INDUSTRIAL ECOLOGY, MARKET PROCESSES AND THE CREATION OF "INDUSTRIAL LOOPS": A CRITICAL REAPPRAISAL

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Most industrial ecologists are skeptical about the capacity of a free market economy to create a web of industrial loops and consequently advocate central planning at the system level. However, historical evidence shows that market prices and private property rights have typically provided sufficient incentives to promote resource recovery on a large scale. It is therefore the purpose of this article to illustrate the environmental benefits of market processes by examining the nature and consequences of economic calculation, human creativity and regulation using historical evidence drawn mostly from the practice of recycling animal residuals. The main conclusion of this article is that movements towards well defined and readily enforceable private property rights, strict liability and freedom of contract are better options than central planning and environmental regulation to achieve the goals of industrial ecologists.

Keywords: Industrial Ecology - New Resource Economics - Prices - Private Property Rights - Technological Change.

When we perceive in nature how nothing is wasted, but that every substance is reconverted, and again made to do duty in a changed and beautified form, we have at least an example to stimulate us in economically applying the waste materials we make, or that lie around us in abundance, ready to be utilized.

P.L. Simmonds. Waste Products and Undeveloped Substances: or, Hints for Enterprise in Neglected Fields. London: Robert Hardwicke, 1862, pp. 1-2.

Industrial ecologists[1] have so far remained skeptical about the capacity of the free market to provide proper incentives and ensure that industrial waste products become a source of usable material or energy for other industrial processes. Although one can find hints toward the importance of market processes for successful implementation of industrial ecology in the field's major books, the fact remains that neither Allenby and Richards (1994), Ayres and Ayres (1996), Graedel and Allenby (1995), Schulze (1996) or Socolow et al. (1994) contains a single index entry for "prices" and "property rights." It is therefore not surprising that most industrial ecologists seem to distrust the capacity of market processes to promote active and widespread resource recovery. Ayres (1997) postulates that our current economic system does not encourage the emergence of integrated "industrial ecosystems." Although he admits that the explanation is open to dispute and that regulatory barriers are one of the problems, he is quick to point out that

> the most plausible explanation is that it is not possible to optimize at the system level without a long-term central planning and coordination authority at the same level ... in its absence, the decentralized "pure" market system, such that each activity (firm) interacts with the others only by competitive buying and selling, is unlikely to achieve the desired degree of integration. In short, the inability of a group of decentralized manufacturing firms to optimize the use of by-products and secondary resources, and thus to minimize overall waste and pollution, constitutes a kind of market failure (Ayres, 1997: 24).

And yet there is plenty of evidence showing that free markets historically have achieved a web of industrial loops in which a minimum of raw materials enter production and very little waste exits. As Max Muspratt, past-president of the Federation of British Industries, put it in 1928:

[1] The premise of industrial ecology is that modern industrial economies should be looked at as a system of raw materials 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 by-products should be reused, repaired, recovered, remanufactured or recycle on a very large scale.

> 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 historical evidence linking market processes with industrial ecology has not been fully assessed. Once this link is established, more reliance on traditional market institutions such as private property rights and the price system should stand out as compelling alternatives to central planning and environmental regulation. The first section of this essay puts recycling in historical perspective to show, mostly through the historical recovery of inedible animal parts, that it has always been an important aspect of human activity. Sections two and three examine economic calculation and human creativity as they relate to solid waste[2] recovery and illustrate how market processes tend to create a large number of "industrial loops" and "ecoparks." The impact of market distortions on the incentives facing individuals to discover and learn new ways of recycling solid waste will then be examined more thoroughly. It will be illustrated that central planning has some inherent deficiencies which make it unlikely to achieve better results than market processes. The main conclusion of this essay is that most of today's problems regarding resource recovery stem from previous government intervention which removed many incentives to turn waste into resources. Restoring pure market incentives is therefore offered as an alternative.

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[2] Solid waste encompass all wastes, except waste water discharges (waterborne waste) and atmospheric emissions (airborne waste). Resource recovery includes recycling plus energy recovery, such as that resulting from the burning of waste in waste-to-energy facilities or from methane gas emissions of landfills.

1. Resource Recovery in Historical Perspective: Some Evidence from Inedible Animal Parts

1.1 Resource Recovery in Historical Perspective

Most people believe that recycling began a few decades ago as an answer to energy or environmental degradation crisis, or in third-world slums as means of survival (Kimball, 1992). Actually, resource recovery has always been big business, as suggested by many old books with titles like "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), "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), and "The Recovery and Use of Industrial and Other Waste" (Kershaw, 1928). Furthermore, a French writer estimated in 1898 that more than 500,000 of his compatriots were involved in "recycling activities" of various sorts (De Silguy, 1989).

The importance of "industrial loops" also seems to have been obvious to many commentators of the past. In his classic On the Economy of Machinery and Manufactures, the polymath Charles Babbage (1835: 217) wrote that among the causes which tend to the cheap production of any article is the care which is taken to prevent the absolute waste of any part of the raw material and that "an attention to this circumstance sometimes causes the union of two trades in one factory, which otherwise might have been separated." As the British engineer and museum curator P.L. 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." A few 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 [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” (Bethnal Green Branch Museum, 1875: 4). In the revised edition of his The Evolution of Modern Capitalism, John Hobson observed that:

> 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. Conspicious 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. Gas tar, formerly thrown into rivers so as to pollute them, or mixed with coal and burnt as fuel, is now “raw material for producing beautiful dyes, some of our most valued medicine, a saccharine substance three hundred times sweeter than sugar, and the best disinfectants for the destruction of germs of disease” (Hobson, 1917: 75).

Following the First World War, many English commentators marveled at the hability shown by the Germans in turning 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 endeavour, he at once sets to work to attempt to discover some use for refuse.” A few years later, the chemical engineer John B. C. Kershaw (1928: ix) replied to some criticisms of his attempt to cover in one volume the wastes in all branches of manufacturing industry in the British Islands and the United States by pointing out that “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."

What is now termed "industrial symbiosis" was therefore prevalent in advanced economies a century ago. In the preface of his book By-Products in the Packing Industry, the economist Rudolf Clemen (1927: vii) wrote that "the development of by-products in industry is one of the most outstanding phenomena in our economic life" and "from the viewpoint of individual business, this manufacture of by-products has turned waste into such a source of revenue that in many cases the by-products have proved more profitable per pound than the main product." He credited market forces entirely for this state of affairs by pointing out that this movement toward the ever-increasing manufacture of by-products arose not only from a desire to enlarge operations with a view to greater profit, but also in order to maintain adequate earnings for dividend-paying purposes. He added that in many cases the development of by-products 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 (Clemen, 1927: vii).

Another important point to be made here is that although most of today's analysts usually point toward goods made of stones, pottery, metals and glass as instances of resource recovery in ancient times, most traded goods, both wasted and recycled - even in the so-called "stone age" - have always been perishable items, which might explain why most people don't intuitively grasp the historical magnitude of practices that are now labeled industrial ecology.[3] Some historical examples of the recovery of animal residuals will now illustrate how typically industrial waste products have become a valuable source of material or energy for other industrial processes. This line of work was selected for five reasons: 1) it is one of the oldest forms of human economic activity; 2) it illustrates that creative people can be found everywhere; 3) it involves perishable products; 4) virtually all of these activities emerged without centrally planned regulatory constraints; 5) along with oil refining and flour milling, and unlike most other industries, the killing and processing of animals is essentially a process of separation of certain complex raw materials, which means that by-products have always been a major concerns for those involed in this trade.[4]

1.2 The Recovery of Inedible Animals Parts [5]

Nobody knows when the inedible parts of slaughtered animals first became resources, but probably the most important event occurred when pelts were turned into clothing and shelter, eventually allowing humans to inhabit colder regions. It is probable, however, that animal blood was used as a crude form of paint and that various bones were used as rudimentary jewelry even earlier. One can also look at more recent artifacts: a 32,000 year old flute made of bone; a 17,000 year old sandstone lamp to burn animal fat; a 15,000 year old village built out of the bones of 149 woolly mammoths (Begley and Lief, 1988). The oldest glue discovered so far was made by Neolithic cave dwellers living southwest of the Dead Sea some 8,000 years ago. It was made from collagen (the fibrous protein taken

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[3] For literally hundreds of examples of recycling in the distant past and the present packed in a few pages, see also Bertolini (1978;1990) and De Silguy (1989). For recent figures on the composition of solid waste, see Hayward and Jones (1998).

