A Study of Potential Effects of Market Forces on the Management of Hazardous Secondary Materials Intended for Recycling

EPA Office of Solid Waste

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Executive Summary

Recycling of hazardous waste supports a variety of environmental goals, including reduced generation of waste and reduced use of virgin materials and landfill space. Proposed revisions to EPA's definition of solid waste identify certain recyclable hazardous secondary material as not being subject to regulation as hazardous waste, thus removing some of the regulatory burdens for managing those materials. A potential concern with these revisions, however, is that the economic forces that shape firm recycling behavior might differ from those that shape manufacturing decisions. Through a closer look at how market forces can affect materials management for various types of recycling, this paper aims to help EPA evaluate these proposed regulatory changes.

Despite the societal-level benefits of hazardous waste recycling, an examination of current damage cases and public comments on EPA's proposed revisions of the definition of hazardous waste reveal cases where hazardous waste recycling has not achieved the beneficial outcomes mentioned above. The objective of the paper is to use economic theory to examine and attempt to explain the market forces that may contribute to both sub-optimal and optimal outcomes from hazardous waste recycling.

From a societal point of view, an optimal amount of an economic activity is the amount which maximizes the net benefits (private and social benefits minus private and social costs). At this point, the marginal benefits of the activity (the benefits associated with the last unit of the activity) equal the marginal costs of it (the costs associated with providing that last unit). Any deviation from this point leads to a sub-optimal outcome where too little or too much of the activity is occurring from a societal point of view. For the case of hazardous waste recycling, a situation of too little recycling would result in inefficiencies, in that an increased rate of recycling (due, for example, to EPA's proposed changes) could realize additional net benefits.

The focus of this paper, however, is on situations where sub-optimal outcomes result from too much of an activity. For hazardous waste recycling, this situation occurs when firms are accumulating too much waste without actually recycling it, or are operating their recycling operation in a way that imposes excessive costs on society (such as excess pollution or mishandling of waste). Thus, while hazardous waste recycling is not an inherently damaging activity, damages can result from it if recycling is practiced in a way that generates excessive social costs. A move from a sub-optimal to an optimal amount of recycling may thus involve two different sets of activities. First would be a reduction in waste mismanagement that result from hazardous waste recycling, which would increase the social benefits and lower the social costs of recycling operations (e.g., reduce leakages, spills). Second would be cessation of activities that occur under the guise of recycling but have little or no benefits and large costs, such as "sham recycling."

In this paper, we present economic models to provide information on how economic forces could influence different kinds of hazardous waste recycling. These economic models are based on three distinct kinds of hazardous waste recycling that occur at commercial and industrial firms. The models discussed in this paper include one for

businesses that are primarily waste handlers, and two for industrial firms that manufacture a primary product and generate hazardous waste as a byproduct:

- **Commercial Recycling** The primary business of these firms is handling hazardous waste and producing secondary materials. Wastes are accepted for recycling from offsite industrial sources (usually for a fee), and may be returned to the same generator or to another company and/or different industry.

- **Industrial Intra-company Recycling** These firms generate hazardous waste as a byproduct in their main production process and, with the objective of reducing their waste management costs, recycle the waste for sale or for their own reuse in production.

- **Industrial Inter-Company Recycling** These firms use or recycle hazardous waste obtained from other firms with the objective of reducing the cost of their production inputs.

In the paper, we discuss these models of recycling in terms of the associated revenues and costs (both direct and indirect). Based on information from the models, we define characteristics of hazardous waste recycling that are hypothesized to contribute to sub-optimal outcomes. We then use economic theory to provide information on how these characteristics might influence recycling at different kinds of firms. These characteristics are

- The value of the recycled product;
- Price volatility of recycling output or inputs; and
- The net worth of the firm.

Based on these characteristics, we identify certain economic conditions that could be seen as increasing the likelihood of waste mismanagement occurring during hazardous waste recycling activities. These conditions are

- A low market value for the recycled product;
- Unstable prices for the recycled product or any inputs to recycling; and
- Firms with low net worth.

One similarity of the characteristics and conditions described above is that they are at least to some degree observable or could be observable given availability of data. In addition to these observable characteristics, we present additional factors that could contribute to sub-optimal recycling. These additional factors arise due to economic conditions known as market failure, and differ from the above characteristics in that they are not readily observable from firm or market data. These market failures are

- Imperfect information; and
- Externalities.

The first source of market failure, imperfect information, suggests that some firms may enter into the hazardous waste recycling market with incorrect information on the true costs or revenues involved. The second source of market failure, externalities, occur when the true societal costs that result from a hazardous waste recycling operation are not borne by the firm, encouraging the firm to produce more recycled product than it would if it had to pay the full social costs of its operation. Identifying these sources of market failure can point to potential solutions to the problems it causes. Similarly, knowing how the hazardous waste recycling market is affected by externalities can point the way toward policies that "internalize" them, and lead to reduced damages.

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1. Introduction

In October 2003, EPA proposed revisions to the definition of solid waste (68 FR 61558). These proposed revisions identify certain recyclable hazardous secondary materials as not being subject to regulation as hazardous wastes. Part of the rationale for this approach is that some types of recycling are considered more akin to manufacturing than waste management and therefore less in need of regulation. ["In EPA's view, a recycler will value secondary materials that provide an important contribution to his process or product and will manage them in a manner consistent with a valuable feedstock material (i.e., will manage them to minimize their loss)"; 68 FR 61583].

As pointed out by some commenters to the proposed rule, the economic forces shaping firm recycling behavior might be different than those at play in manufacturing processes using virgin materials. For example, the inherent value of hazardous material is often very low compared to virgin materials used in manufacturing, resulting in a different set of economic incentives. Additionally, different economic incentives between hazardous waste recycling and manufacturing may arise due to differences in these two business models. As opposed to manufacturing, where the cost of inputs is greater than zero and revenue is generated from the sale of the output, some models of hazardous waste recycling involve generating revenue from inputs (acceptance of hazardous waste) in addition to the sale of outputs. Recyclers of hazardous wastes may thus respond differently than traditional manufacturers to economic forces and incentives. An increased understanding of these unique aspects of hazardous waste recycling can help to guide rulemaking designed to influence this activity as practiced by firms.

Recycling of hazardous waste supports a variety of environmental goals, including reduced generation of waste and reduced use of virgin materials and landfill space. Proposed revisions to EPA's definition of solid waste identify certain recyclable hazardous secondary material as not being subject to regulation as hazardous waste, thus removing some of the regulatory burdens for managing those materials. A potential concern with these revisions, however, is that the economic forces that shape firm recycling behavior might differ from those that shape manufacturing decisions. Through a closer look at how market forces can affect materials management for various types of recycling, this paper aims to help EPA evaluate these proposed regulatory changes.

Despite the societal-level benefits of hazardous waste recycling, an examination of current damage cases and public comments on EPA's proposed revisions of the definition of hazardous waste reveal cases where hazardous waste recycling has not achieved the beneficial outcomes mentioned above. The objective of the paper is to use economic theory to examine and attempt to explain the market forces that may contribute to both sub-optimal and optimal outcomes from hazardous waste recycling.

