

Reverse Logistics And Clean Technology Adoption: The Case Of The Steel Industry

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ABSTRACT

Promoting the diffusion of “clean technology” – technology that helps to reduce polluting inputs and processes at the beginning of production, rather than at the “end of the pipe” – is an important step towards more environmentally sustainable production practices. The use of clean technology coupled with “reverse logistics” practices is particularly effective at reducing environmental impact, and many industries are attempting to move in this direction. Reverse logistics is the process whereby a manufacturer accepts end products from consumers for possible remanufacturing, recycling, and reuse. However, the diffusion of clean technology and reverse logistics practices in the economy is not well understood, and there remains a need for case and industry analysis in order to derive theory and to provide possible lessons. This paper focuses on the core of heavy manufacturing, the steel industry. Steel producers, particularly the mini-mill sector, have a long history of relative success with various reverse logistics techniques, especially recycling. Utilizing a qualitative theoretical framework and drawing from extant case and industry data, we document and analyze the adoption and diffusion of clean technology and reverse logistics in the industry.

1. Introduction

Firms, consumers, and governments have begun to pay much more attention to the impact of economic activity on the environment – particularly with regard to carbon dioxide emissions. Indeed, the need to reduce this impact is now pressing – in individual countries and globally (“Ecosystems”). However, reducing pollution and curbing the depletion of the world’s natural resources is a daunting task given current consumption patterns.

The “IPAT” equation, Environmental Impact = Population * Affluence * Technology, illustrates the basic choices for reduction. If we reduce population, environmental impact is reduced. If we cut consumption (affluence), the same thing holds. Finally, we can promote and use technology that pollutes less per unit.

Given rapid globalization and the growing scale of the world’s voracious demand for energy, cars, and other goods, particularly in India and China, the answer does not lie strictly in conservation on the demand side, although this is important. One of the most important pragmatic issues in environmental economics and related fields today revolves around the diffusion of “clean technology” and related processes such as reverse logistics (Goodstein 2004). Clean technology reduces polluting inputs in the first place (not after the fact – as with “end of the pipe” pollution prevention), and it represents a fundamental shift towards sustainable production practices and zero pollution. If one billion people drive one automobile, each emitting five tons of carbon dioxide a year, an obvious solution is to convert to autos that emit no carbon dioxide. This is more appealing than eliminating autos, or reducing population to zero.

However, markets alone may not do the job in ensuring the diffusion of clean technology and reverse logistics practices - the real world is replete with the “Qwerty” keyboard stories that Paul David (1985) made famous. Historical path dependency can lock in outcomes that may not dovetail with a sustainable future. Brian Arthur (1989) demonstrates how industries and economies may become locked-in to inferior technological paths. Lock-in can also

include inferior environmental paths. In circumstances of increasing returns to adoption, early-established technologies may become dominant such that superior alternatives diffuse more slowly than is optimal, or not at all.

Keeping this in mind, our aim in this paper is to document and analyze a relatively successful environmental impact minimizing process and its supporting technology – “reverse logistics.” Certain industries may be further along than others, and we can learn from these cases. We choose to concentrate on a core industry: the steel industry. Steel production has high environmental impact and yet has made large strides in pollution reduction over the last fifty years – and much of this is due to reverse logistics practices and the use of technology facilitating reverse logistics. On the other hand, the metals industry remains one of the heaviest polluters in manufacturing, particularly with regard to carbon dioxide emission, and there is room for improvement.

For this task, we find that casework is particularly useful and necessary. Analysis of case histories may give us leads to how firms, industries, and societies may avoid ecologically damaging path dependencies and overcome obstacles to innovations of high ecological utility. Recent work along these lines include Seitz and Peattie (2004), who present a holistic, in-depth, industry case study focused on successful reverse logistics network developed to support automotive engine remanufacturing.

We utilize several qualitative models in the reverse logistics literature to frame a case investigation utilizing extant case and industry-wide steel data. We document and analyze reverse logistics within basic steel and related industries with the intent to derive a basic pattern from the case and some preliminary reflections.

2. Reverse Logistics

Reverse logistics (RL) is a process whereby a manufacturer accepts products from consumers for possible remanufacturing, recycling, reuse or disposal (Dowlatshahi, 2000). In the traditional supply chain, the logistician managed the flow of products from the producer to the consumer. In reverse logistics, the reverse flow of the products from the consumer to the producer is managed. It is more than recycling because there is an emphasis on actual reduction of materials used, on remanufacturing, and on reuse of materials. Reverse logistics can also be viewed as a process whereby companies can become more environmentally efficient through recycling, reusing and reducing the amounts of materials used. RL includes the reduction of materials in the forward system in such a way that fewer materials flow back, reuse of materials is possible, and recycling is facilitated (Craig and Ellram, 1998).

If the focus is on reducing environmental impact, then reduction is most preferable, then reuse, then recycling. This is because indirect and direct pollution tends to be most minimized with reduction. All of these options are preferable to disposal. You want to recycle a grocery bag over throwing it away, but if you can reuse it (you could refurbish the bag to prolong its use), that’s even better. Finally, avoiding a bag altogether (for small purchases, for example) through reduction has the most impact (Goodstein, 2004, p. 380).

If new or established firms manage to adopt reverse logistics practices, it can pay handsomely. A traditional microeconomic depiction of pollution reduction, particularly if it involves “end of the pipe” technology, is that it costs firms money. Installing smokestack scrubbers supposedly shifts a firm’s private marginal cost curves up, lowering profits. However, reverse logistics processes may be able to increase profitability and productivity relatively quickly for a firm – for example, by lowering inputs and/or reducing input cost at the point of production (Dowlatshahi, 2000).

The total cost ownership (TCO) can be significantly impacted by RL during all phases of the product's life cycle (Tibben-Lembke, 1998). In terms of indirect benefits, Andel (2004) state that recycling damaged and returned products, as well as used transport packaging material, can beautify both the bottom line and the environment.

If the ratio of outputs to inputs increases, costs per unit can fall by as much as 60% and profits rise (Heeb 1989; Toensmieier 1992). However, the visible private financial incentive for firms to reduce, reuse, or recycle may vary substantially. For example, depending on the product or the process, the firm may or may not see obvious financial incentives for reuse (perhaps even if they are there), but may see it for recycling. Practices associated with these kinds of visible cost savings are typically the “lowest hanging fruit” in the sense that firms may not need much

government intervention or other external pressure in order to adopt them – the practice is a source of immediate competitive advantage and can raise profits.