[4] Social activist Upton Sinclair's fictional work, The Jungle, has given a bad name to meatpacking. Yet it can be argued that the historical evidence does not corroborate his story entirely (Yeager, 1981).

[5] As Mayer (1939: 27) put it: "It is unfortunate that Mother Nature misplanned the anatomy of the meat animal by not taking counsel with modern housewives." Mayer also estimated that the meat and lard content 68% for hog, 55% for beef and 47% for lambs. For a more detailed treatment of the reuse of animal by-products than the few exemples listed in this paper, see Bethnal Green Branch Museum (1872), Clemen (1927), Institute of Meat Packing (1947), Mann (1963), Semenov (1973) and Simmonds (1875).

from animal skin, cartilage and bone) and was used to waterproof rope baskets and containers, but also to decorate skulls (Discover, 1998).

The production of useful goods from what had previously been residuals was not limited to a few goods and services, as can be illustrated by the various uses to which bones have put in ancient times. Thus archeological evidence dug up from the Neolithic city of Çatal Hüyük[6] suggests that workers specializing in recovering bones made awls, punches, knives, scrapers, ladles, spoons, bows, scoops, spatulas, bodkins, belt hooks, antler toggles, pins and cosmetic sticks (Jacobs, 1969: 33). Some Latin texts written millennia later describe shops located close to slaughterhouses in order to turn bones and ivory into various items such as pins, tokens, buttons, components of hinges and wall fittings (Chevalier, 1993). The same process was also going on in North America, for Plain Indians turned bones into fleshing tools, pipes, knives, arrowheads, shovels, splints, sleds, saddle trees, war clubs, scrapers, quirts, awls, paint brushes, game dice, tableware, toys, and jewelry (Weber, 1992: 167-8). However, few people had more incentives to turn animals parts into resources than Arctic Inuits. Among the items that they produced were shovels made of seal hide and caribou horns and tendons; bows made of caribou horns, hide and tendons; sledge toys made of seal jaws, caribou tendons and various small bones; "sunglasses" made of caribou bones; long whips made of seal hide and small bone pieces; kayaks made of various animals bones, hide and horns, etc.[7] The oldest saddle found so far, in Western China, was made of hides and bones.[8]

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[6] A settlement located in what is now Turkey that thrived between 7,000 and 6,000 B.C.

[7] These examples are taken from a documentary broadcasted by the Société Radio-Canada on December 21, 1997.

[8] From a Nova documentary aired on a PBS affiliate in Plattsburgh (New York) on January 22, 1998.

Yet other inedible parts than bones were put to good uses. For example, the strong cables of some Roman war machines (*palintonon*) were made of women's hair and animal nerves (Klemm, 1966), while the intestines of various animals were turned into cords for bows, catapultic engines and other war machines (Bethnal Green Branch Museum, 1875: 44). Not all intestines were used for destructive purposes, however, for they were also a major component in musical instruments "at a period earlier than authentic history began" (idem). Meanwhile, many Polynesian peoples were making fishhooks out of oyster shells (Diamond, 1997). Whaling also affords another illustration. As is well-known, whales were often hunted for their oil rather than their meat. Matthews (1958) reminds us, however, that whale meat and bones were kiln-dried and reduced to meal, the better grades being compounded in food for pigs and poultry, and the poorer used as fertilizers. The horny plantes of baleen also found a limited use in the manufacture of brushes and sieves, while whalebone were formerly used extensively for making umbrella-ribs, corset "bones," hoops for crinolines, and the handles of punch-ladles. They were also turned into springs in light mechanical devices and, when fayed out into its component fibers, for the plumes on soldier's helmets. Whale bones have also often been used as building materials.

The most prominent forms of recycling of slaughterhouse by-products in the early nineteenth century were to turn them into glue, hog and chicken feed, fertilizers and soap (Mowery and Rosenberg, 1994). Yet, more creative uses were also to be found. According to Simmonds (1862: 345), the French entrepreneur L.F. Grenet was the first to fabricate "beautiful and diverse products" on a large scale from the various residues of animal bodies.

> Among the numerous productions of this industry are different kinds of gelatine in layers, adapted for the dressing of stuffs, and for gelatinous baths in the clarifications of wines, whic contains a sufficient quantity of tannin to precipitate the gelatine; pure and white gelatine, cut into shreds, for the use of confectioner; very thin, white and transparent sheets, called "papier glacé," or in paper for copying drawings; and finally, a quantity of objects of luxury or ornaments, formed of dyed, silvered, or gilt gelatine, adapted to a variety of

> purposes, and to the fabrication of artificial or fancy flowers... Under the various names of glue-pieces, sizing, spetches, and scrows, the offal or parings of skins and hides, and the pelt from furriers, the hoofs and ears of horses, cattle, and sheep, are used by the glue-makers. Old leather scraps are even converted into glue. Gelatine is purer kind of glue, also obtained from waste materials, such as the raspings and trimmings of ivory, the bones, cartilage, and tendons of animals. The clippings of parchment, vellum, gloves, leather and other kinds of skin and membrane yield size. The French buy up largely our written parchments, and after removing the writing, return them to us in the shape of kid gloves. The shavings of seal and other skins are used for filling tennis and cricket balls.

Some British entrepreneurs were also busy turning former waste products into valuable inputs at the same time. Babbage (1835: 217-18) provides more details on the reuse of horns.

> 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.

Bones became an increasingly valuable commodity in 19th century. Even though British production was thought to be between 70 000 and 80 000 tons annually, the trade in bones grew increasingly large, as 64 000 tons of bones were imported in 1857, 66 509 tons in 1861 and 92 000 tons in 1871 (Bethnal Green Branch Museum, 1875: 49; Simmonds, 1862: 353). These included bones from giraffe, elephant, horse, ox, buffalo, and whale. Most of these went to cities such as London, Birmingham and Sheffield, were they were transformed into everything from combs to umbrella tops and knife handles (Simmonds, 1875: 133-147). For example, about 2 000 000 shank bones of oxen were turned into knife-handles, spoons, nail brushes, combs, fans, bone flats for button molds and various other miscellaneous articles every year in Sheffield. Yet, this was only part of their use, as Simmonds (1875: 147) points out:

> In the several stages of the useful applications of bones, we have first the shank and cut bones just alluded to for working up, next carbonised bones, burnt in closed air-tight retorts for about twelve hours, which are then ground between grooved plates to make animal charcoal in grain. This is employed as a filtering substance to clarify sugar in the process of refining. The portions of the carbonised bones which, in the process of grinding become too fine for filtering charcoal, are reduced to an impalpable powder and sold as bone-black to the blacking-maker. The grease of fat extracted from the bones before carbonising is used for making soap. Sulphate of ammonia, the liquor distilled out in the process of carbonising bones, afterwards saturated with sulphuric acid and evaporated, is used as smelling salts, and largely as a valuable manure. Bone ash, when ground to moderately fine powder, is the material of which the cupels of the gold and silver asseyers are made, being at the same time very infusible and sufficiently porous to discharge the litharge and other impurities, while the fine metal remains on its surface.

Much the same process was going on in major cities around the world, for it is easy today to forget that before the advent of railways and the refrigerated car, meat-packing and dairy productions were urban operations. In the middle of the 19th century, some 375 000 animals a year were slaughtered in New York City, while the milk for the city came from urban cows that lived on the swill of local distilleries in 260 city stables (Miller, 1998: 78). Even though New York's "animal district" was described by many commentators as a rather unsanitary place, it was a model prototype of an "eco-industrial park" where no potential resource was dilapidated. Here are some examples of the reuse of bones and hooves that were going on daily.

