually 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

[5] For a much more detailed treatment of this issue, see Dower (1995), Gertler (1995), Landy and Cass (1997), Lowe et al. (1996, Appendix D); Segerson (1995), Stroup (1996), Viscusi (1996), Viscusi and Hamilton (1996) and Volokh (1995).

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 regime, the 1986 *Superfund Amendments Reauthorization Act* gave whoever had to pay the clean-up costs the right to collect from any others who might have contributed to the damages. Superfund therefore has a major impact on firms' decisions about where to locate and what to do with their by-products. Thus General Motors 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 to be unrealistically strict, and developers are often afraid that if they take the trouble to clean up a site, they will not only have to spend money to chase the last stray of molecule, but they will still be sued by a future user of the property to clean up contamination that they did not even cause. Because the program's liability scheme is so menacing, land near hazardous waste sites that have or might be designated Superfund sites becomes virtually unsalable, despite some potential advantages, such as location and existing amenities. Vast stretches of urban real estate have therefore been written off for development because of Superfund, in the process starting a cycle of urban blight and promoting the development of "green fields" area (Landy and Cass, 1997: 207).

In the end, it is probably fair to say that, in light of RCRA, CERCLA and other features of the American regulatory apparatus, developing the Kalundborg "industrial symbiosis" would have been a very difficult, if not impossible, task in the USA. For example, the Statoil flue gas being piped to Gyproc and the liquid sulfur that Statoil sells to Kemira would probably not have been approved in the United States because both substances would be classified "hazardous waste," while the new resources created out of these by-products would have been subjected to the "mixture and derived from" rule. Furthermore, the movement of sulfur from Statoil to Kemira and the movement of scrubber ash gypsum from Asnæs to Gyproc would break the ninety days storage rule, which would again in all likelihood prevent the profitable reuse of these byproducts (Gertler, 1995).

In any case, under the current regulatory framework, an EIP development team or company personnel need to be in constant dialogue with federal, state and local regulators, the community's planning departments and future tenants in order to deal with special permits, changes in zoning and liability issues (Lowe, 1997). Of course, it is possible to obtain derogations from the EPA, but such a process is typically long and very arduous, for even though the EPA has launched some pilot programs to reduce the negative impact of regulatory barriers to transporting materials involved in exchanges or recycling, such administrative measures can only go so far given the current statutory framework and the fact that such initiatives require funding, staff and consistent follow-through that might simply be unavailable. Furthermore, regulatory agencies simply cannot undo the structural aspects of environmental legislation that work against technological innovation (Business Council for Sustainable Development, 1997; Cohen-Rosenthal and MacGalliard, 1997; Heaton and Banks, 1997). Another much talked-about way to alleviate regulatory constraints is the emission of site-wide or "umbrella" permits, although this solution is not without creating other problems (Would each plant be liable for the non-compliance of any plant under the permit? Would it make sense to lump together large and small firms, or those with very different levels of potential exposure and liability?) and still involves considerable expense of time and energy to alleviate the regulatory burden (Lowe, 1997; Martin et al., 1996).

4.3 Policy Implications

An EIP development team can certainly spot a few business opportunities that have so far escaped the attention of market participants. It is unlikely, however, that such events would occur often in an industrial setting where employees that are currently paid to ensure regulatory compliance were instead working on finding new markets and developing creative new uses for byproducts. If byproducts were instead looked at as any other manufacturing inputs and outputs (i.e. for their chemical composition and not their place in the industrial pecking order), it is obvious that much more energy would be spent by private sector agents on the creation of industrial symbiosis. They would negotiate deals and sign contracts to transfer byproducts, 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. In light of past practices, the case for regulatory reform - including a possible return to common law practices (Meiners and Yandle, 1999) - should be given a much higher priority than the planning of EIP.

Conclusion

The planning of a community of companies in a region that exchange and make use of each other's byproducts has been advocated in many academic, business and political circles. The real world examples that justify such an approach, however, were entirely the result of market forces. Further historical investigation demonstrates that the phenomenon is much older than currently believed. Whether greater industrial symbiosis can be promoted is therefore more likely to depend on the degree to which obstacles such as other contradictory or incompatible policy objectives can be overcomed, most notably (but not solely) the way the current environmental regulatory framework often excludes recycling and reclamation.

Perhaps also the fundamental metaphor that was derived from the Kalundborg industrial symbiosis, the concept of an "eco-industrial park," has misled policy makers on the geographical scale of what is at best a regional phenomenon. Other metaphors might be more fruitful in that respect. For example, in her discussion of cities and recycling, Jacobs (1970:107-117) writes about one producer of book paper that refers to New York City as its "concrete forest", but argues that cities should rather be referred to as "waste-yielding mines." Unlike typical mines, however, she notes that cities will become richer the more and the longer they are exploited as 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" (p. 111). The metaphor of cities as mines was also used a few decades earlier by Ostrolenk (1941: 21) in his classic economic geography textbook.

> Even the sources of important raw commodities are changing. What becomes of the traditional relation of steel production to iron ore fields, when almost half of the nation's steel comes from scrap gathered in our large cities? 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.

Of course, the metaphor of cities as mine does not really convey the idea of local synergy between firm with complementary byproduct outputs and needs. On the other hand, it does not preclude taking a wider geographical look at industrial symbiosis. In the end, whatever one may choose to label inter-firm recycling linkages, removing barriers to reuse should probably be given greater priority than the planning of EIP.

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