At times, the cost savings can be indirect. Mollenkopf and Closs (2005) state that to understand how reverse logistics can create value, both the marketing and logistics components need to be analyzed. The impact from effective returns management comes from: increased revenue from secondary sales, goodwill earned for acting in a responsible manner, cost reductions from reduced cost of good sold, and an improvement in asset turnover. In another paper, Geyer and Jackson (2004) present a supply loop framework designed as a tool that enables firms to assess the environmental and economic potential of specific value recovery options. Along the same theme, Guide, Jayaraman, and Srivastava (1999) present recoverable manufacturing systems that minimize the environmental impact of industry by reusing materials, reducing energy use, and reducing the need to landfill industrial products.

Another issue is how end-of-life products are managed. Toffel (2004) discusses how manufacturers need to manage the products once these have reached end-of-life (EOL). He discusses the motives, strategic choices, role of recovery technologies, and the strategic management of product recovery. Most of the reverse chains have five key processes - product acquisition, reverse logistics, inspection and disposition, remanufacturing and marketing (Blackburn, Guide, Souza, and Wassenhove (2004).

The fact that reverse logistics can substantially reduce environmental impact is ultimately one of the main reasons for encouraging its use. Reverse logistics often extends the life cycle of a product and promotes alternate use of resources that can be ecologically-friendly (Melbin, 1995). The beneficial environmental “savings” is not typically built into the price of production and the final price of the product. However, as customers and governments become more concerned about the environment and with correctly pricing and internalizing pollution externalities, the pressure on industry increases, often through regulation and demand-side pressure. If and when these externalities are priced properly, the economic rationale for reverse logistics practices becomes that much more compelling.

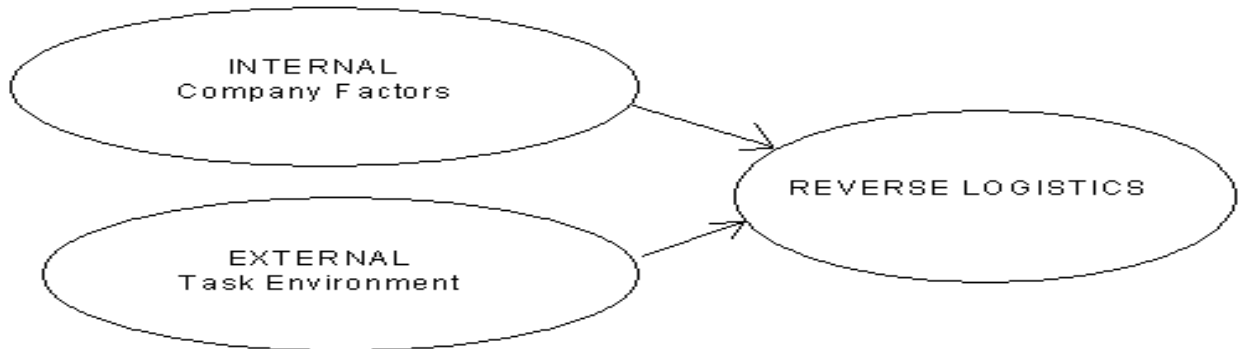
In addition, assuming that externalities can never be truly priced (for example, because of uncertainty regarding the benefits of ecological preservation), and that ecological depletion is often irreversible, the argument for promoting impact-minimizing production techniques can be made on “precautionary” principles (Daly, 1996). As the Brazilian rain forest yields benefits today we had not predicted in the past, the case for preserving that unique resource in anticipation of future (as yet unknown) benefits increases. Of course, promoting the diffusion of reverse logistics practices on these grounds alone is a more difficult proposition.

3. Qualitative Models For Reverse Logistics

The internal and the external environment of the firm affect reverse logistics practices, their implementation success, and their long run viability over time. (See Figure 1) Three primary intra-organizational activities that impact reverse logistics hypothesized in the literature are 1) a sincere commitment to environmental issues, 2) successfully implemented ethical standards, and 3) the existence of policy entrepreneurs who are responsible for organization adoption and operationalization (Carter and Ellram, 1998). In addition, the reverse logistics activities of an organization are impacted by four external environmental forces: customers, suppliers, competitors, and government agencies. Internal and external factors are not mutually exclusive; rather both impact reverse logistics practices.

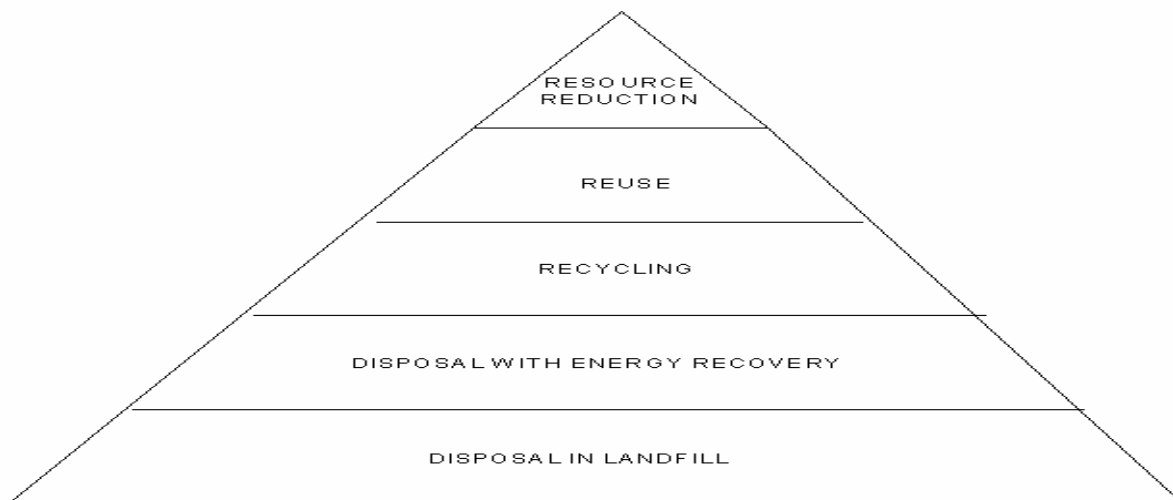
To understand and rank the importance of various reverse logistics practices, a reverse logistics “hierarchy” is proposed by Stock (1992) and Kopicki et. al. (1993) in which resource reduction is stated to be the ultimate goal. Resource reduction would include both the minimization of materials used in the product along with the minimization of waste and energy through the design of more environmentally efficient products. Once resource reduction has been exhausted, the next option is reuse and once this has been exhausted, recycling is targeted. In this approach, disposal ought to be the last option and, even then, incineration is stated to be preferable since some form of energy recovery is possible (Carter and Ellram, 1998). (See Figure 2)