> Bones were a valuable commodity. The best were used for handles and buttons. The next-best were ground and charred to be used by sugar refiners to filter the dark liquid they pressed from the cane; bone black was also used in making pigments and china. Even the least desirable bones fetched an attractive price from the emerging industry for commercial fertilizers, whose promising future seemed to offer an eternal new life for the urban Eastern seaboard's exhausted market-garden soils. Ninety percent of the marrow could be converted to tallow that was valuable to chandlers and soap-makers, and to the rapidly expanding chemical industry... Hooves were used for gelatin, and in the dye known as "Prussian blue" (Miller, 1998: 82).

Again, New York's animal district producers did not only rely on local refuse, for countless railway cars freighted with buffalo bones frequently arrived in the metropolis to be worked up into button molds, knife handles, and other uses (Simmonds, 1875: 98).

Bones were not, however, the only valuable part of animal by-products. Intestines were also highly sought-after for many uses, ranging from musical instruments to clock-making. Here is a description of the preparation and uses of "catgut" in the second-half of the nineteenth century.[9]

> Catgut is now generally prepared from the intestines of the sheep and the goat; rarely from those of the horse, ass, or mule, and never from those of the cat as one would naturally suppose from the name. The first stage in the process of manufacture, is to the thorough cleansing of the entrails by means of a blunt knife or scraper... The intestines are then steeped in water for several days, or until the external membrane becomes sufficiently loosened to allow of its ready removal by scraping. The material which is thus scraped off

[9] See also Simmonds (1862: 347-352).

> is employed for the cords of battledoors and rackets, and also as thread in sewing the ends of intestines together. The intestines are then steeped in water and scraped again, when the larger are cut and placed in tubes with salt to preserve them for the sausage maker; the former are allowed to steep in pure water, and are then treated with a dilute solution of alkali... After remaining in this bath a sufficient lenght of time... the intestines are drawn through a perforated brass thimble, and assorted in their respective sizes, when, after drying, their manufacture is considered completed...
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> The best catgut strings are those known as Roman, which are made in Italy, from the intestines of sheep and goats. These are the strongest made, and mostly used for musical instruments... The cords used by clock makers are made from the smallest of the intestines, and from larger ones which have been split longitudinally into several lenghts, which lengths are then sewed together with thread made from the external membranes scraped off during the process of manufacture, as described above. Whip cord is made from catgut which has been twisted in a manner somewhat similar to that employed in the manufacture of single corded ropes. The catgut obtained from the intestines of horses, asses, and mules is principally made in France, and is employed in many cases instead of leather belts for driving machinery (Bethnal Green Branch Museum, 1875: 44-5).

Simmonds (1862: 347) also adds that catgut were also used in bow-strings for hatters' use and for archers' bows. Despite advances in the creation of new materials that eventually substituted for animal residuals, much higher levels of resource recovery would be achieved in following decades with the coming of age of the American meat-packing industry. According to Clemen (1923: 6-7), there converged four factors whose combination was essential in turning American meat packing from a mostly small local business into a large-scale industry concentrated in a few major centers: 1) the opening and developing of a new source of supply of livestock (mostly the American West and Texas); 2) the extension of railroad transportation to the source of supply; 3) the coming of age of mechanical refrigeration; 4) the arrival of men on the scene who were able to organize the distribution of livestock and meat in the most efficient way (most notably Philip D. Armour, Nelson Morris and Gustavus F. Swift).[10] As an annual report of

[10] For more detailed descriptions of the rise of the American meat packing industry and of the innovative uses of what were formerly wastes, see, among others, Clemen (1923; 1927), Goddard (1975),

packing giant Armour and Company (1918, non-paginated document) put it: “Scientific laboratory work has utilized the inedible portions to the last vestige, and today these once worthless parts are made into hundreds of marketable products, from violin strings to soap, from pharmaceutical supplies to glue.” Actually, according to all credible sources, the packers early on received less from the sale of the dressed-beef carcass than the amount paid for the live animal after paying transportation. However, this loss plus a reasonable profit was covered by the sale of hides and other waste materials that were turned into valuable by-products (Unfer, 1951: 132). The economist Frank W. Taussig (1920: 42-43) could therefore write that: "Every part of the animal is used, and every part is manipulated on a large scale under a further minute division of labor. The output in all its varied forms - the meat of all qualities, the fat, the hide, the bones, the horns, the very hair - all is then marketed to millions of people." Clemen (1927) also argued that it was only once the waste accumulated in large quantities that the use of techniques of chemical analysis could transform them into valuable products. The revenue derived from these by-products, in turn, not only more than offset the charges incurred concerning transportation, but also lowered the price of the meat (Talbot, 1920).

The earliest more innovative work of chemists focused on food products such as oleomargarine and beef extract, but it eventually turned to more distant fields such as pharmaceuticals, commercial fertilizers, soap, explosives, lubrication oils and cosmetics that would expand dramatically in the early decades of the twentieth century (Clemen, 1923; Mowery and Rosenberg, 1994). However, this process was not carried out only by a few gigantic firms. Soon enough, that yards district of Chicago (also known as “Packingtown”) turned into what some would now label an "ecopark," for there grew around mammoth cattle-killing plants a number of separate satellite industries, which

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Kershaw (1928), Lipsett (1963), Mowery and Rosenberg (1994), Talbot (1920, Unfer (1951) and Yeager (1981).

bought the unfinished by-products of the plants and transformed them, among other things, into tanning, glue, gelatin and animal feed products. As Clemen described it:

> This process of integration in the packing industry and its by-products differs from what is normally understood as integration by the professional economists. While many of the products ... are manufactured by certain of the national packers themselves, or through subsidiary corporations such as leather and tanning companies and fertilizer companies, in many instances by-products processed to a certain degree within the packing industry proper are transferred to other subsidiary industries over which individual packers have no control, for further elaborate and expensive processing into final, highly finished articles (Clemen, 1927: 27)

Thus 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 plants materials. Butterine manufacturers used neutral lard and oleo oil from packing plants for manufacturing 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). By the turn of the century, the use of by-products in the meat-packing industry had become so huge that Chicago humorist Finley Peter Dunne (Mr. Dooley) observed that: "A cow goes lowin' softly into Armour's an' comes out glue, gelatine, fertylizer, celooloid, joolry, sofy cusions, hair restorer, washin' sody, littrachoor an' bed springs so quick that while aft she's still cow, for'ward she may be anything fr'm buttons to pannyma hats" (quoted in Yeager, 1981: 68).

Many more uses have been found for meat-packing by-products since then. In fact, it has long been said that "everything but the squeal" is being used as a productive input in the meat-packing industry (Weld et al., 1925: 140). It is also worth noticing that the productive use of the least valuable parts of an animal (things like hair, hooves and glands) has often been the difference between profit and loss for many slaughterhouses (Centre de création industrielle, 1984; Lipsett, 1963).

Another way to look at the various uses to which animal residuals were put is to compare what the North American Plain Indians did with the residuals of buffalos (Table 1) and what the 1960's meat-packing industry did with the residuals of cattles (Table 2). In both cases, it is argued that nothing was lost.

Table 1

Some Buffalo By-Products and their Use by the North American Plain Indians

Rawhide
Containers
Shields
Buckets
Mocassin Soles
Drums
Splints
Mortars
Cinches
Ropes
Sheaths
Saddles
Saddle Blankets
Stirrups
Bull Boats
Masks
“Parfleche”
Ornaments
Lariats
Straps
Caps
Quirts
Snowshoes
Shrouds

Buckskin
Cradles
Mocassin Tops
Winter Robes
Bedding
Shirts
Belts
Leggings
Dresses
Bags
Quivers
Tipi Covers
Tipi Liners
Bridles
Backrests
Tapestries
Sweatlodge
Covers
Dolls
Mittens

Hind Leg Skin
Preshaped Mocassin

Bones
Fleshing Tools
Pipes
Knives
Arrowheads
Shovels
Splints
Sleds
Saddle Trees
War Clubs
Scrapers
Quirts
Awls
Paintbrushes
Game Dice
Tableware
Toys
Jewelry

Teeth
Ornamentation

Skull
Sun Dance
Medicine
Prayers & Other Rituals

Blood
Soups
Puddings
Paints

Hair
Headdresses
Pad Fillers
Pillows
Ropes
Ornaments
Hair Pieces
Halters
Bracelets
Medicine Balls
Mocassin Lining
Doll Stuffing

Beard
Ornamentations

Tail
Whips
Medicine
Switch
Fly Brush
Decorations

Hoofs, Feet & Dewclaws
Glue
Rattles
Spoons

Muscles
GluePreparation
Bows
Thread
Arrow-Ties
Cinches

Chips
Fuel
Diaper Powder

Stomach Contents
Medicines
Paints

Fat
Tallow
Soaps
Hair Grease
Cosmetic
Aids

Bladder
Pouches
Medicine Bags

Stomach Liner
Water Container

Scrotum
Rattles
Containers

Paunch Liner
Wrappings (Meat)
Buckets
Collapsible Cups
Basins
Canteens

Liver
Tanning Agents

Gall
Yellow Paints

Source: National Bison Association (www.nbabison.org/history/chart.shtml/)

Table 2
Some Animal By-Products and Their Use, 1963.