From a societal point of view, an optimal amount of an economic activity is the amount which maximizes the net benefits (private and social benefits minus private and social costs). At this point, the marginal benefits of the activity (the benefits associated with the last unit of the activity) equal the marginal costs of it (the costs associated with providing

that last unit). Any deviation from this point leads to a sub-optimal outcome where too little or too much of the activity is occurring from a societal point of view. For the case of hazardous waste recycling, a situation of too little recycling would result in inefficiencies, in that an increased rate of recycling (due, for example, to EPA's proposed changes) could realize additional net benefits.

The focus of this paper, however, is on situations where sub-optimal outcomes result from too much of an activity. For hazardous waste recycling, this situation occurs when firms are accumulating too much waste without actually recycling it, or are operating their recycling operation in a way that imposes excessive costs on society (such as excess pollution or mishandling of waste). Thus, while hazardous waste recycling is not an inherently damaging activity, damages can result from it if recycling is practiced in a way that generates excessive social costs. A move from a sub-optimal to an optimal amount of recycling may thus involve two different sets of activities. First would be a reduction in waste mismanagement that result from hazardous waste recycling, which would increase the social benefits and lower the social costs of recycling operations (e.g., reduce leakages, spills). Second would be cessation of activities that occur under the guise of recycling but have little or no benefits and large costs, such as "sham recycling."

Using comments to EPA's proposed rule revisions discussed above, we define characteristics of hazardous waste recycling that are hypothesized to contribute to sub-optimal outcomes and use economic theory to provide information on how these characteristics might influence different recycling models. These characteristics are

- The value of the recycled product;
- Price volatility of recycling output or inputs; and
- The net worth of the firm.

In this paper, we present economic models of hazardous waste recycling to provide information on how economic theory might support or refute the hypothesized influence of these characteristics on hazardous waste recycling. Utilizing economic theory, these characteristics identify certain economic conditions that could be seen as increasing the likelihood of waste mismanagement resulting from hazardous waste recycling. These conditions are

- A low market value for the recycled product;
- Unstable prices for the recycled product or any inputs to recycling; and
- Firms with low net worth.

One similarity of the characteristics and conditions described above is that they are at least to some degree observable or could be observable given availability of data. In addition to these observable characteristics, we present additional factors that could contribute to sub-optimal recycling. These additional factors arise due to economic conditions known as market failure, and differ from the above characteristics in that they are not readily observable from firm or market data. These market failures are

- Imperfect information; and
- Externalities.

For simplicity, throughout this paper we use the term "hazardous waste" to denote both hazardous secondary materials that are regulated as hazardous wastes and materials that have been specifically excluded or exempt from regulations as hazardous wastes when they are recycled. This paper is not intended to be an exhaustive, quantitative, waste-by-waste analysis. Rather, the paper is intended to provide some insights into the forces that drive firms' hazardous waste recycling decisions and, to support the findings, to the extent possible, with the market data on a few selected hazardous wastes.

The remainder of this introductory section presents background information on the major regulations that influence recycling activity and a brief snapshot of the current state of hazardous waste recycling. We then briefly introduce the models of recycling activity used in this paper and discuss some variations on the types of recycling presented in the models.

1.1. Regulatory Framework for Hazardous Waste Recycling

Facilities engaged in hazardous waste recycling are required by federal statutes and regulations to ensure that they protect human health and the environment. The primary statute governing these activities is the Resource Conservation and Recovery Act (RCRA), which is implemented at the federal level by EPA. RCRA is only one of several regulatory programs in place to protect the environment. The RCRA regulations work closely with other environmental statutes, such as the following:

- Comprehensive Environmental Response, Compensation and Liability Act (CERCLA);
- Hazardous Materials Transportation Uniform Safety Act (HMTUSA);
- Clean Air Act (CAA);
- Clean Water Act (CWA);
- Emergency Planning and Community Right-to-Know Act (EPCRA);
- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA);
- Marine Protection, Research, and Sanctuaries Act (MPRSA);
- Occupational Safety and Health Act (OSHA);
- Safe Drinking Water Act (SDWA); and
- Toxic Substances Control Act (TSCA).

Though other statues and regulatory bodies may control recycling activities, this paper focuses on RCRA because compliance with RCRA typically entails the highest regulatory burden on recycling activities. Background on CERCLA is also provided because that regulatory regime is tied closely to RCRA.

The Resource Conservation and Recovery Act (RCRA) was enacted in 1976 to address the huge volumes of municipal and industrial solid waste generated nationwide. The hazardous waste management program, Subtitle C, is intended to ensure that hazardous

waste is managed safely from the moment it is generated to the moment it is finally disposed. Although much of the material that is recycled is not considered hazardous waste, this discussion focuses on requirements under RCRA Subtitle C because these requirements are the ones most likely to impose a regulatory burden on recycling activities. Facilities that are involved in the recycling process may be subject to RCRA Subtitle C if the materials they recycle are considered to be hazardous waste.

The definition of solid waste under RCRA, which serves as the starting point for the hazardous waste management system, reflects EPA's effort to minimize generation and land disposal of hazardous waste. Materials that are recycled are a special subset of the solid waste universe. When recycled, some materials may qualify for an exclusion from the definition of solid waste and either fall out of RCRA regulation or become subject to less stringent regulatory controls. In consultation with the appropriate regulatory agency the generator of a recyclable solid waste must determine if it is subject to reduced requirements or full regulation.

A material is deemed to have been recycled if it is used, reused, or reclaimed (§261.1(c)(7)). These three terms have specific regulatory definitions. A material is reclaimed if it is processed to recover a usable product or if it is regenerated (e.g., regeneration of spent solvents) (§261.1(c)(4)). A material is used or reused if it is either employed as an ingredient in an industrial process to make a product (e.g., distillation bottoms from one process used as feedstock in another process) or if it is employed as an effective substitute for a commercial product (e.g., spent pickle liquor used as a sludge conditioner in wastewater treatment) (§261.1(c)(5)).

The RCRA regulatory regime contains provisions to reduce the regulatory burden on recycling activities and thereby increase recycling. Though waste recycling and recovery are major components of RCRA's goals, they must be implemented consistently with proper hazardous waste management.

As a result, RCRA contains provisions to ensure safe hazardous waste recycling and to facilitate the management of commonly recycled waste streams. Reuse, recycling, and reclamation should be viewed as ways of managing hazardous wastes which, if properly conducted, can avoid environmental hazards, protect scarce natural resources, and reduce the nation's reliance on virgin materials and energy. Promoting reuse and recovery is certainly one of the goals of RCRA; however, this goal does not take precedence over assuring the proper management of hazardous waste. EPA has tried, to the extent possible, to develop hazardous waste management regulations that foster environmentally sound recycling and conservation of resources while at the same time providing adequate protection of human health and the environment.

How a material is regulated under RCRA (i.e., whether or not it is a solid and potentially a hazardous waste) when it is recycled depends on what type of material it is, and what type of recycling is occurring. If the recycled material is not a solid waste, then it is not a hazardous waste and is not subject to RCRA Subtitle C requirements. However, if the

material qualifies as a solid and hazardous waste, it is subject to RCRA Subtitle C jurisdiction.