Figure 1 – Causal Antecedents And Determinants Of Reverse Logistics Activities



Source: Carter and Ellram, 1998

Figure 2 – The Reverse Logistics Hierarchy

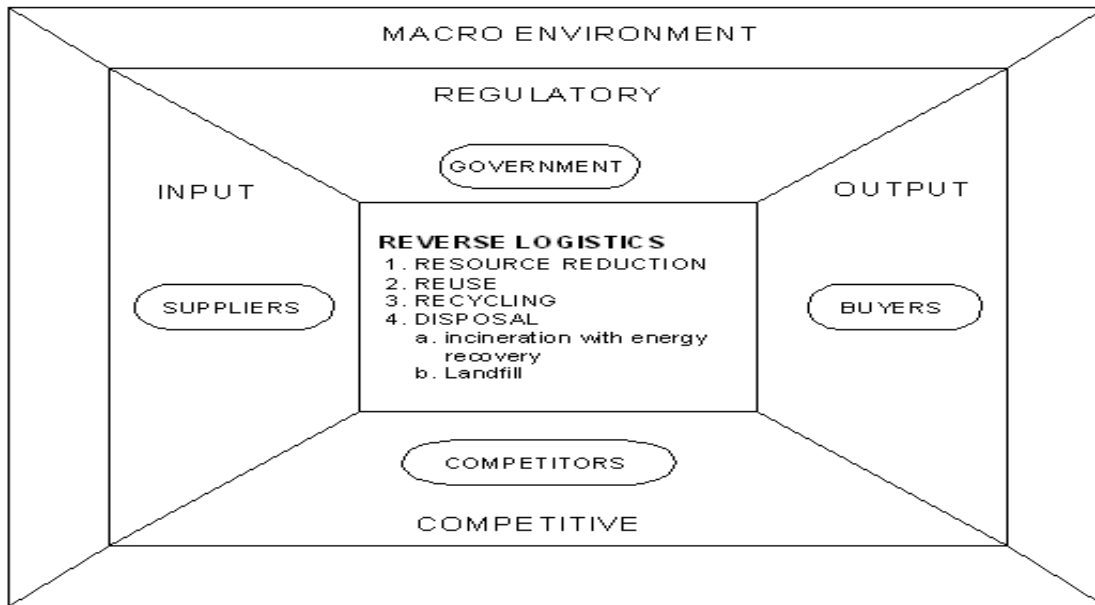


Note: Based on the work of Stock (1992), Kopicki, and others

To further understand the forces impacting this hierarchy, Carter and Ellram (1998) modified a model by Achrol, Reve, Stern (1983). The task environment of the firm is divided into four sectors: Input, Regulatory, Output and Competitive. The macro environment surrounds the task environment (see Figure 3). Although this paper does not extensively explore these factors, they are important to consider in case investigations of reverse logistics diffusion.

Two other applications need to be mentioned. In one work, Gonzalez-Torre, Adenso-Diaz, and Artiba (2003) present a model for the analysis of collaborative relationship both upstream and downstream in the glass container value chain for Belgium and Spain. In another paper, Barros, Drekker, and Scholten (1998) discuss a two – level network for recycling sand where results vary depending on the location of demand points and type or quality of the sand needed.

Figure 3 – A Model Of The Environmental Forces Impacting Reverse Logistics Practices



Carter and Ellram (1998) - modified from Achrol, Reve, Stern (1983)

4. The Steel Industry

The following sections below consist of a brief overview of the steel industry and the steel making process, followed by an application of the reverse logistics hierarchy to the steel industry, and a final section reflecting on patterns in the case and future work and application.

4.1 Steel Industry Overview

The steel industry is big. In 2004, more than 1 billion metric tons of steel were produced worldwide. To give a relative sense of this, production levels in other basic materials in that year were: aluminum at 22 million metric tons, copper at 15 million metric tons, and timber at 300 million metric tons (IISI, 2004). In 2004, the world’s largest steel producer is China, with the U.S. ranking fourth.

Table 1 – Top Steel Producers, By Region

No.	Region	Crude Steel Production, million metric tons, 2004
1	China	272.5
2	European Union	192.9
3	Japan	112.9
4	United States	98.9
5	Russia	65.6
6	South Korea	47.5
7	Ukraine	38.7
8	India	32.6
9	Brazil	32.9
10	Turkey	20.5

Source: International Iron and Steel Institute

The impact on the environment by the steel industry is also relatively large, and is second to fossil fuel consumption. The steel production process in the U.S. consumes more electricity than electricity consumption of all U.S. households. There are high CO2 emissions - roughly 1.6 tons of CO2 for every ton of steel produced. This amounts to roughly 1.6 billion tons of carbon dioxide out of total world emissions of roughly 25 billion tons (IISI, 2004), or between 5 and 10% of all emissions.

The steel industry has changed significantly in the postwar period. Particularly since the 1980s, the world’s most competitive plants are adopting new technology and work arrangements, driving up productivity and significantly reducing the typical plant workforce. U.S. steel-makers have had to adjust quickly, or go out of business.

The dominant U.S. “integrated” facilities that evolved over much of the century were essentially huge oligopolies capable of producing a variety of steel products, largely using raw materials, for a market that was uncontested. These integrated facilities have had the most trouble adapting. After World War II, the steel mills in the U.S. built before and during the war were still standing, and these mills utilized “open-hearth” furnaces, which were much less efficient than new options being constructed in Japan and elsewhere. From 1945 to 1973 integrated steel companies in the U.S. planted the seeds of their own gradual decline by keeping these open hearth furnaces and even further investing in them.