Skins:	**Bones**	**Blood**
Leather	*Grease*	*Blood Serum*
Harness, Whips, Saddlery		Pharmaceutical Products
Furnishing, Bookbinding	*Bones for Bone-made Objects*	
Shoes, Gloves, Belts	Buttons	*Albumin*
Suitcases, Bags	Knife Handles	Water-resistant glue
Industrial Belts	Various Objects	Primer for dyeing fixatives
Clipping and Trimming Waste	*Bone Flour*	
Brushes	Animal Food	*Dried Blood*
Gelatin	Mineral Supplement	Animal Food
Glue	Burned Bones	Fertilizers
Fertilizers	Animal Black	
Grease		
Animal Food	*Ossein*	
	Glue	
	Gelatin	
Hair, Wool and Bristle	**Feet**	**Faeces, Litter**
	Tendons	*Compost*
Felt	Glue	
Stuffing, Padding	Gelatin	*Methane*
Animal Food		Light
Covering, Carpets,	*Extract*	Heat
Texture, Thread	Beef Feet Oil	Power
Fertilizers	Animal Food	
Lanolin		**Hoofs and Horns**
		Buttons
Intestines	**Non-edible Meat**	Combs
Bowel	*Grease*	Hairpin
Sausage Wrapper	Soap	Various Objects
Various Food Products Wrapper	Stearin, Candles	Hoof and Horn Powder
Surgical Catgut	Tannery Grease	
Tennis Racket Strings	Industrial Grease	*Horn Filling*
Music Strings		Gelatin
	Poultry Food, Animal Food	Glue
Animal Food		Fertilizers
	Meat Flour	
Grease		*Bone Flour*

Pharmaceutical Products

Blood	*Pineal*	*Thyroid*	*Parathyroid*	*Hypophysis*	*Mammary*
Hemoglobin					
Serum	*Stomach*	*Pancreas*	*Lard*	*Liver*	*Gall Bladder*
Testicle	*Ovary*	*Surrenal*	*Thymus*		

Source: Translated and adapted from Mann (1963: 266).

Statistics and historical anecdotes, however, are useless if there is no theoretical understanding of the facts. The economic processes underlying solid waste recycling will therefore be discussed before the importance of technological change in that matter is examined. It will then be argued that the decentralized market system is more likely than central planning to achieve tremendously high levels of resource recovery and to spontaneously create "industrial loops" and "ecoparks."

2. Market Processes and Solid Waste Recovery

Economics has often been defined as the study of how humans use scarce resources to fulfill competing objectives. Much of economic analysis, however, has assumed away human qualities of innovation and creativity. According to Ayres (1996: 4), this has "mainstream economists using equilibrium models assuming that all current choices are optimum ... to conclude that any major change in technology must be costly and therefore that its adoption will necessarily reduce economic growth." A more promising way of looking at environmental issues can be found in what is now labeled the "New Resource Economics" (NRE).[11] NRE is at its core a revised version of traditional resource economics which introduces ideas from Property Rights, Public Choice and Austrian economics. To put it succinctly, the main message of NRE theorists is that, in a world characterized by innovation and the discovery of previously unknown possibilities, private property rights are a more efficient way of solving environmental problems than "command-and-control" regulations. This section will provide a broad outline of this paradigm.

[11] For examples of works in this tradition, see Anderson (1995), Anderson and Leal (1991), Block (1990; 1994), Ellig (1995), Meiners and Yandle (1994), Smith, (1995a; 1995b), Stroup and Goodman (1992) and Taylor (1992). For a critical look at this paradigm, see, among other sources, the vol. 15, no. 2 (1992) issue of the Harvard Journal of Law and Public Policy and the vol. 6, nos. 2-3 (1993) issue of Critical Review.

2.1 The Market Process[12]

The market process can be defined as the voluntary and peaceful complex interaction of humans living in a world of scarcity. It is based on the fact that humans can accomplish more by specializing in what they do best, and then cooperating with others, than they can totally on their own. Its ultimate result is to produce the most desired *combination* of outputs; i.e. not the largest quantities of goods X, Y or Z, but the combination that will satisfy individuals most in terms of both quantity and quality. In the market process, humans act to substitute a more satisfactory state of affairs for a less satisfactory one from their various points of view. Exchange of goods and services, raw materials, labor and capital is therefore the central human activity. Human action always implies the employment of the means for the attainment of the ends, but every action implies both taking and renunciation. In the market, something is said to have economic value when its owner ascribes it a usefulness in facilitating the attainment of an end. The value of one thing varies from person to person and from time to time for the same person. The same thing can therefore be a resource or a waste, depending on the point of view of the person looking at it. As one author wrote earlier in this century, in some instances "waste is merely raw material in the wrong place" (Talbot, 1920: 11). To quote the popular saying: "one man's trash is another man's treasure."

The consequences resulting from human action, however, are not always those that were expected because humans act in real time and without perfect knowledge. This means that the consequence of one action can supply data for succeeding choices, with an evolutionary process being set into motion that often produces unintended consequences. Some unintended consequences cause problems that demand further problem-solving, while others turn out to be orderly patterns of behavior and institutions that provide

[12] The market process view described in this essay is essentially a summarized version of some central tenets of the "Austrian" school of economics. See, among others, Boettke (1994), Hayek (1948), O'Driscoll and Rizzo (1996) and Von Mises (1966) for a more detailed discussion of this tradition.

guidance for survival and growth. The market process therefore does not imply perfection, but a trial-and-error process of discovery and improvement. The market can thus be viewed as an institution that generates and transmits information about the plans of millions of individuals trying to economize efforts and resources. All knowledge in the economy, however, is far from explicit. Most of it is dispersed and tacit, like the personal and context-specific know-how that is gained through practice and mistakes along with what the Nobel Laureate in economics F.A. Hayek labeled the "particular circumstances of time and place" (Hayek, 1948).

2.2 Market Institutions and Scarcity

Producing something valuable by choosing a particular combination of materials and know-how among a wide array of alternatives always implies foregone courses of action. The two main market institutions that have evolved historically to cope with this problem are private property and the pricing process.

2.2.1 Private property rights

Property is anything that people can use, control, or dispose of. A property right delineates the freedom to use, control, or dispose of an object or entity. Property rights are usually defined according to four main characteristics: universality, exclusivity, transferability and enforceability (Tietenberg, 1996). However, a strict definition of private property requires that we move a step further. As Von Mises (1966: 655) put it more than three decades ago: "Carried through consistently, the right of property would entitle the proprietor to claim all the advantages which the good's employment may generate on the one hand and would burden him with all the disadvantages resulting from its employment on the other hand. Then the proprietor alone would be responsible for the outcome."