Many hazardous wastes can be recycled safely and effectively. To encourage recycling while protecting human health and the environment, EPA has tried to tailor the level of regulation to reflect the actual hazard of the recycling activity. In this approach to regulation, recycling standards range from full regulation to specialized standards to exemptions from regulation. Handlers of hazardous waste slated for recycling must determine, in consultation with the appropriate regulatory agency, what type of regulation they fall under based on the recycling activity being conducted and the type of material being managed. Different types of regulation for recycled hazardous wastes are described below.[1]

1.1.1. Full Regulation

Most recycled hazardous wastes are subject to full hazardous waste regulation. This means that handlers of these recyclable materials (i.e., persons who generate, transport, or store prior to recycling) are subject to the same regulations as handlers who are managing hazardous wastes prior to disposal. While management of the hazardous wastes prior to recycling is subject to regulation, the recycling process itself is exempt from RCRA (except for some air emissions standards). For example, if a facility receives hazardous spent solvents from another facility for redistillation (heating a mixture to separate it into several pure components), the recycling units themselves are not subject to RCRA design and operating standards for hazardous waste units. However, the owners and operators of the recycling facility must follow all applicable Subtitle C requirements (including the requirement to obtain a permit) for container or tank storage areas used to store such wastes prior to recycling.

1.1.2. Exemptions

Not all hazardous wastes pose the same degree of hazard when recycled. EPA believes wastes that may be recycled in a protective manner, or that are addressed under other environmental regulations, warrant exemptions from RCRA Subtitle C. Consequently, handlers of these materials are not subject to any hazardous waste regulations. These exempt recyclable hazardous wastes are:

- Industrial ethyl alcohol
- Scrap metal
- Waste-derived fuels from refining processes
- Unrefined waste-derived fuels and oils from petroleum refineries.

[1] Information for this section is taken primarily from the EPA RCRA Orientation Manual, January 2003, EPA530-R-02-016

1.1.3. Special Standards

While RCRA specifically exempts some wastes when recycled, some recycling processes may still pose enough of a hazard to warrant some degree of regulation. However, due to the nature of the recycling process itself or the nature of the materials being recycled, these processes may require a specialized set of standards. These processes are:

- Use constituting disposal
- Precious metals reclamation
- Spent lead-acid battery reclamation
- Burning for energy recovery.

For example, persons who generate, transport, regenerate, collect, and store spent lead-acid batteries prior to reclamation, but do not perform the actual reclamation, are not subject to hazardous waste regulation. EPA established those provisions to encourage the recycling of these batteries. However, owners and operators of facilities that store spent batteries before reclamation, other than spent batteries that are regenerated (processed to remove contaminants and restore the product to a useable condition), are subject to regulation in a manner similar to hazardous waste Treatment, Storage and Disposal Facilities (TSDFs).

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or Superfund, is closely tied to RCRA: both are designed to protect human health and the environment from the dangers of hazardous waste. Though these programs are similar, they do have different regulatory focuses: RCRA regulates how wastes should be managed to avoid potential threats to human health and the environment; CERCLA focuses on actual releases, or substantial threats of a release in the environment of a hazardous substance, pollutant, or contaminant, that present an imminent and substantial threat to human health. CERCLA, which was enacted by Congress in 1980, created a tax on the chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. Over a five-year period, $1.6 billion was collected and deposited in a trust fund for cleaning up abandoned or uncontrolled hazardous waste sites. Recyclers are likely to be subject to CERCLA provisions for reporting releases of hazardous chemicals, emergency preparedness and response, and financial assurance. In addition, should recycling activities result in releases of hazardous materials, facilities may be liable for cleanup under CERCLA.

1.2. Snapshot of the Current State of Hazardous Materials Recycling

According to EPA's 2003 Hazardous Waste Biennial Report, more than 42 million tons of wastes were managed in 2003 by 569 facilities, of which 399 (or approximately 70 percent) managed hazardous wastes onsite. In terms of quantity of waste managed, over 80 percent is managed onsite. Of the total waste managed, only about 11 percent is recycled, mainly at offsite facilities. The rest is deposited in landfills or treated.

Exhibit 1-1: Hazardous Waste Managed in 2003

	Hazardous Waste Managed		
	Onsite	**Offsite**	**Total**
Hazardous Waste Managed			
Quantity (in million tons)	34.9	7.2	42.1
As a Percentage of Total Waste Managed	82.8%	17.2%	100%
Hazardous Waste Recycled			
Quantity (in million tons)	1.1	3.4	4.5
As a Percentage of Total Waste Recycled	24.8%	75.2%	100%
As a Percentage of Total Waste Managed	2.7%	8.1%	10.8%

Source: BRS 2003.
Note: Offsite recyclers may include recyclers who use recyclable materials, either produced by themselves or outside firms, as an input to their production process.

In terms of quantity of hazardous wastes recycled, energy recovery is a dominant waste management practice for both onsite and offsite recyclers. The focus of this paper, however, is on recycling practices other than energy recovery.

Exhibit 1-2: Hazardous Waste Recycled, 2003

Recycling Type	Hazardous Waste Recycled (million tons)		
	Onsite	**Offsite**	**Total**
Energy Recovery	0.45 (40%)	1.01 (30%)	1.46 (32%)
Metals Recovery	0.20 (18%)	0.95 (28%)	1.15 (26%)
Fuel Blending	0.16 (14%)	0.76 (22%)	0.92 (20%)
Other Recovery	0.23 (21%)	0.50 (15%)	0.73 (16%)
Solvents Recovery	0.07 (7%)	0.19 (5%)	0.26 (6%)
Total	1.12	3.41	4.53

Notes: Values in parenthesis indicate quantity recovered through a given recycling method as a percentage of the total hazardous waste recycled.
Totals may not add due to rounding.
Offsite recyclers may include recyclers who use recyclable materials, either produced by themselves or outside firms, as an input to their production process.
Source: BRS 2003.

1.3. Models of Hazardous Waste Recycling

As discussed in further detail below, firms face decisions about how to handle the hazardous waste they generate, and about the mix of inputs they use in production. While a host of factors might affect these decisions, this paper assumes that firms' actions are aimed at realizing the highest possible profit. Despite this focus on profit maximization, it is important to realize that this does not mean that firms will always choose the cheapest option. Production and waste management decisions entail both direct and indirect costs, and firms are assumed to weigh the full range of costs in their decision-making. In terms of waste management, recycling and disposal are competing options. In addition to differences in their direct costs, the indirect costs will vary as well, especially in relation to the resulting liability issues. Similar differences between

direct and indirect costs would occur in relation to the use of production inputs. These issues are explored in further detail in this paper.

Recycling of hazardous waste occurs both onsite at industrial manufacturing plants and offsite at commercial waste management facilities. In this paper, "industrial facilities" are defined as firms whose primary business is manufacturing of a product, and "commercial facilities" are firms whose primary business is management of wastes generated by industrial firms. There are three distinct models of hazardous waste recycling that occur at these firms; all are included in this study:

- **Commercial Recycling** The first model is commercial recycling, which happens only at commercial waste management facilities. The primary product of these firms is recycled material. Wastes are received for recycling from offsite industrial sources, and may be returned to the same generator or to another company, which may or may not be in the same industry.