This opened integrated steelmakers to competition at the “hot end” of steel production: foreign integrated players were using the modern basic oxygen furnace (BOF) to convert iron to steel. Also, increasing numbers of both domestic and foreign “mini-mills” were utilizing the electric arc furnace (EAF), which mainly utilized scrap steel as an input (Magnum and McNabb, 1997). By 1970, only 64 % of the production in the U.S. was associated with these two new furnaces, while in Japan’s case, the figure was almost 96%. (See Table 2 on next page)

As steel imports increased from less than 1% of domestic U.S. consumption in 1950 to over 20% by 1983 (AISI, various years), U.S. integrated facilities had trouble competing. On the other hand, U.S. based but often foreign owned mini-mills were able to compete domestically and internationally, and began taking more and more market share.

Table 2 – Adoption Of New Steel Production Technologies In The U.S. And Japan, 1960-1981

Year	U.S.		Japan	
	Percent of Total Domestic Steel Production	Metric Tons	Percent of Total Domestic Steel Production	Metric Tons
Basic Oxygen Furnace (BOF)				
1960	3.4	3.3	11.9	2.9
1965	17.4	22.9	55.0	24.9
1970	48.1	63.3	79.1	81.2
1975	61.6	71.8	82.5	92.9
1981	60.6	73.2	75.2	84.1
Basic Oxygen Furnace Plus Electric Arc Furnace (EAF)				
1960	11.8	11.7	32.0	7.1
1965	27.9	36.7	75.3	34.1
1970	63.5	83.5	95.9	98.4
1975	81.0	94.5	98.9	111.3
1981	88.8	107.3	100.0	111.9

Source: Barnett and Shorsch 1983, p.55

Using the EAF, mini-mills can inexpensively produce steel using recycled scrap using approximately one-quarter of the labor per hour and much less energy. Because of the basic advantages of the EAF and the production process, competitive pressure on the integrated facilities continues to this day. The steel industry is witness to the rise of a significant cost advantage garnered through a basic reverse logistics technique: recycling. In fact, electric arc furnace production of steel now represents the largest recycling industry in the U.S. and the world (Stuart, 2001, p. 40).

4.2 The Steel Making Process

Integrated facilities are being out-flanked in part because of their dependence on a steel-making process that does not stress re-cycling. Integrated iron and steel plants make steel primarily from coke and iron ore, with only up to about 25% scrap, using a basic oxygen furnace (BOFs). The BOFs use mainly 75-85% virgin “pig iron” made of iron ore. In contrast, electric arc furnaces mainly use secondary (recycled) raw material, scrap steel. For the mini mills utilizing EAFs, much of the previous work (refining iron ore to pig iron, then refining iron to steel) has already been done with scrap steel; the steel has to be melted, filtered for impurities, and reshaped into a desired (new) form.

In the basic oxygen furnace, steel is produced mainly from molten iron (pig iron). The pig iron is first produced in blast furnaces requiring a whole prior series of steps, and significant energy. Raw materials for producing pig iron include prepared iron ore, coke, and fluxes (mainly limestone – these help in the chemical process). Iron has a relatively high carbon content of 3 to 4% and contains other impurities that make the metal hard and brittle.

Converting pig iron to steel reduces its carbon content and impurities, and makes it stronger and more flexible.

In this process, a small amount of scrap steel is first “charged”, or inserted, into a furnace (known as a “converter”), followed by pig iron from the blast furnace. A balance (for example, 20%/ 80%) between the amounts of scrap and hot pig iron charged into the furnace is used as a means of controlling the temperature and to ensure that steel of the required specification is produced. A water-cooled lance then blows high pressure, high purity oxygen onto the metal to remove impurities such as carbon monoxide, silicon, and manganese, which combine with lime and dolime in the mix to form a steel waste “slag” that can be separated from the molten steel. During this process, the carbon content of the steel lowers to under 1.7%, and the liquid steel is poured into a ladle, while slag is retained and then tapped into a separate slag “pot.” Importantly, in terms of energy sources, the blast furnace and the basic oxygen converter require significant energy sources: a lot of coal, natural gas, and electricity (Miller 1984).

In integrated facilities, at the end of the process, the hot steel is often then refined into higher end steel products. It might be poured out of the furnace, cast into solid slabs, which are hot rolled into relatively thin sheet “coils.” The steel is often later “cold-rolled” to further reduce its thickness (up to 0.2mm). A final thickness reduction (skin-pass) enables a further thickness reduction up to 0.12 mm. The coil is then electrolytically coated on both sides with tin or chromium/chromium oxide and further processed to be delivered to a manufacturer. The kind of sheet steel produced in the basic oxygen process is used for packaging applications like cans, but also for cars and appliances.

Mini mills differ significantly from integrated facilities, particularly in their use of inputs for production. Although some integrated steel mills have EAFs for specific purposes, EAFs are a key component of mini mills. Instead of raw iron, mini-mills typically use up to 100% scrap steel, primarily from three sources: home, prompt, and obsolete scrap. Using scrap offers several advantages to mini-mills. First, because the mini-mills are starting with scrap, they do not have to invest in raw materials and transport facilities, and pig iron, as discussed above, does not have to be created. Second, melting scrap down in electric arc furnaces is much less energy intensive. For mini-mills, the main goal in terms of energy inputs is to secure a constant source of inexpensive electricity, and this is inevitably supplied by the utility companies. This is in contrast to integrated facilities, which need to procure coal, natural gas, and electricity to fire its furnaces (Miller, 1984).