Such a strict interpretation of private property rights is at the core of NRE theory. These authors therefore argue that for a long time, the common law, through legal actions for trespass and nuisance, was an efficient way of protecting the environment. Yet things changed in the middle of the nineteenth century with the emergence of a legal philosophy putting "the greater good" of the nation (usually meant by industrialization at all costs) before private property rights. The fact that some courts held that pollution was just a fact of modern life and necessary for progress to occur in turn nullified the environmental incentives role of private property rights and ended up "legalizing" pollution.[13]

The common-law approach has never been perfect and may never solve all environmental problems.[14] Yet a case can be made that this approach to environmental issues would prove much more efficient than regulation in dealing with solid waste, for unlike non-excludable goods such as air and water, solid waste can be isolated from the human population and divided into privately owned parcels.[15] The most obvious solution of strict liability, at least regarding solid waste, then becomes the criteria of the physical invasion of the property of others. What would then be illegal would be human-made emissions evident to the senses emanating from one person's landed property and invading the property of another. Of course, such a notion of strict liability is not without practical problems, but most NRE theorists point toward the common law notion of "reasonabless" when applied to nuisances (i.e. what is an unreasonable nuisance is that which the reasonable person living in the area would find unacceptable) as a good legal rule of thumb. Specific people would consequently reap either the benefits or the costs of their

[13] See Anderson and Leal (1991), Block (1990), Ellig (1995), Meiners and Yandle (1994) and Smith (1995a) for a much more detailed exposition of this argumentation.

[14] It is often pointed out that multiple polluters that each inflict low levels of damage are unlikely to be held liable, especially when the damage is shared by many. Injuries and harms that come after long gestation periods present another challenge, because 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.

[15] A number of authors have addressed the practical workings of a common law regime with regards to non-excludable goods (Anderson, 1995; Anderson and Leal, 1991; Block, 1990; Stroup and Goodman, 1992; Willey 1992), but it is clearly beyond the scope of this essay to address this issue in much detail.

actions. The owner of any type of goods would then have to employ them without infringing on the rights of others.

If one accepts this approach, environmental failures are no longer attributable to excessive material consumption or to a failure of markets to price goods, but rather to the fact that some agents are not held accountable for external effects. The actual cost of producing a factory's goods therefore includes not only the expense of materials, labor, and machinery, but also the cost of proper waste disposal. Liability as understood by NRE theorists does not imply banning incineration and land-filling, it rather means that a factory must not impinge upon the property of others. Pollution therefore refers to a private property border crossing, while waste disposal refers to the disposal of residuals without negatively impacting others' rights. These are obviously legal definitions, for in chemical terms the same product can be "pollution" or "disposed waste."

A movement away from regulation and toward restoration of private property rights as the primary solution to externalities and pollution might, at first glance, seem a rather unrealistic proposal. It is true that defining and enforcing strict liability is a much more complicated matter than the general principles outlined in this essay may seem to suggest. Yet it can be said that if such an agenda departs drastically from contemporary practices, it seems nonetheless to be an alternative that deserves more careful examination, as will be argued in the remainder of this essay.

A market economy is unthinkable without private property. Yet private property alone is not sufficient because trading - that most peculiar human activity - implies calculation. We will now look at the importance of a price system, the complimentary market institution that emerged to deal with the scarcity of valuable inputs.

2.2.2 The Pricing Process

Prices may tell us the cost to consumers, but they also embody many other qualities. As Boaz (1997: 150) states: "Each price contains within it information about consumer demands and costs of production, ranging from the amount of labor needed to produce the item to the cost of labor to the bad weather on the other side of the world that is raising the price of the raw materials needed to produce the good." Prices are in a sense the means to convey and make usable the dispersed knowledge of the myriad of humans in a market economy.

In the market process, millions of individuals make their own decisions, and buy and sell accordingly. The pricing process is thus a social process, the outcome of which is to satisfy consumers by giving them the highest output using the least-cost input combinations. It is through competition, which is to say the profit and loss test, that producers find out how things can be produced at the least cost. If a firm makes a profit, it is using resources efficiently. If it experiences a loss, it is not. Profit-and-loss is therefore the only way to assess the opportunity costs of production decisions. Entrepreneurship describes that aspect of human action that is alert to and seizes upon opportunities to make profit or avoid loss.

Private property and the pricing system are the institutional building blocks, so to speak, of an effective market economy. There cannot be sustained exchange without these. But many people believe that these institutions lead to excessive material consumption and pollution. As will now be argued, this is not the case, for prices and property actually provide incentives to minimize waste production.

2.3 The Market Process, Waste Reduction and Resource Recovery

2.3.1 Prices and Resource Recovery

The pricing process in a context of properly enforced private property rights is a powerful feedback mechanism to prevent resource exhaustion. As a material becomes more scarce, prices and profit-and-loss act as mechanisms to conserve it and provide incentives to develop more efficient technology and substitutes. Market processes also provide incentives for recycling, 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, lowering further processing costs; 3) residuals are often produced much closer to their potential buyers than virgin materials, therefore lowering transportation costs.

Faced with the competition of others, private property owners are likely to choose the most economical ways to go about their business. Instead of paying for incineration or land filling, producers can be expected to improve their ecological behavior by producing less residuals and engaging more often in resource recovery than would be the case in other institutional arrangements. Of course, there will only be such "spontaneous" recycling if the resources saved are more valuable than the costs forgone. If, in a context of strict liability, recycling a residual proves more expensive than using a virgin material, it is often not the best environmental option, for it may end up using more scarce resources and producing more waste than would the use of virgin materials.

2.3.2 Pricing Mechanism Failure

Even though the ecological case for market processes seems strong, a number of people have always called upon government officials to correct some "market failures," especially those of the pricing mechanism. But, as I stated previously, some of these failures can be traced to a poor definition of property rights which then distort the true cost of a good. Additionally, some of the remaining problematic situations can usually be traced to other state interventions which have prohibited or preempted the pricing mechanism. Some measures, such as subsidies and tax advantages to promote the discovery, extraction, processing and transportation of virgin materials, decrease the demand for residuals, while enlarging the waste flow. Others, such as "set aside" programs, "price preference" approaches and minimum content laws, arbitrarily channel residuals in closed-loop instead of open-loop recycling and therefore impede innovation and creativity. Furthermore, municipal solid waste disposal typically bears no relation whatsoever to the amount of waste generated by each household and therefore provides no incentives to reduce it. Although it is eminently difficult to measure the true impact of these market distortions on the utilization of residuals, it is generally agreed that the net result is fewer incentives to recycle residuals (OECD, 1994).

The main objection to true prices is an ethical one, centered on the specter that true prices will place an intolerable burden on the poor. Yet in most third-world economies, and for that matter throughout history (Koller, 1918; Simmonds, 1862), poor people have always been at the vanguard of recycling activities and are therefore among the first to be hit by price distortions discouraging recycling (Hiebert, 1993; Sinha, 1993). Besides, being poor generally implies generating less trash than more affluent people in the nearby societal environment. Most municipal waste disposal systems end up transferring wealth from low and middle-income households to above average households (Tietenberg, 1996).[16]

It has so far been argued that in an appropriate institutional setting, market processes provide incentives to behave in an ecologically responsible way. Yet the efficient allocation of resources is not the whole story here, for resources are not static objects waiting to be plundered. It will now be argued that resources are created by humans and that when new uses for waste products were found in the past, these solutions were not an

[16] In commenting on a volume pricing scheme that replaced such a system, Tietenberg (1996: 184) remarked that: "One preimplementation concern about the program was that it might impose a hardship on the poor residents of the area (...) That concern apparently was misplaced. Many of the town's 4000 residents were elderly and living on relatively meager fixed incomes. Under the old system of financing trash collection, every household paid the same fee regardless of how much trash was produced. Since elderly households produce less trash, they were in effect subsidizing wealthier households under the old system. Under the new system, elderly households paid only the flat fee since they didn't need extra stickers. The expense of these stickers was less than the average cost of disposal, the basis for the previous fees. Poor households were better off, not worse off, under the new pricing system."

economical or ecological burden upon their societies, but rather increased true wealth. If it has often been said that technology is the means by which humans turn adversity into opportunity, it will now be argued that this has definitely been the case in almost every successful instance of resource recovery.

3. Technological Change and Solid Waste Recycling

3.1 Technological Change and Recycling

The profit-and-loss test provides a powerful incentive to continually develop new processes and technologies that reduce the waste/output ratio and raise the level of waste recovery. As an industry executive once said, "Research is what you do to find out what you are going to do when you cannot make money doing what you do now" (Lipsett, 1963: 356). This was also obvious to the economist Alfred Marshall (1986 [1920]: 232) who wrote at the turn of the century that "no doubt 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 been generally 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.