- **Industrial Intra-company Recycling** The first type of hazardous waste recycling at industrial firms (and the second model of recycling considered in this paper) is called industrial intra-company recycling. This model involves the recycling of hazardous waste by the industrial firm itself as part of the firm's waste management, with the objective of reducing its waste management costs. In some instances intra-company recycling may involve offsite exchange of the recyclable or recycled materials with offsite facilities owned by the same company.

- **Industrial Inter-Company Recycling** The second type of hazardous waste recycling at industrial firms (and the third model of recycling considered in this paper) is industrial inter-company recycling. This model involves the recycling of hazardous waste from one company as an input to another firm's production process.

Recycling under all three of these models is driven by a host of economic factors. These factors influence the costs and benefits to be gained from hazardous waste recycling and will have an effect on the amount of recycling done by a firm. Examples of these factors include the value of the waste that goes into the recycling process, the value of the recycled products, the various costs (both direct and indirect) of managing and processing recyclable material into a recycled product, and the costs of managing any resulting waste. Some important components of these costs are the transportation and transaction costs that firms incur in their production and waste management operations. In this paper, we discuss the influence of these economic factors on the three models of hazardous waste recycling.

Within these three models of recycling, there are variations on how recycling can be done, in terms of the flow of materials and the relationship between commercial and industrial firms. For example, recycling can occur as either an open-loop or a closed-loop process. In an open-loop process, the material is recycled and made into a different product, possibly to be used in a different industry or at least by a different firm. Closed-

loop recycling refers to a recycling process in which the recycled material is made into the same product again or fed back into the same process. A variation of closed-loop recycling is practiced by Gage Industries. In this recycling model, Gage owns solvents that it rents to the automobile industry for use. Gage then takes back the used solvent and recycles (or reclaims) it for further use. Since Gage actually owns the solvent, as opposed to being a commercial recycler that is recycling solvents owned by other firms, they have a built-in incentive to handle it with care; any spillage or leakage means that they will have less of the solvent to rent out. Under another alternative to traditional recycling operations, called a tolling arrangement, an industrial firm agrees to supply a certain amount of waste to a commercial firm, which in turn agrees to send back a certain amount of recycled materials for a given price. One potential advantage of tolling arrangements is that they protect recyclers from sudden fluctuations in materials prices.

1.4. Outline of the Theoretical Analysis

The theoretical analysis of the hazardous waste recycling market is presented in section two of the paper, and is broken down into the three models of hazardous waste recycling discussed above. Following a general introduction to each of the three types of recycling, the main drivers of recycling are presented in terms of the revenue and cost structures of the participating firms. For the cost structure of the firms, the discussion is divided into sections on the direct and indirect costs. Section two of the paper then concludes with a discussion of various types of market failures, i.e., situations where competitive markets do not function properly leading to undesirable outcomes from the perspective of both the affected firms and society as a whole. Section three then summarizes the major findings from the paper and presents concluding remarks.

As part of the development of the theoretical models of hazardous waste recycling, a literature review was conducted to determine the current state of information on hazardous waste recycling in both the economic and non-economic literature. Insights from this literature are included in this paper, and a summary of the literature review is included in Appendix I. Finally, Appendix II presents an empirical analysis of five selected hazardous materials being recycled and links the empirical analysis with the theoretical analysis presented earlier. The five materials analyzed are lead-acid batteries, brass dust, spent pickle liquor, solvents, and drums.

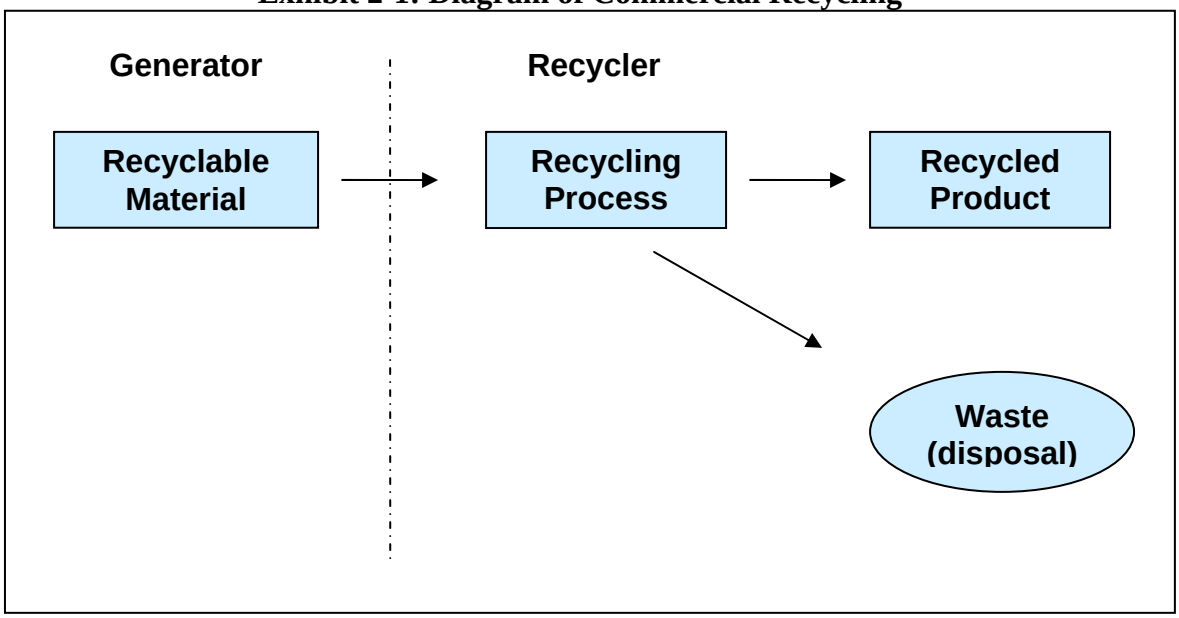
2. Theoretical Analysis

This section of the paper develops a theoretical model of the hazardous waste recycling market. First, three models of hazardous waste recycling are presented and discussed within the context of profit-maximizing decisions made by commercial and industrial firms. For each of the three models, we discuss the recycling process's revenue and cost structure, including both direct and indirect costs. This discussion is followed by a formal presentation of a model for each type of recycling. Lastly, we discuss different kinds of market failure. This discussion includes a theoretical explanation for why the hazardous waste recycling market may produce sub-optimal outcomes, with marginal costs that exceed the activity's marginal benefits. These sub-optimal outcomes can result either from the acceptance of an excess of waste (not all of which is recycled) or from mismanagement during the recycling process.

2.1. Commercial Hazardous Waste Recycling

Commercial recyclers are firms whose primary business is accepting hazardous waste, recycling it, and selling the output to outside entities. A diagram of the recycling process for commercial recyclers is shown in Exhibit 2-1. The output of this process is a final product, which is then sold to an outside entity, and waste which is usually either hazardous or contains hazardous constituents. This waste must be managed and disposed of by the commercial firm. In the following sections, the revenue and cost structures of commercial recyclers are discussed in further detail.