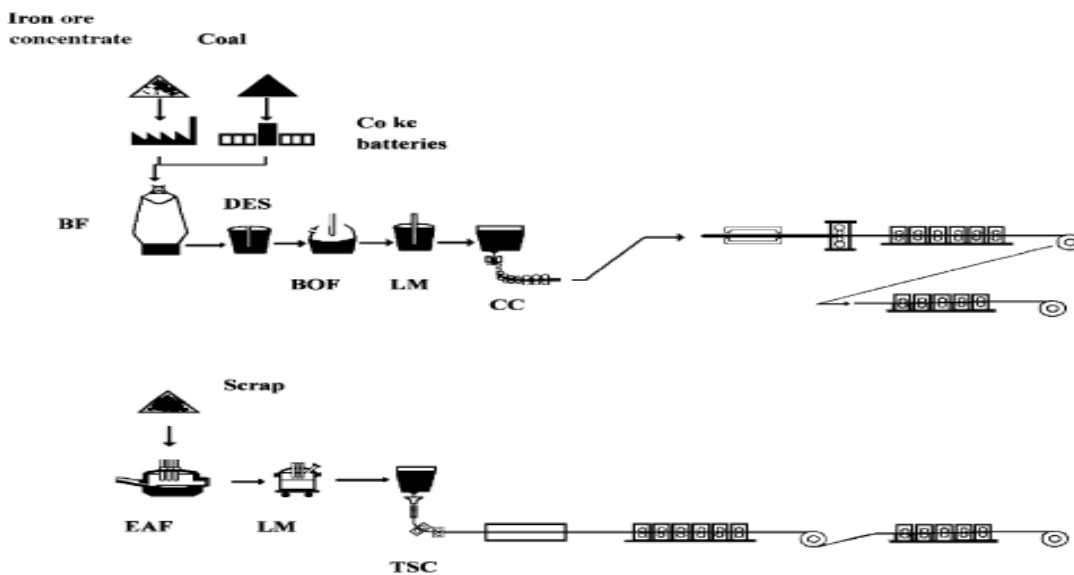
Mini mills save large amounts of raw materials and energy because they are inherently designed to recycle materials in the EAF. For every ton of steel recycled, roughly 1.25 tons of iron ore, 0.5 tons of coal and 40 lbs of limestone are conserved – all three of which require energy to convert to iron, then steel (“Recycling Scrap”). With an integrated facility, the energy required to make pig iron, then slab steel, then steel “semi-product” like sheet coils might amount to 20 to 25 GJ (giga-joules) of energy. In contrast, the mini-mill process might require only 40 to 50% of this energy. While some of the energy saved is a result of a leaner production line, much of the energy saved is right at the start, by using recycled steel (Johansson and Holappa, 2004).

The electric arc furnace has existed for around 100 years, but up to the 1960s, EAFs and the supporting technology were not very efficient and could only produce relatively simple steel products. The EAF, like the BOF, produces a steel slag as a byproduct. However, it also produces an increased concentration of toxic metals in mini-mill dust, sludge, and slag. Scrap often has metal coatings like zinc, tin, or lead, and scrap often has to be treated before entering the EAF to remove coating.

However, since the early 1980s the technology has improved dramatically, in part due to the ability of mini-mill producers to avoid the huge fixed costs of integrated facilities (thereby freeing them to invest in other improvements). With metallurgy advancing such that melted scrap steel can be analyzed and refined out of the furnace in a separate “ladle,” a wide variety of steel grades and products (even higher end) can now be produced that are competitive on quality and price. The share of production of mini-mills has steadily risen in the past few years, and now accounts for over 50% of U.S. steel production (AISI, 2004).

Mini-mills have been able to design very lean production facilities by cutting out many of the steps required in the integrated facilities even as it moves up the product chain, further boosting productivity and lowering costs. Through the melting of scrap in an electric arc furnace, sophisticated ladle metallurgy, then casting in sequence with modern billet or thin slab casters, mini-mills have managed to compete in higher end products such as cold rolled strip steel, which might typically be used for an auto body. The difference in steps between an integrated facility and a mini-mill in producing this steel is illustrated below.

Figure 4: Comparison Of Conventional Integrated Ore-Based Steel Production (Upper Process Scheme) With New, Scrap Based Mini-Mill (Lower Process Scheme)



The current integrated steel plant consists of sintering of iron ore and coke making; blast furnace iron making (BF); hot metal desulfurization (DES); converter process to crude steel (BOF – basic oxygen furnace); secondary or ladle metallurgy (LM); continuous casting (CC); hot rolling; strip rolling; cold rolling. The modern scrap-based mini-mill consists of scrap melting in electric arc furnace (EAF); ladle metallurgy; thin slab casting (TSC); minimized hot rolling; cold rolling. Source: Johansson, L. Holappa, 2004, p.178

A mini-mill has comparatively lower steel production capacities, but smallness and lack of dependence on infrastructure makes it much more flexible. They can be sited on a few acres, and they do not need to be near rail or water transportation systems. Large integrated facilities are centered around Chicago and Lake Michigan because they need easy access to raw materials. In the case of the mini-mill, main needs are scrap, electricity, and a market.

The table on the following page lists some main differences between integrated steel mills and mini mills.

Table 3 – Differences Between Integrated Mills And Mini Mills In The U.S.A.

	Integrated Mills	Mini Mills
Current production share (U.S., 2002)	50%	50%
Number of facilities (U.S.)	20	> 100
Materials input, from most to least	iron ore, coke, steel scrap, oxygen, limestone	steel scrap, iron, oxygen, limestone
Products	iron, carbon steel	stainless steel, special alloy, carbon steel
End uses	construction, motor vehicles, appliances, food cans	specialty applications
Throughput	approximately 400 tons/hr	approximately 100 tons/ hr
Energy input	coal, natural gas, electricity	electricity

Sources: American and Iron and Steel Institute, various years, <<http://secure.environmentaldefense.org/documents/1778Mini%20Mills.htm>>

4.3 Application Of The Reverse Logistic Hierarchy To Steel

Metals have essentially an unlimited life span and have the potential for unlimited recycling; as such, they can be considered as renewable materials, even though the materials used in making metals are not renewable. With steel and other basic metals, recycling is the common practice through the electric arc furnace. Many steel products are bought as intermediate goods and are then reformed into final products (for example, flat panel cold rolled steel is used to make a car body), and reuse of intermediate goods is relatively rare (because they are often transformed, as with sheet steel to a car fender). On the other hand, the degree of reuse of final goods with heavy steel content is increasing. Primary examples would be “white goods” such as refrigerators or washing machines, and cars. This section briefly applies the reverse logistics hierarchy to basic steel, touching on related industries.

4.3.1. Resource Reduction

By improving new alloys and coatings, the amount of steel required for all steel products has been substantially reduced over time. For example, in basic “long steel” products like steel beams, girders, and rail ties, if the Eiffel Tower were to be rebuilt today, the engineers would only need one-third of the amount of steel. In “flat steel” products, there is also significant progress. Tin coated steel cans, car body panels, refrigerators and office furniture are all made of thinner, stronger, longer lasting steel and coatings. With improved coatings, steel can be thinner without rusting. Modern cars have an overall shell weight that is 25% less than the 1970s, and progress is still occurring in this area (“The Measure”).