More recently, Lipsett (1963: 355) has made similar comments: "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." French economist Gérard Bertolini described the importance of technological change for resource recovery in the most appropriate terms when he pointed out that "the thin line between a commercial product and waste can never be thought of as permanent; the existence of a waste product may only mean that a close technological breakthrough has not yet happened" (Bertolini, 1978: 75, my translation).

From a producer's point of view, residuals are therefore potential means to achieve ends that can substitute or be substituted by other materials. Cotton, nylon and various textile fabrics have supplanted animal hides in many uses, while wood, minerals and plastics have supplanted bones in many applications. Meanwhile, new uses have been found for hides and bones. If it is true that the economic value of residuals rests on their advantages over other substitutes available, it must be kept in mind that their value at a given point in time cannot be dissociated from human creativity and efforts in turning them into resources. Mann (1963: 1-9) has noted in much detail that the most complex societies are the ones making the best possible use of all the parts of slaughtered animals. It is therefore not poverty or the lack of substitutes alone that determines the value of by-products. It is rather human creativity, know-how and entrepreneurship that create marketable resources out of residuals. Engineers, inventors and entrepreneurs discover better ways of doing something or a new process and product altogether. Recyclables are in that sense neither "natural" nor finite. The more a society is advanced technologically, the more the sheer diversity of the technical, managerial and professional capacities of its individuals allows many different ways of turning its residuals into resources, while at the same time providing many different potential markets for them. All of today's recyclables were considered waste at one point in time before someone, somewhere, saw an opportunity and turned them into a resource by combining skills, ideas, materials and the collaboration of other people. Of course, the same is true of everything that humans use today; large game animals only became resources once hunting tools and social organizations were created. In short, waste reduction and resource recovery stem primarily from consumers' demands for better or new products at the lowest possible prices and from the resulting competition for scarce resources on the part of producers.

3.2 Human Creativity and Technological Change

Historically, turning residuals into resources has required various amounts of resources and time, first and foremost though is the use of specialized knowledge and imaginative skills to create a new technology or to adapt a technology already used in another industry. Invoking technological change as the most effective answer to environmental problems is nothing new,[17] but how can we be sure that what was true in the past will still be true in the future? The main reason to adopt an optimistic outlook on this issue is to look at the human creative process, a faculty which has evolved over tens of thousands of years. It is therefore useful to provide the reader with a more detailed pattern of technological creativity to illustrate why some individuals in the context of a market economy will always find new ways of turning solid waste into valuable commodities.[18]

1) <u>Technological innovation is essentially a problem-solving activity</u>. As Petroski (1992: 22) puts it: "The form of made things is always subject to change in response to their real or perceived shortcomings, their failures to function properly. This principle governs all invention, innovation, and ingenuity; it is what drives all inventors, innovators, and engineers." But the problems identified by an inventor or an engineer are not limited to shortcomings in artifacts. It can also be the awareness that certain residuals of potential usefulness are being discarded and that something must be done about them. Weber (1992: 168) writes about the Plain Indians that: "One wonders where the ideas for these

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[17] See, among others, DeGregori (1985), Jacobs (1969), Palmer, Oates and Portney (1995), Simmons (1862) and Simon (1996).

[18] The creative steps identified in this essay can be found, in one form or the other, in any book dealing with technological creativity. See, for example, De Gregori (1985) and Weber (1992). The only exceptions are some sociological frameworks denying the importance of individuals in technological change. A more detailed version of this model can be found in Desrochers (1996).

applications [of buffalo's residuals] came from. Certainly, some of them originated in need: given a need, one then looks around for a material that will satisfy it. Others may well have originated by saying to oneself: Materials are scarce; here is a part of the buffalo that I haven't used yet. What can it be used for?"

2) There are always many ways to look at a particular problem. There is always a surprisingly wide range of alternative methods of getting a job done, each method being characterized by a different mix of capital, labor, and resource inputs.

3) Creative individuals can be inspired by many things. Creative individuals will use their accumulated knowledge, what is available to them (material and financial resources, but also the knowledge of other people) and their capacity of observation (of natural and man-made things as well as other people's actions) to come up with new solutions.

4) Technological innovation is a trial-and-error process. Technological problems are typically underspecified and what is potentially the best solution can rarely be recognized from the outset.

5) Technological innovations are the combination of existing things. It has often been pointed out that any act of creation is an act of synthesis. Technological innovations are typically combinations of existing things, whether it is combining a number of things into a single artifact or production process, or finding a new use for an already existing artifact or process.

6) Critical revision. Once a problem is solved, another is usually created as an unintended consequence. According to DeGregori (1985: 5): "Progress in the human endeavor is most meaningfully defined not in terms of the ultimate or final solution to problems but in creating smaller or less important ones than those we solve." And then these smaller problems also require problem-solving, which means that this process goes on again and

again. For example, when the practicality of extracting gas from coal was demonstrated in the nineteenth century, many producers began to exploit gas and only gas. However, dangerous substances such as ammonia and tar threatened the whole enterprise, until new uses were found for those by-products (Talbot, 1920: 14-15). To quote Petroski (1992: 22): "Since nothing is perfect, and, indeed, since even our ideas of perfection are not static, everything is subject to change over time. There can be no such thing as a "perfected" artifact; the future perfect can only be a tense, not a thing."

Thus there is no limit to the applications of human creativity, for there is always opportunities to reduce inputs or waste in the production of a good. And because innovations come about by way of new combinations of existing applications, there will always be a better way to do something. Only the scarcity of a valuable resource limits the number of innovations that may be created. Provided there are proper incentives and consequent productivity gains, it can be expected that humans will create additional uses from fewer resources and find creative uses for by-products. Two examples will illustrate this process: the influence of the meat packing industry on the Ford Motor Company and the influence of whaling on garbage reduction.

It is generally acknowledged that the success of the Ford Motor Company owes much to previous developments in other industries, such as the production of interchangeable parts, the idea of continuous flow and the rise of an efficiency movement (Hounshell, 1991; Klemm, 1966). Thus the technical people at the Ford Yet came up with an adapted assembly line in order to increase the assembly rate of their tremendously successful Model T. One industry that provided a model of efficient material handling was the meat packing industry. As the historian of technology David Hounshell describes:

> In his autobiography, written in collaboration with Samuel Crowther, Henry Ford suggested that the "disassembly" lines of Chicago meatpackers served as a model for "flow production" at the Ford factory... William Klann, head of the engine department at Ford, recalled that he had toured Swift's Chicago slaughterhouse and had then suggested to superintendent P.E. Martin, "If they

> can kill pigs and cows that way, we can build cars that way and build motors that way" (Hounshell, 1991: 241).

Klann also stressed that the Ford flow production drew upon the mechanical conveying system of both the flour milling and brewing industries. He states: "We combined our ideas on the Huetteman & Cramer grain [conveying] machine[ry] experience, and the brewing experience and the Chicago stockyard. They all gave us ideas for our own conveyors" (quoted in Hounshell, 1991: 241). It is interesting to note that, according to Hounshell, the process technology employed in food canning might also have influenced some of Ford's employees.

The influence of the whaling industry on garbage reduction provides another illustration. As was previously noted, it was largely the demand for whale oil and whalebones that increased whaling's popularity in the early nineteenth century. As whales became scarce, however, whale oil prices soared to over $137 a barrel and encouraged creative innovations both in the whaling industry and outside the industry to develop alternative lighting technologies. One of the first substitutes was pork lard oil. Beginning in the early 1840's, factories for the rendering of this product were erected in most American cities where packing of any considerable amounts was carried on (Clemen, 1923: 130). In time, however, coal gas, kerosene, natural gas, paraffin and electric light proved to be better alternatives. These substitutes, along with the passing of the crinoline and the introduction of steel busks for corsets, eventually led to the collapse of whaling (Matthews, 1958; Smith, 1995b; Talbot, 1920).

Nonetheless, a set of valuable skills had been acquired by individuals working in this industry. One of these was "reduction," which was used in the rendering of blubber.[19]

[19] As Matthews (1958: 58) writes: "the Americans developed the practice, adopted by whalers of other nations, of stripping the blubber from the dead whales in the water alongside the ship and extracting the oil by boiling the finely minced blubber in a series of cauldrons set in brickwork. The fuel used was the oil-soaked fibrous scrap remaining after the oil had been boiled out of the blubber. Despite the danger of such operations on a wooden ship there was no unduly high loss from fire."