Exhibit 2-1: Diagram of Commercial Recycling



2.1.1. Revenue Structure of Commercial Recyclers

The primary revenue for commercial firms is from the sale of their recycled product. Commercial firms may also generate revenue by charging a fee for accepting hazardous waste. Depending on market conditions, commercial firms will either buy hazardous waste or receive a fee to accept it. This acceptance fee's relative importance in the firm's overall revenues primarily depends on the price the commercial firm receives for its recycled product. Other factors that may affect the importance of the acceptance fee include the strength and stability of the market. Depending on these factors, the acceptance fee may play a negligible role in the firm's revenue structure, and the firm might even be willing to pay to accept recyclable material. If, however, the firm cannot charge a sufficiently high price for the recycled material, or it faces a weak or unstable market for its recycled product, the acceptance fee may be an important component of the firm's overall revenue. This kind of scenario could encourage firms to continually accept waste when they cannot realistically process or sell it. The influence of the different components of the commercial recycler's revenue on the firm's operation will be discussed in further detail below.

In cases where generators pay commercial recyclers to accept hazardous waste, landfill disposal fees are one factor that influences the acceptance fees received by commercial recyclers. Since commercial recyclers are competing with landfills, and with each other, to obtain waste from generators, the acceptance fees would need to be relatively similar to landfill disposal fees to attract waste from industrial firms. Cost data collected by the Environmental Technology Council indicate that landfill tipping fees for treatment and landfilling of hazardous waste were, on average, $140 per ton for treated bulk and soil, and between $100 and $200 per 55-gallon drum for treated drummed wastes from 2002 to 2004. Thus, we would expect that the acceptance fees ranged, on average, between

$100 and $200 per ton or 55-gallon drum in the same period. (See Appendix II for more information.)

2.1.2. Direct Costs of Commercial Recyclers

The direct costs faced by commercial recyclers are the costs they face for recycling the hazardous waste they receive from waste generators. These direct costs can be broken down into capital and operating costs. Capital costs represent investments in equipment and facilities needed for recycling of hazardous waste and managing the resulting wastes. Operating costs cover labor, utilities, materials and the waste treatment and disposal process. These costs can vary according to the characteristics of the hazardous waste being recycled. Recycling some waste materials might require a complex and capital-intensive process. Recycling of other waste materials might have low capital requirements, but have high operating costs in terms of the labor, utilities or materials needed to manage and process them. Firms would be expected to weigh direct costs against expected revenues when determining whether to enter the market for a particular recycled material.

Another component of direct costs that might influence the operation of commercial firms is transportation costs. These costs would most likely occur for commercial recycling firms in the sale of their recycled output, and also in the management and disposal of waste from the recycling process. Transportation costs could also be incurred to obtain of hazardous wastes as an input to their recycling process, although these costs are generally borne by the hazardous waste generator.

Additional factors that influence the direct costs of recycling at commercial firms are the size of a commercial firm and the amount of hazardous waste it can recycle. As with most industries, recycling is subject to economies of scale, meaning that as the amount of recycled material the firm is producing increases, the cost of recycling decreases on a per-unit basis. A general expectation would be that, other things being equal, an increase in firm size or the amount of hazardous material recycled would lower the per-unit cost of recycling hazardous materials (McLaren and Yu, 1997). For commercial recyclers, attempting to achieve economies of scale could be an incentive for them to expand their operations. A real-world example is found in the solvents recycling market, where Safety-Kleen, the largest US commercial solvents recycler, has increased economies of scale by expanding its network of solvent collection centers. (See Appendix II for more information.)

2.1.3. Indirect Costs of Commercial Recyclers

In addition to the direct costs discussed above, commercial recyclers incur indirect costs for functions like administration and reporting. These would include the costs of obtaining a RCRA permit and keeping it current. For smaller firms, these costs could be large enough to serve as a barrier to entry into the commercial recycling market. Along with other administrative costs associated with operating a commercial recycling

business, these indirect costs would need to be considered by commercial firms in their decisions on whether to enter or exit the market, and on their level of production.

The largest and most complex category of indirect costs is liability costs associated with the handling of hazardous waste. In the case of an accident or environmental damage caused by the mishandling of waste, commercial firms would be liable for these damages. 40 CFR 264.147 requires owners and operators to "have and maintain liability coverage for sudden accidental occurrences in the amount of at least $1 million per occurrence with an annual aggregate of at least $2 million, exclusive of legal defense costs." They are also required to provide financial assurance for facility closure (40 CFR 264.143) and post-closure care (40 CFR 264.143). It is expected that the firm would take these various costs into consideration in their decision to enter into the recycling market, or to remain in it if there were a change in regulatory requirements that would substantially increase these costs. Since firms are liable for damages up to their net worth, it would be expected that firms with a greater net worth would have more incentive to operate in a careful matter and guard against potential liabilities than smaller firms that could escape large liability risks by declaring bankruptcy (Alberini and Frost, 1999).

A commercial firm's treatment of liability issues may influence the amount of business it can get. If hazardous waste is mishandled by a commercial firm, the *generator* of that waste can be held liable for the damages (Rosenbaum, 1990). Many waste generators that are looking to transact with a commercial recycler consider the potential liability risk of a commercial firm before sending waste to them. Commercial firms with a history of RCRA violations or a history of health and safety accidents might need to charge a lower acceptance fee in order to obtain business than firms with stronger reputations. Waste generators that are concerned only about costs might be willing to send waste to commercial firms that have a greater liability risk but have lower fees, whereas waste generators that are more careful or cautious in relation to liability issues might be willing to send waste only to commercial firms with a low liability risk or that have insured against their risks.

Transaction costs are another economic factor that can influence the indirect costs of recycling for commercial firms. Transaction costs are the costs that a firm incurs as a result of dealing with other economic agents. Since commercial firms do not generate the waste they use for recycling, they face transaction costs in obtaining hazardous waste and also for the sale of their recycled output. These costs again can be viewed as part of the firm's operating costs, and would be considered by the firm in making its operating decisions. The effect of transaction costs would be to raise the cost of recycling for commercial firms in comparison to industrial firms that might use their own waste as inputs for a recycling process.

In the next section, we graphically illustrate commercial recyclers' behavior using cost curves. Cost curves are a standard economic tool for analyzing and graphically illustrating firm's behavior. We use the same tool later in the paper to analyze and illustrate industrial recyclers.

2.1.4. Model of Commercial Recyclers

This section incorporates the discussion of the costs and revenues of commercial recyclers presented above into a formal model for recycling by commercial facilities. Commercial recyclers' primary product is recycled material derived from the hazardous waste they receive from other firms. In this model, commercial recyclers receive a fee (R) for accepting hazardous waste (Q_{hw}) from waste generators.[2] The commercial recycler then processes this material and sells the recycled product (Q_r) at the prevailing market price (P_r). In the production of the recycled materials, the commercial recycler incurs various direct and indirect costs (C). Since commercial recyclers have two potential sources of revenue, their total revenue (TR) is the sum of the revenue they receive for accepting hazardous waste and the revenue they receive for selling the recycled product ($TR = (R*Q_{hw}) + (P_r*Q_r)$).[3] In determining their output decisions, profit-maximizing firms will look at the revenue from producing one more unit of output, which is their marginal revenue (MR), relative to the cost of producing that unit, which is their marginal cost (MC).