In the steel production process, all resource use has been reduced, and the electric arc furnace is central to this story. Raw material use has been reduced, from 145 tons of raw material per 100 tons of steel product in 1970, to 116 tons per 100 today. In 1975, the U.S. steel industry consumed about 34 million BTUs of energy per shipped ton

of steel. Now only 18 million tons are used, which represents a decline of about 45 percent. The increased use of scrap and the diffusion of the electric arc furnace is one major reason for this (ISII, 2004).

4.3.2. Reuse

A market for trading salvaged steel is just emerging. The norm in the basic steel industry is to melt products down and recycle. In related industries, there are examples of steel intensive design that anticipate reuse, particularly in industries closely related to the basic steel industry, such as construction and transportation. However, there obviously remains much work to be done in this area. Buildings or cars can and are sometimes designed for deconstruction, but this remains the exception. In construction, Penn State built its Beaver Stadium using all bolted steel construction, allowing officials to deconstruct the stadium and relocate it a mile away when the campus grew larger. In auto, an entire industry revolves around re-using parts made primarily of steel. Doors, hoods, engines, starters, alternators are often remanufactured and reused. However, cars are not yet designed very carefully with deconstruction – reuse and remanufacturing - in mind, although this is beginning to change (Grogan, 2000).

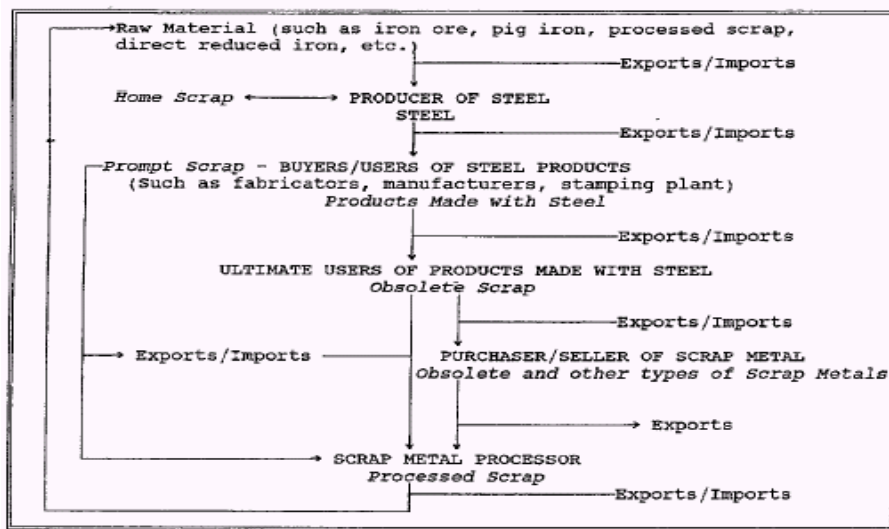
In the steel production process itself, much of the material that is generated as a byproduct is reused. This includes iron and steel “slag,” a silicate melt which includes non-metal impurities. Slag can be used for asphalt, cement manufacturing, and soil conditioning. Many other byproducts and waste products are reused. For example, gases released in the coke making process are recovered, cleaned and reused as fuel to save energy. More than 95 percent of the water used for steelmaking is reused.

4.3.3. Recycling

Steel is the most recycled material in the world. More steel is recycled annually than all other materials, including aluminum, glass and paper, combined. About 65 million tons were recycled in the U.S. alone in 2003; this represents a recycling rate of around 70% (AISI, 2004, 1). As mentioned above, the properties of steel enable it to be recycled indefinitely with little reduction in quality, and it can be easily separated from waste magnetically. These properties enabled the relatively quick rise of the mini-mill after the electric arc furnace was perfected.

Worldwide, the recycling figure is around 400 million tons, which is over 40% of total world crude steel produced that year (IISI, 2004). Steel recycling has at least a 150 year old history, and it is estimated to be at least a 60 billion dollar a year business (U.S. Recycling Economic Information Study, 2001, p 15).

Figure 5 – Steel Scrap Flow Diagram



Source: Houck, 1994

Steel recycling helps to conserve raw materials, energy, and costs, as well as to preserve landfill space and the environment. Each year, steel recycling saves the energy equivalent of the annual electrical needs of one-fifth of the houses in the United States – about 18 million households (“The Inherent”). Consumption of iron and steel scrap by re-melting reduces the burden on landfill disposal facilities and prevents the accumulation of abandoned steel products in the environment. As scrap prices have risen over the past two years, all over the world, abandoned rusting busses and tractors have magically disappeared.

Scrap steel includes two broad categories – new and obsolete scrap. New scrap, often split into home scrap (in-house) and prompt scrap (scrap generated at other manufacturers) is generated in the production process (such as stamping and trimming an auto fender). It is valued because of its known quality, but it is much less common than obsolete scrap. Obsolete scrap is post-consumer. In 2004, over 1800 U.S. scrap processors recycled autos, cans, appliances, and other steel products in the “obsolete scrap” industry (Houck, 2004). (See Figure 5) Steel scrap processors in the U.S. obtain product from domestic sources, and sell to the home market and abroad. Exports of scrap from the U.S. are generally larger than imports of scrap. This has accelerated with China’s economic boom and increased demand for steel scrap.

As availability of scrap declines relative to demand and prices for scrap increases, the relative cost advantage of the EAF over the BOF narrows. In fact the world’s demand for steel outpaces the availability of scrap, even if recycling rates were to hit 100%. This is perhaps one of the most fundamental constraints to the recycling component of reverse logistics in steel (and it is a constraint for all reverse logistics practices in all industries).