This technique came to be used in stewing wet garbage and dead animals in large vats in order to produce grease and a substance called "residuum." The grease was sold for between three and ten cents a pound and was used in the manufacture of soap, candles, glycerin, lubricants, and perfume. Meanwhile the residuum brought between five and ten dollars a ton, and was used for fertilizer (Rathje and Murphy, 1992: 175).[20]

3.4 Market Processes, Technological Change and Solid-Waste Recycling

It has so far been argued that producers striving to make a profit in a context of properly defined private property rights can be expected to develop new devices that are more efficient, use fewer or different resources, produce less waste, and therefore cause less environmental harm than previous technologies. If residuals are an inescapable fact of life, the market process tends toward recycling by rewarding organizational and technological innovations. Recycling is a manufacturing process requiring resources and producing waste. One implication of this state of affairs is that the use of virgin materials is not necessarily more harmful to the environment when they are cheaper than residuals. Consequently, a significant portion of the industrial solid waste stream will always end up in incineration and landfilling,[21] for it is the economic and environmental thing to do. However, the cost of disposal provides incentives to create new technologies or to find new outlets to recycle discarded residuals. Thus in the 1850's, the Chicago packers found a way to avoid paying someone in order to have the refuse from the slaughter houses destroyed by carting it away to be used as a food for hogs (Clemen, 1923: 127).

4. Markets Vs Central Planning in Solid Waste Recovery

[20] There was, of course, much more sophisticated resource recovery going on in this matter, for many parts of the dead animals, such as the hide, the flesh, the shoes and nails, the hair, the tendons and other parts were all profitably recovered (Bethnal Green Branch Museum, 1875: 47-8).

[21] Although this is not the place to discuss these issues, a case has been made that these alternatives, when properly employed, are usually not harmful to the environment (Rathje and Murphy, 1992).

The point of departure of this essay was the widely held belief that free markets are inherently deficient in creating an interwoven system of production and consumption where the waste of one industry becomes a source of usable material or energy for other industrial processes. It has been pointed out, however, that market incentives in an appropriate institutional setting spontaneously create such a state of affairs, for reused, remanufactured and recycled materials are almost always cheaper inputs than virgin materials. Countless trash pickers, collectors, creative technicians, factory workers, traders and shrewd entrepreneurs have always made sure that recycling be big business.

It will now be argued that free markets are actually more likely to create "industrial" loops and ecosystems than central planning, even if the latter is done with that explicit purpose. Because many studies document some unintended consequences of government regulation,[22] this section will deal mostly with the main differences between private and public planning and on the likely outcomes of these different features in terms of industrial ecology. The relative cost of each problem-solving approach will, however, be dealt with first.

4.1 The Costs of Implementation

Any legal action is costly, and a common law approach to solid waste disposal will be expensive to the parties involved in a legal battle, even though some provisions, such as "losers pay" (attorneys' fees and legal costs) clauses to mitigate adversarial legalism, may help keep costs down. Such an approach would entail other expenses to internalize costs and to deal with bonding, monitoring and imminent threat of release. However, it is not clear that the current regulatory approach, which might initially seem to provide a more stable and predictable business climate, is less expensive. There are monitoring and

[22] See, among others, Allenby and Richards (1994), Breger et al. (1991), Geffen and Marcus (1994), Graedel and Allenby (1995), Landy and Cass (1997), Schulze (1996), Socolow et al. (1994), Volokh (1996) and Wallace (1995) for a more detailed treatment of the issues involved.

enforcement costs for government agencies, information gathering and reporting costs for businesses, and both have to bear litigation costs when controversial decisions are taken and acted upon.[23]

All the time and money spent complying with regulations are time and money not devoted to increasing productivity, developing new products and transforming waste into resources. A large number of U.S. managers have pointed out that compliance problems tend to take up a great deal of their time and so much effort goes into staying abreast of regulation that little time is left for pollution prevention (Geffen and Marcus, 1994). The cost of environmental regulation in the United States, estimated to be around $130 billion per year, more than 2% of GDP, in 1996, is not cheap (Nerht, 1998). Additionally, command-based regulations tend to favor large, established businesses at the expense of new and smaller enterprises if only because bigger businesses can spread the administrative costs of regulation over larger amounts of output (Geffen and Marcus, 1994; Taylor, 1992).

4.2 Planning and Decentralized Knowledge

A remark must also be made about the capacity of a central authority to deal with local conditions. As has already been shown, the most important knowledge in a market economy is the knowledge acquired by people over time coupled with the knowledge of the particular circumstances of time and place. In a market economy, individuals confronted with specific problems can easily tap into this decentralized knowledge because they possess it or they know all the particularities of a situation. On the other hand, central planners cannot be aware of the peculiarities of each situation and cannot possess the detailed knowledge of various alternative ways of doing things. This is especially problematic for endeavors such as resource recovery where local conditions often play a

[23] It has been estimated that four out of five EPA decisions are currently challenged in court (Porter and van der Linde, 1995).

crucial role. It has therefore often been argued that one-size-fits-all policies quickly become arbitrary and impede entrepreneurship and creative solutions to particular problems. If there is much to be said on behalf of "performance standards" (i.e., the replacement of regulations that specify the exact means of compliance by general targets that regulated firms can decide how to meet), the problem still remains that these standards are set by a central authority and may provide distorted incentives in specific cases. The fact that standards are often set by industry groups does not solve that problem either, for many small manufacturers have often complained that these groups are controlled by large, established companies who write the standards to allow use of their own products. These companies are loath to rewrite the standards that may benefit new firms with innovative products which might be made of residuals (Volokh, 1996).

Meat packing affords an illustration of the importance of local conditions. Before the advent of the giant cattle slaughtering plants, a significant portion of the non edible portions of animals were dumped into waterways. Yet each case was specific. In Cincinnati, meat packing wastes were dumped into the Ohio River, but since the current was swift enough to carry it away and since dumping was done in the winter, it apparently proved to be an acceptable method of waste disposal.[24] The same approach was tried in Chicago, but because the waters of the South Branch of the Chicago River were not able to carry away their load, the city council forbade the packers to dispose of their refuse in that way. The blood was allowed to be discharged into the river, but the remaining material was transported to a location sufficiently far from the city to be buried, an operation entailing considerable expense (Clemen, 1923). The point, however, is that these waste were typically considered as health hazards by most contemporaries. The authors of the “Descriptive Catalogue of the Collection Illustrating the Utilization of

[24] It is doubtful, however, that in a world of properly defined and strictly enforced private property rights the practice of dumping wastes into streams would have been allowed in the first place. Some owners of a portion of a stream would have exercised their right of ownership and upheld their rights to clean water.

Waste Products" considered many of the refuse of manufactures as likely to produce "disease and death" if allowed to decompose (Bethnal Green Branch Museum, 1875: 3) and the instant removal of bones "an absolute necessity, both to the butchers and the health of the community generally" (idem, p. 35). Similarly, Koller (1918, preface) viewed the creative transformation and reuse of byproducts as "of the utmost value both from a sanitary and economical point of view." Even though the problems facing turn-of-the-century societies were numerous, most contemporary writers understood well that technological change and turning dangerous waste into valuable commodities were the best way to deal with those by-products.

> One of the greatest benefits that Science can confer on man is the rendering useful those substances which being the refuse of manufactures are either got rid of at a great expense, or when allowed to decompose produce disease and death. A large number of such are now used in various ways which were formerly regarded as offal, and cast away, but many others still exist inviting the ingenuity of men of science to find for them useful applications... [It] is high time that science should step in and teach us how to transmute the waste and refuse materials, elements of pollution, into sources of economy and wealth. The utilization of the sewage of great cities for agricultural ends has virtually been a demonstrated success; the same success, by patient experiment, is obtainable in many other waste products, which through ignorance of their value we suffer to defile our streets, pollute our noses, and taint the air we breathe (Bethnal Green Branch Museum, 1875: 3-4).