Commercial recyclers are assumed to be "price takers" with respect to their outputs, meaning that they sell their output at the price determined in the market by the intersection of demand and the aggregate supply of all of the producers of recycled hazardous materials. The actions of the individual commercial recycling firm do not influence this market price, and the firm must use this price to determine its appropriate level of output.[4] The commercial recyclers can also be assumed to be "fee takers," in that they are competing with other offsite disposal options and other recyclers for getting hazardous waste from generators.

It is assumed that the actions of the commercial recycling firm do not affect landfill disposal fees, and it again must set its acceptance fee based on the prevailing market forces regarding hazardous waste disposal. Since the commercial recycler is both a price taker and a fee taker, the firm's marginal revenue is equal to the price of recycled materials it produces plus the acceptance fee for the waste it receives ($MR = P_r+R$).

Under the standard microeconomic model of a competitive market, a firm will enter the market as long as the market price is high enough to cover its average total costs ($ATC=TC/Q_{hw}$). For commercial recyclers, however, it is not only the price of the recycled product that affects their entry/exit decision. Rather, commercial recyclers will

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[2] It is also possible that the commercial recycler might need to pay to obtain waste from a generator, instead of getting paid for it. This situation could be represented in Exhibit 2-2 by showing the MR (P_r+R) line as below the price (P_r) line instead of above it.

[3] An implicit assumption in this model is that one unit of hazardous waste (Q_{hw}) will produce one unit of the recycled product (Q_r). This is a simplifying assumption since it is likely that one unit of Q_{hw} would produce less than one unit of Q_r, after impurities in Q_{hw} have been removed.

[4] Data available in the EPA's 2003 RCRA Hazardous Waste Biennial Report on the quantity of hazardous materials recycled by type and quantity and the number of recycling facilities indicate that annual average amount of waste processed by an individual commercial recycler is 0.02 million tons. Compared to the total waste recycled by both commercial and industrial recyclers totaling 4.5 million tons, the amount recycled by individual recyclers is too small for them to influence the market.

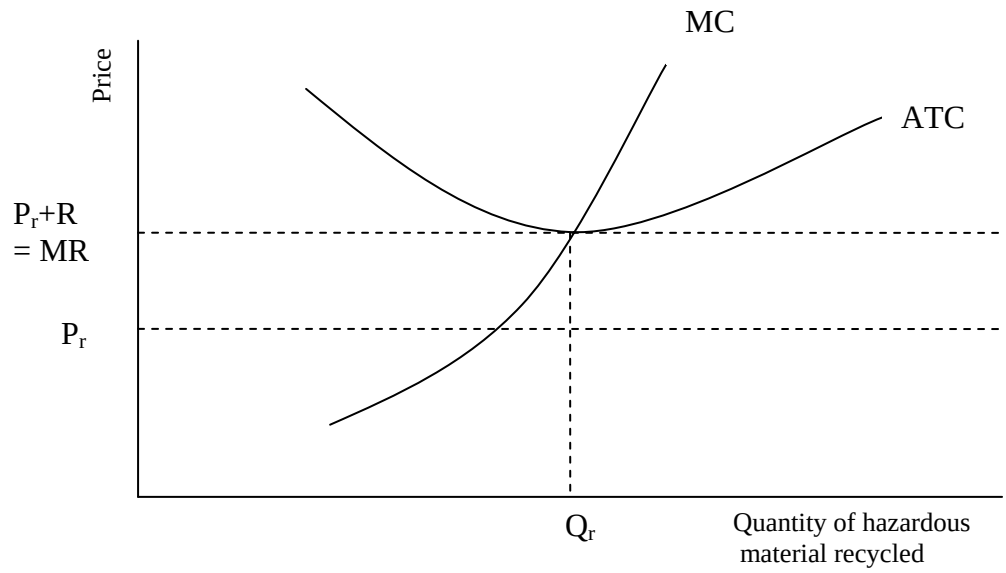
enter the recycling market as long as the price of recycled materials plus the fee they receive for accepting hazardous waste is greater than the cost of producing the recycled good. They will then accept hazardous waste and produce recycled materials as long as their ATC is less than the price of recycled goods plus the acceptance fee ($ATC<(R+P_r)$).

The costs faced by the commercial recycler to produce different amounts of recycled goods can be shown graphically. Plotting the firm's average cost for the production of different units of recycled materials will yield the firm's average total (ATC) cost curve.[5] Another important curve that can be shown is the firm's marginal cost (MC) curve, which represents the cost of the last unit produced, or the change in total cost divided by the change in quantity for each additional unit. This MC curve is upward sloping, and the portion of the MC curve that is above the ATC curve represents the firm's supply curve for recycled materials. A profit-maximizing commercial recycler will produce recycled materials up to the point where its marginal costs of production equals its marginal revenue (MC=MR). This will be the profit-maximizing output for the commercial recycler since any additional unit would cost them more than the revenue they would be able to receive for it. This situation is illustrated below in Exhibit 2-2.[6]

[5] The firm's average cost curve is initially downward sloping, indicating that costs are decreasing with each additional unit produced. As more units are produced, the curve begins to slope upward, indicating that the average costs are increasing for each unit being produced.

[6] In the figures presented in this paper, the marginal revenue of the firm (P_r+R for commercial recyclers or P_r for industrial recyclers) intersects with the firm's cost curves at the lowest point of ATC. This represents the minimum value at which MR would need to be for the firm to enter the market. The firm will choose to enter the market and produce recycled materials as long as MR intersects with MC at any point equal to or above this point (where MC and ATC cross, or the minimum point of ATC).

Exhibit 2-2: Model of Commercial Recyclers



ATC – Average total cost of producing recycled materials
MC – Marginal cost of producing recycled materials
R – Acceptance fee for hazardous waste
MR – Marginal revenue of the firm
P_r – Market price of recycled materials
Q_r – Quantity of recycled materials produced by firm