Indeed, recycling rates have improved in the past 15 years. Since 1988 appliance recycling (such as washing machines and dryers, refrigerators, and office desks) has risen from 20 percent to 90 percent. Steel can recycling has risen from 15 percent to 60 percent. In 2003, the industry re-melted over 18.2 billion old cans into new products. In 2003, this was the highest rate for any packaging material, including aluminum cans. (“Recycling Rates”)

Automobile recycling is consistently above 100% (more steel is being recycled from junked cars and trucks than goes into new vehicles). In 2003, over 14.5 million tons of steel was recycled from automobiles in the U.S., and the recycling rate for automobiles was 102.9 percent. In construction, structural beams and plates continue to be one of the most recycled steel products, at a 96 percent rate. Even concrete reinforcement bars (which are difficult to extract) are being recovered, and in 2002, it was estimated that 60 percent of them were delivered to the recycling stream. (“Recycling Rates”)

Overall, current recycling rates for steel hover around 70%. When scrap prices fall, not surprisingly, recycling rates fall as well, as can be clearly seen in the late 1990s. (See Figure 6) Economic drivers, backed by the EAF furnace, are clearly an important reason for increased recycling. There are other drivers that are arguably increasing the pressure to maintain and increase these rates, including local campaigns for recycling services. But municipal waste remains the area where the most improvement can be made: with home goods intermixed with other materials, there is often little private incentive to recycle steel.

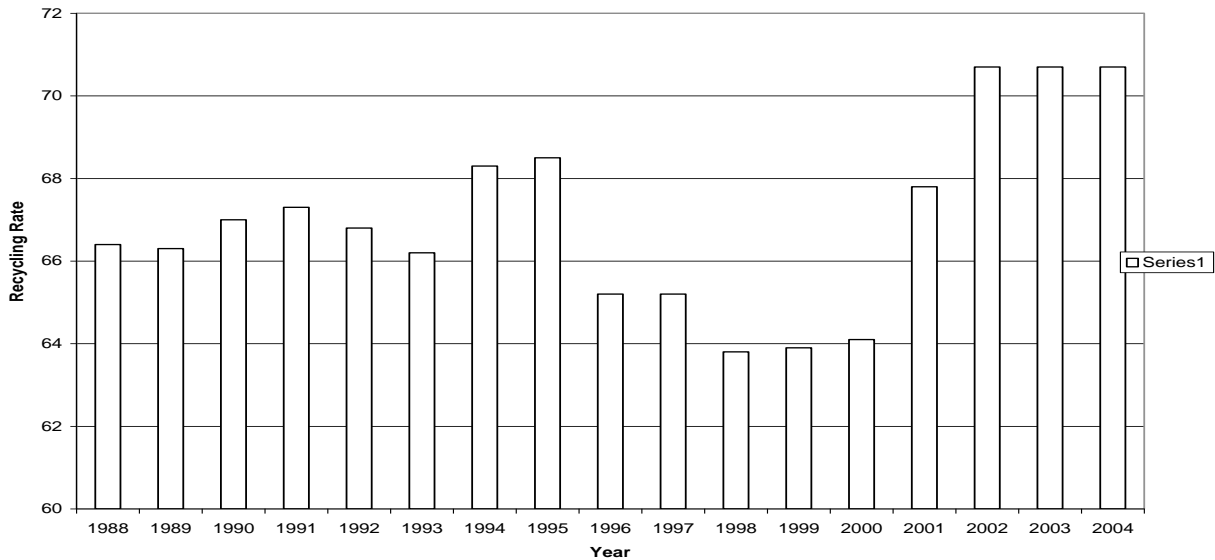
4.3.4. Disposal

As a 70% overall recycling rate for steel in the U.S. implies, not all steel is recycled. If the steel is intertwined and fused with other materials, the cost and time expense of retrieving steel privately at home is often too high. With automobiles, there is enough steel content in the auto to make the process of retrieving steel through shredding, magnetic separation, and other techniques worthwhile. This is despite the fact that the price of an automobile still does not include its end-of-life costs, and there is a lack of incentive to design for disassembly or design for the environment.

Municipal waste is an area where recycling rates of steel could improve, but it is seemingly constrained by economics, habit, and inconvenience. In 2000, of approximately 4.8 million tons of municipal steel waste generated, about 3.2 tons of it was thrown away. Many of these goods are smaller, intertwined with other materials, and not normally seen as valuable by consumers. Legislation is beginning to help; for example, states are beginning to enact

landfill bans for large, steel intensive appliances like refrigerators (known as “white goods”), which helps to direct this steel into the post consumer scrap pile (and this has helped to drive up recycling rates of appliances). Overall, however, improving recycling in the municipal waste stream remains a major challenge.

Figure 6 – U.S. Steel Recycling Rates



Source: Steel Recycling Rates. Steel Recycling Institute. 1 Nov. 2005 <<http://www.recycle-steel.org/PDFs/ratesheet.pdf>>.

5. Conclusion

The story of reverse logistics in steel is just beginning, and it is a story that may be instructive for other industries. The mini-mill, combining reverse logistics and a relatively inexpensive electric arc furnace, has been able to generate significant profits and has put major competitive pressure on the BOF steel making process and the larger integrated steelmakers. Furthermore, the minimills have been able to substantially reduce environmental impact. The major firm specific actors in this evolution were undoubtedly motivated by the lure of higher returns, although mini-mills are now beginning to stress their relative “greenness” in their promotional literature. The fact that the EAF process also generates a much lower impact on the environment through reduction, reuse, and recycling is significant: firms and entrepreneurs might do well to remember that finding ways to reduce environmental impact through reverse logistics practices often translates to significantly reduced, not higher, costs.

Size and close proximity to suppliers is also important. Integrated facilities are vertically integrated, locked into expensive (dirty) input and capital commitments, and may be relatively resistant to new innovation. Mini-mills did not have these obstacles, and they are leaner and able to draw from a wide network of local recyclers to procure critical inputs as they close the production loop. They have been able to create close relationships with these suppliers analogous to the approach of Japanese manufacturers. They are also very close to their customers: they can nimbly adjust to demand, changing their product line and adjusting their smaller production batches accordingly. These characteristics help to further reduce waste, inefficiency, and pollution. For particular industries where economies of scale no longer hold because of new technical innovation, the “mini”-mill concept begins to be compelling. In the case of steel, this process and technology emerged largely without government pressure or promotion. In other industries, it may yet emerge without this push; for example, in the paper industry (Johansson and Holappa, 2004). In other high environmental impact industries that are seemingly “locked in large scale,” like automobiles or electricity,

external pressure on the part of consumers and governments may be important to encourage clean technology and reverse logistics diffusion (Wells and Orsato, 2004).