4.3 Institutional Arrangements and Resource Recovery

Unlike domestic waste, the recycling of industrial and commercial waste products is usually not problematic, for their volume and their quality have always made them sought after commodities. Yet different sets of rules and levels of public intervention will have drastic consequences on the actual level of industrial recycling. The meat-packing industry can, once again, afford an illustration of the impact of different institutional arrangements. As was previously shown, the American meat-packing industry experienced an extraordinary period of growth in the late nineteenth and early twentieth centuries. However, this did not happen simultaneously in the British Isles, despite the more advanced state of the British economy and the considerable expertise of some British manufacturers of by-product installations (Talbot, 1920). One institution can be singled out for the backwardness of Great Britain in this area: the publicly-owned and operated municipal abattoir. As Talbot (1920: 107) put it:

> City and borough corporations, unlike private organizations, are not in the position to scrap an existing plant for one which is of later date and greater efficiency, because there is not the same incentive to reap the utmost benefits attainable as prevails under private conditions where the full brunt of competition is encountered... Furthermore, the municipality is not in the position to run a plant under full load, or even at a uniform pressure the whole time. It is only able to handle the waste as it accumulates during its own abattoir operations. On the other hand, the private exploiter can acquire a plant of such capacity as to cope with the steady flow of material from the slaughter-houses, thereby keeping the by-product recovery installation working steadily at a point approaching its productive limits.

Because public management does not rely on the price system, the only option available becomes various command-and-control solutions. Under a command-and-control regime, individuals have fewer incentives to reduce wasteful activity or to use more efficient processes because such activities are typically penalized. Good people trapped in a bad system rarely produce satisfactory outcomes.

4.4 Technological Change, Regulation and Recycling

In a common-law framework, only the outcomes of an activity are subject to liability. Producers will therefore assess the relative merits of alternatives available to achieve their objectives. In a regulatory framework, however, processes are often mandated by a central authority. It has long been known that such regulations stifle innovation. The eighteenth century French economist Turgot wrote: "To assume it to be possible to prevent successfully, by regulation, all possible malpractices ... is to sacrifice to a chimerical perfection the whole progress of industry; it is to restrict the imagination of artificers to all narrow limits of the familiar; it is to forbid them all new experiments" (quoted in Rothbard, 1995: 387). It comes as no surprise that a number of commentators have shown that some laws and regulations can have harmful effects on resource recovery. Although it is beyond the scope of this essay to look at the minute details of how some environmental regulations mandate or shut out the use of recycled materials, a few comments are necessary here.

Some have remarked that governments often define pollution prevention in a way that excludes recycling and reclamation. Consequently, some by-products that might otherwise flow into further productive use become waste due to arbitrary labeling laws and regulations.[25] It is sometimes argued that regulation for waste and hazardous-waste material should recognize movement and disposal by use in an industrial process as equivalent to final disposal (Frosch, 1996). Yet that would be unnecessary in a common-law regime because regulations are voluntary and specified in terms of performance standards rather than based on mandatory technologies or materials.

There are also other problematic situations. Emission limits are often too rigid and tend to rule out cost-effective pollution prevention solutions, so compliance with regulations therefore impedes waste reduction and recycling. As Geffen and Marcus (1994) remind us, a cost-effective pollution prevention solution that substantially decreases the release of several kinds of harmful emissions below official standards while slightly raising levels of less harmful pollutants above allowed levels is typically prohibited under existing laws. Problems arise from some consumer protection statutes requiring an entire product to be labeled as "used" or "second-hand" if it contains any refurbished parts. This can substantially damage a corporation's trademark or reputation for quality, and therefore remove many incentives to recycle residuals. It has also been argued that antitrust laws, especially in the United States, hinder industry cooperation that would be critical for

[25] For a much more detailed treatment of this question, see Breger et al. (1991), Frosch (1995), Geffen and Marcus (1994), Landy and Cass (1997), Volokh (1996), Wernick et al. (1996).

developing comprehensive product and material recycling systems (Graedel and Allenby, 1995).[26]

4.6 Human Creativity and Incentives: Policy Implications

Modern regulations - especially environmental regulations - often cause unanticipated side effects. This cannot be avoided, however, because as was pointed out earlier, humans act in real time and without perfect knowledge. They attempt to solve one problem at a time, but can never achieve a perfect solution. Other problems are likely to arise once one is solved. This situation is not problematic in the market process, for there are no institutional barriers to spontaneously correcting mistakes. This is usually not the case, however, in public planning approaches. In short, the central planning of resource recovery, relying on command-and-control, would likely have the effect of increasing both the amount of waste created and the amount of waste to be disposed of, meanwhile impeding resource recovery by creating various barriers to reuse.

It has been argued that market processes in a common-law regime provide incentives to act in an environmentally sensible way because such an institutional setting would make the owner of a resource fully responsible for the outcome of his actions. Entrepreneurs and managers no longer must face the artificial distinction between making a profit and achieving sustainable development. But in the last century, a number of government interventions have nullified the motivating function of private property rights and have ended up "legalizing" pollution. As Breger et al. (1991: 470) have written: "most people who are at least somewhat familiar with the issue see that regulation is a license to pollute, and a license to pollute for free." This legalization led to the consideration of

[26]It is interesting to note that the major meat packers were sued under the Sherman Act by a coalition of smaller producers at the turn of the century, but that they were eventually cleared of all accusations as it was found that they were simply more efficient than their competitors. Had they been found guilty and broken the way Standard Oil was, it is probable that the amount of resource recovery in that industry would have been much smaller than it turned out to be. Yeager (1981) provides the most detailed treatment of this issue. See also Boudreaux and DiLorenzo (1993) and Unfer (1951).

environmental impacts as external to industries and households, to the growth of various bureaucracies with an essentially negative view of residuals and to business practices where it was no longer useful to assess the opportunity costs of wasted resources.

It is doubtful that environmental regulations create pressures for innovation and progress that are stronger than prices, competition and private property rights. Most public interventions are barriers to recycling or distorted incentives that have greatly reduced the volume of resource recovery. The market process is in the end a more compelling alternative because it leaves more room for imagination and forces individuals to focus on the most important problems. The salient point of our analysis is therefore that the most thorough way to promote recycling is via a genuine return to free markets and strict liability. Where possible, common law remedies and citizen action under the law of private and public nuisance should be substituted for centralized command-and-control regulation. Citizens once again should be empowered and encouraged to bring private suits against any party who violates rights and imposes damage to person or property by pollution. Our policy prescription can thus be summed up under three headings 1) well defined and readily enforceable private property rights; 2) strict liability; and 3) freedom of contract. Once these three conditions are met, market prices will provide the proper incentives to create a significantly larger number of "industrial" loops and ecoparks.

Conclusion

The first sections of this paper were an attempt to illustrate a pattern of waste reduction and recovery throughout history. This "model" was based both on theoretical insights and historical evidence. It lead to the general conclusion that the market process provides incentives to change what humans produce and how they produce it in order to make better use of scarce resources. By increasing throughput, using less material and energy per unit of production, and lowering rework rates and waste, waste reduction allows firms to save money, enhance efficiency, and become more competitive. It also shows that due to an ever increasing division of labor, one producer's residuals often become another producer's raw materials. The private sector is the most significant force leading to resource recovery, simply because it is the economic thing to do. So if the market game is played by the proper rules, there is no contradiction between economic growth and turning what was previously waste into a salable product. Creative economic development has always been sustainable.

However, there does not seem to be much faith placed in human creativity and market processes by industrial ecology theorists. It is true that the market process is not perfect, but it is a better institutional framework than central planning for at least two reasons: 1) It offers a diverse choice of approaches to solving problems that can be tested and emulated when successful, something that central planning cannot achieve; and 2) Private owners take better care of resources than public owners because private owners directly benefit from their actions and are free from political pressure. The removal of those market distortions introduced in the last decades is a more logical solution to resource recovery than an increase in state intervention and central planning. In terms of handling resource recovery, controls must be returned to waste producers so they may bear the full costs of their actions, but be free to pursue creative solutions to their problems. It is the hope of this writer that today's policy advisors will show more faith than their predecessors in the creative power and resourcefulness of humans and markets.

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