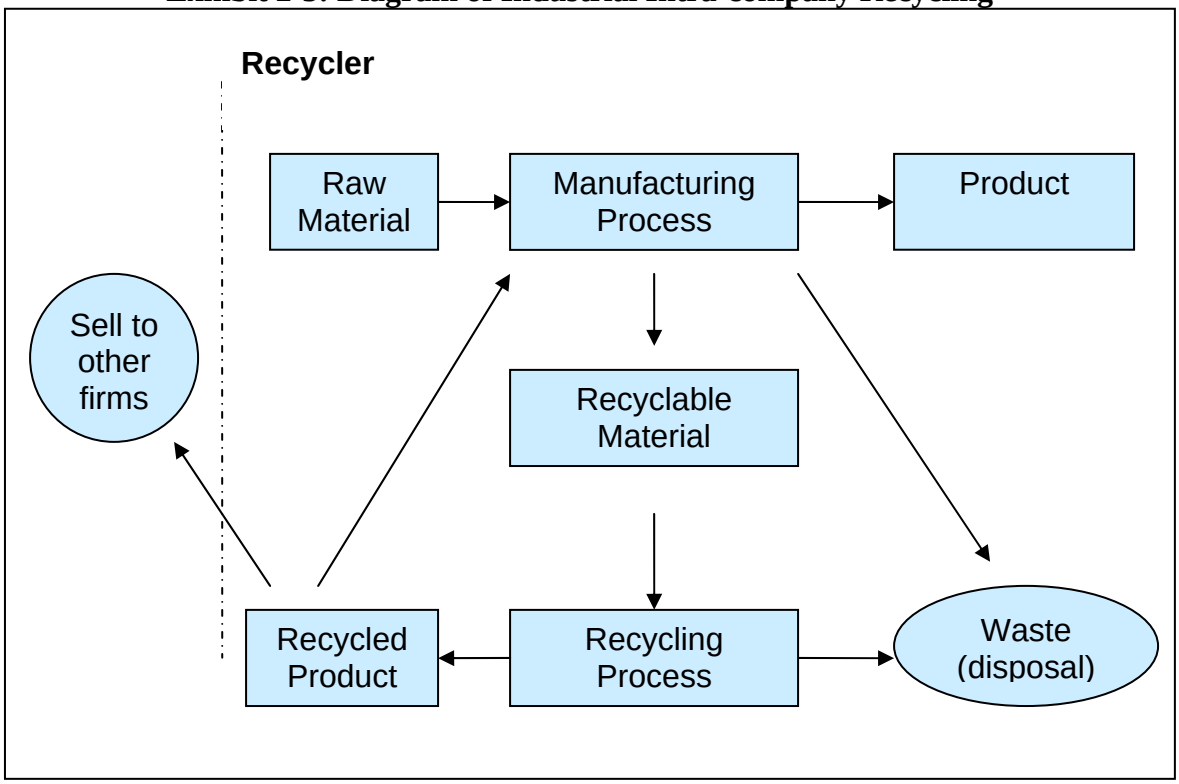
As shown in Exhibit 2-2, the successful operation of the commercial recycling firm depends on its ability to produce output at a cost no greater than the combined price of the recycled materials it produces plus the acceptance fee for receiving the hazardous waste. Exhibit 2-2 depicts a situation, for instance, where the price of the recycled materials (P_r) is below the firm's cost curves, and the firm is dependent on the acceptance fee to operate a profitable business. Fluctuations in the firm's revenue stream or its costs can thus affect its operation. If the price of recycled material goes down, for example, due to decreases in the price of virgin materials, the marginal revenue of the firm could fall below the firm's ATC curve. This results in a situation where the firm would not be able to recover its cost by accepting and recycling hazardous waste. In the long run, this would typically mean that the firm would shut down and exit the market.

2.2. Industrial Intra-company Recycling

The primary business of industrial firms is manufacturing a product and recycling hazardous wastes is a secondary activity. Industrial firms can be involved in hazardous waste recycling in two different ways, resulting in two different models. The first of these models, termed intra-company recycling, involves hazardous waste recycling by firms as part of their waste management strategy. A diagram of how industrial intra-company recycling works is shown in Exhibit 2-3. The firm receives raw materials,

which it puts through a manufacturing process. The output of that process is the firm's product, and hazardous waste is a byproduct. The firm has three main alternatives for managing its hazardous waste: ship it off for disposal, send it to a commercial recycler, or recycle the waste themselves (at an onsite or offsite location). In intra-company recycling, the company utilizes hazardous waste generated during production and runs it through a recycling process. The result is a recycled product that the firm can either feed back into its production process (thus substituting for the use of virgin materials), or sell to other firms. A byproduct of this recycling process is waste for disposal.

Exhibit 2-3: Diagram of Industrial Intra-company Recycling



2.2.1. Revenue Structure of Industrial Intra-company Recycling

The primary source of income for industrial firms is from the sale of the products they manufacture. Though recycling its hazardous waste may result in revenues for the firm, this is viewed as a secondary source of income and would not significantly influence the production decisions of the firm. Since intra-company recycling enters into the firm's process in its waste management decisions, the revenues generated from this process can be viewed as something that serves to offset waste management costs. As shown above in the diagram, the firm could also choose to use the recycled product it generates in its own production process. The choice of whether to sell the recycled product or use it in its own production process would be assumed to be based on profit-maximizing

objectives, with the recycled product going to the use that generated the largest amount of cost savings for the firm.

2.2.2. Direct Costs of Industrial Intra-company Recycling

The categories of direct costs faced by intra-company recyclers are similar to those discussed above for commercial recyclers. The main categories of direct costs are capital costs (equipment and facilities) and operating costs (labor, utilities, materials, waste treatment and disposal, etc.). Capital costs must be incurred to participate in recycling, while operating costs can vary with the amount of production or changes to the recycling process. Since intra-company recycling is one of the firm's waste management choices, the firm would be expected to weigh the direct costs of various waste management options when determining whether to engage in intra-company recycling.

The main difference between intra-company recycling and the other waste management choices of the firm is that recycling is undertaken by the firm itself, while other waste management options involve the firm shipping the waste to another entity. This difference influences the composition of the direct costs faced by the firm for waste management. Waste management options undertaken by another entity would involve primarily operating costs, such as transportation of waste and payment of disposal fees or possible acceptance fees to commercial recyclers. By comparison, recycling would likely entail significant capital costs, but then might involve lower operating costs than offsite waste management options. The large capital requirements could serve as a barrier against firms engaging in intra-company recycling (Technology Resource Inc., 1988).

Transportation costs could influence waste management choices at industrial firms, and they may vary greatly depending on the location of the firm relative to landfills and commercial recyclers that could potentially accept the industrial firm's waste (Alberini and Bartholomew, 1999). For firms that had convenient disposal or offsite recycling choices located nearby, transportation costs would likely not be a significant factor in determining the firm's waste management choices. On the other hand, industrial firms far from disposal sites or commercial facilities might face substantial transportation costs that could serve as an incentive for them to set up an onsite recycling operation.

As with commercial firms, economies of scale would also be expected to play an important role in the decisions of industrial intra-company recyclers. Economies of scale can influence waste management decision since larger firms that produce more hazardous waste may face lower per-unit costs for recycling than smaller firms (Technical Resource, Inc., 1988; McLaren and Yu, 1997). We would therefore expect to find a higher level of intra-company recycling at larger firms, with smaller firms substituting away from recycling to other waste management options. Other things equal, an increase in firm size or the amount of hazardous material recycled would lower the per-unit cost of recycling hazardous materials and thus would be expected to increase the amount of recycling. Evidence that a firm's size influences its waste management choices is seen in the steel industry, where smaller steel mills may not be generating enough spent pickle liquor to make it cost-efficient for them to recycle it onsite, given that regenerating plants

require high start-up costs and are designed to run continuously. (For more information, see Appendix II.)

Another cost factor that might influence the waste management decisions of industrial firms is the cost associated with producing heterogeneous goods (Harrington et al. 1999; Bailey et al. 2002). Since the primary business of these firms does not involve producing goods from recycled hazardous material (rather, hazardous material is generated as a byproduct), recycling hazardous waste can be viewed as a secondary line of business. In other words, beyond the direct and indirect costs associated with recycling hazardous waste onsite, the industrial firm faces additional costs in terms of diverting their scarce resources (e.g., labor force or managerial attention) from their primary operation. This diversion of resources involves opportunity costs, since those resources could be devoted to the production of the firm's primary product instead of to the recycling operation (Technical Resource, Inc., 1988). This diversion of resources would raise the firm's cost for the option of recycling onsite, and we would expect that firms would consider this cost when deciding whether or not to engage in intra-company recycling. In the steel industry, for example, finished steel products and regenerated pickle liquor are not distributed to the same consumers, so a steel company with a regeneration plant would likely need to develop two supply channels. This need to divert resources from its main operation (i.e., making steel) may discourage a steel company from operating a regeneration plant onsite. A steel company may find it more profitable to concentrate on making steel, while outsourcing K062-regeneration. (See Appendix II for more information.)