Inevitably external pressure must be accompanied by internal firm commitment as firms struggle to pick off the higher hanging fruit on the reverse logistics hierarchy. For the firm, low hanging fruit often translates to practices that can help to reduce costs and generate higher profits; this certainly happened in the steel industry with substantially more recycling and a certain degree of increased reuse and resource reduction. Mini-mills garnered competitive advantage in large part because of these practices. As obvious practices are exhausted, it then becomes more important for particular players to look harder for cost advantages and to move beyond a static framework that does not take externality costs into account. Environmental champions within the industry must promote environmental issues while maintaining competitive integrity. Ray Anderson, founder of Interface Inc. a modular carpet company, is a classic example of an environmental champion who has had good success in a mature petrochemical industry. Despite the initial skepticism from all fronts, he managed to generate both lower costs through reverse logistics and other techniques, and to generate increased revenue based on having a “greener” product. As external and internal “champions” push for further progress in sustainable steel manufacturing, it is instructive to remember Anderson’s ability to (profitably) rally customers, employees, and the community around the theme of sustainability.

References

1. Andel, T. Rethinking Recycling. *Material Handling Management*, Vol. 59, No. 5, 2004, pp. 35-38.
2. Astier J. The impact of mini-mills in the USA. *Ironmaking and Steelmaking*. Vol 25, No 1, pp. 7–12.
3. AISI. American Iron and Steel Institute. Annual Statistical Report. Washington, D.C, various issues
4. Astier J. The impact of mini-mills in the USA. *Ironmaking and Steelmaking*. Vol 25, No 1, pp. 7–12.
5. Arthur, W. Brian. Competing Technologies, Increasing Returns, and Lock-In by Historical Events. *The Economic Journal*. London: Mar 1989. Vol. 99, Iss. 394; p. 116
6. Barnett, D. and L. Shorsch, *Steel: Upheaval in a Basic Industry*. Ballinger: Cambridge. 1983
7. Blackburn, J., Guide, V., Souza, G. and L. Wassenhove. Reverse Supply Chains for Commercial Returns. *California Management Review*, Vol. 46, No. 2, 2004, pp. 6-22.
8. Carter, Craig and Lisa Ellram. *Reverse Logistics: A review of the literature and framework for future investigation*. Vol. 19 no 1 1998, pp. 85-102
9. Daly, Herman. *Beyond Growth: The Economics of Sustainable Development*. Boston: Beacon Press. 1996.
10. David, Paul. Clio and the Economics of QWERTY, *American Economic Review*, Papers and Proceedings, vol. 75, pp 332-337, 1985.
11. Dowlatshahi, Shad. Developing a Theory of Reverse Logistics. *Interfaces*. 30(3) May-June 2000, pp. 143-155.
12. *Ecosystems and Human Well-being: Synthesis Millennium Ecosystem Assessment*. Island Press, Washington, DC. 2005.
13. Fenton, Michael, Iron and Steel Scrap, U.S. Geological Survey Minerals Handbook. 2002
14. Geyer, R. and T. Jackson. Supply Loops and their Constraints: The Industrial Ecology of Recycling and Reuse. *California Management Review*, Vol. 46, No. 2, 2004, pp. 55-73.
15. Gonzalez-Torre, Pilar L., Adenso-Diaz, and Kakim Artiba, Environmental and reverse logistics policies in Europe bottling and packaging firms. *International Journal of Production Economics*, 2003.
16. Goodstein, Eban. *Economics and the Environment*. Wiley, 2004.
17. Grogan, Peter L. Not Your Father’s Oldsmobile, *Biocycle*, Vol 41, No. 11, November 2000, p. 76
18. Hasegawa, Harukiyo. *The Steel Industry in Japan*. New York: Routledge. 1996.
19. Heeb, H.B. Can old workhorses still pull their weight? *Manufacturing Engineering*, Vol. 102. No. 4, 1989, pp. 74-76.
20. Houck, Gerald W. Iron and Steel Scrap, Washington: U.S. Geological Survey, 1994.
21. IISI, International Iron and Steel Institute, Annual Statistical Report, various years.
22. Jayaraman, V., Guide, V. D. R., and R. Srivastava. A Closed-loop Logistics model for Remanufacturing. *Journal of the Operational Research Society*. Vol. 50, No. 5, 1999, pp. 497-508.
23. Johansson, Allan, and Lauri Holappa. From megaplants to mini-mills—a trend in steelmaking—a prospect for papermaking. *Resources, Conservation and Recycling*. Vol 40, 2004, pp. 173–183

24. Magnum, Garth and R. S. McNabb. *The Rise, Fall, and Replacement of Industry-Wide Bargaining in the Basic Steel Industry*. London, England: M.E. Sharpe. 1997
25. Melbin, J.E. The never –ending cycle. *Distribution*. Vol. 94, no. 11. October 1995, pp. 36-38
26. Miller, Jack. Steel Minimills. *Scientific American*, Vol 250, No. 5, May 1984.
27. Recycling Rates. Steel Recycling Institute. Nov. 1 2005 <<http://www.recycle-steel.org/PDFs/ratesheet.pdf>>.
28. Recycling Scrap Iron and Steel. Institute of Scrap Recycling Industries, Inc., 1990, 1993.
29. Scrap Metal Industry, Department of the Treasury Internal Revenue Service, Training 3123-001 (2-99)
30. Stuart, Eric. EPA and EAF recyclers. *Iron Age New Steel*. Jul 2001. Vol 17, Iss7, p. 40.
31. The Inherent Content of Today's Steel. Steel Recycling Institute. <<http://www.recycle-steel.org/leed/2002Inherent.pdf>>
32. The Measure of Our Sustainability, Report of the World Steel Industry, International Iron and Steel Institute, 2004
33. Tibben-Lembke, Ronald S. The impact of reverse logistics on the total cost of ownership. *Journal of Marketing Theory and Practice*, 1998.
34. Toensmeier, P.A. Remanufacture does more than just save on investment, *Modern Plastics*. Vol 69, No. 4, 1992, pp. 77-79.
35. Toffel, M. Strategic Management of Product Recovery. *California Management Review*, Vol. 46, No. 2, 2004, pp. 120-141.
36. U.S. Geological Survey, Mineral Commodity Summaries, January 2004
37. U.S. Recycling Economic Information Study, The National Recycling Coalition, July 2001
38. Wells, Peter, and Orsato, Renato, The Ecological Modernisation of the Automotive Industry, Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change, Environmental Policy Research Centre: Berlin, 2004, pp. 373 – 385.

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