2.2.3. Indirect Costs of Intra-company Recycling

As with commercial recyclers, industrial intra-company recyclers also face indirect costs that influence their recycling decisions. In terms of how these indirect costs influence recycling by these firms, it is important to understand how indirect costs influence waste management choices more generally. Similarly to commercial recyclers, the largest area of indirect costs are liability issues. A complicating factor of liability costs is that, unlike other categories of costs associated with waste management, liability costs are long-term and uncertain (Alberini and Frost, 1999). It is thought that industrial firms will factor potential liability costs into their waste management choices, and invest in proper waste management up to the point where they reduce their potential liability costs to a level they find acceptable. The greater the net worth of the firm, the more it potentially has to lose from liabilities associated with improper handling of its waste (Alberini and Frost, 1999). The firm thus has more incentive to engage in careful waste management and to protect itself against potential liabilities.

Secondary liability issues are another area in which liability influences industrial firms. As discussed above, an industrial firm could be held accountable for mishandling of its waste by another entity such as a commercial recycler (Rosenbaum, 1990). Industrial firms that have a high level of concern about potential liabilities would likely consider these secondary liability issues in their waste management choices. These secondary liability issues could increase the attractive of onsite waste management choices such as

intra-company recycling. If the industrial firm engages in onsite waste management, it reduces its exposure to secondary liabilities associated with other entities handling its hazardous waste.

Additional indirect costs to be considered for the firm's waste management options include transaction costs of dealing with other economic agents, such as disposal site or commercial facilities. Transaction costs would raise the costs to the firm of waste management involving another entity, and could serve as an incentive to engage in recycling. By recycling, industrial firms would reduce the transaction costs associated with waste management, but they could incur additional transaction costs if they sold their recycled product to outside entities instead of reusing it in their own production process.

2.2.4. Model of Intra-Company Recycling

In this section, a formal model is developed for industrial intra-company recycling. A representative industrial firm is in the business of producing good Q_p, and a byproduct of this production process is hazardous waste material Q_{hw}. It has three options for managing Q_{hw}, each with a different associated cost:

1) Dispose of the hazardous waste in a landfill and pay disposal fee (D), which includes the direct costs of management as well as indirect (regulatory, liability, etc.) costs.

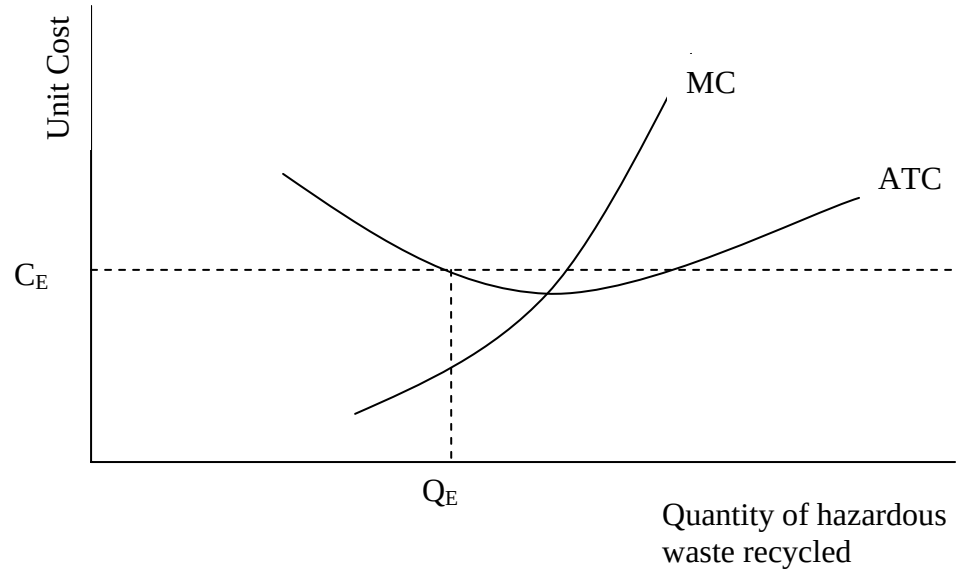
2) Pay a fee (R) to, or accept a fee from, commercial recyclers to recycle $Q_{hw.}$

3) Recycle Q_{hw} itself, which can be done at some cost (C). The recycled product (Q_r) can then either be used as an input in the production of Q_p or be sold at the prevailing market price P_r. The price the firm receive for selling the recycled product offsets its total recycling costs ($TC = (C*Q_{hw})–(P_r*Q_r)$).

Under the assumption that the firm's waste management decisions are driven by profit-maximizing motives, the firm will choose the option that minimizes its waste management costs, or the minimum of D, R and $C–P_r$. If there is no existing stable market for the recycled good, P_r can be assumed to be zero and the firm will choose among D, R or C. Even with a zero value for the recycled good, the firm may still choose to recycle if C is the least costly option due to the decreased indirect costs (i.e. regulatory and liability costs) involved in disposing of hazardous waste (D). In the long run, it is assumed that the industrial firm can switch freely between these waste management options since if it did not possess the infrastructure needed to recycle onsite, it could invest in new capital or equipment to do so. In the short run, it is assumed that the industrial firm could choose between the different offsite waste management options (disposal or sending to commercial recycler) and would base this decision primarily on the relative costs of the different offsite disposal options.

In examining the firm's decision of whether or not to recycle hazardous waste itself, Exhibit 2-4 shows per-unit costs for two different waste management options by the firm for its hazardous waste. First, the per-unit cost of external waste management methods (such as shipping waste to a landfill or a commercial recycler) is shown by the line C_E. To simplify the graph, these two external waste management options are shown by this one line since, for reasons discussed above, an industrial firm's cost for each of these options would be similar. The cost an industrial firm faces for external waste management is constant for the firm and determined by the market. The set of cost curves (ATC and MC) represent the firm's cost for managing its hazardous waste internally through intra-company recycling. Two different factors work to offset the firm's recycling costs. First the recycled product would either be sold, resulting in revenues for the firm, or used as an input in the firm's production, resulting in reduced input costs. Second, engaging in intra-company recycling would enable the firm to avoid costs associated with disposal or shipping waste to a commercial recycler. For the situation in Exhibit 2-4, the firm would choose to engage external waste management for low quantities of waste (less than Q_E) since that is the least cost option. For quantities of waste above Q_E, the firm would choose to engage in intra-company recycling since the per-unit costs are lower than the costs of the waste management options involving disposal or shipping to commercial recyclers. The exhibit demonstrates the importance of economies of scale for recycling, since the firm needs to produce more than a certain quantity of waste in order for industrial intra-company recycling to be the most cost-effective choice.

Exhibit 2-4: Model of Industrial Intra-company Recyclers



ATC – Average total cost of recycling waste internally
MC – Marginal cost of recycling waste internally
C_E – Per-unit cost of external waste management
Q_E – Quantity of hazardous waste recycled

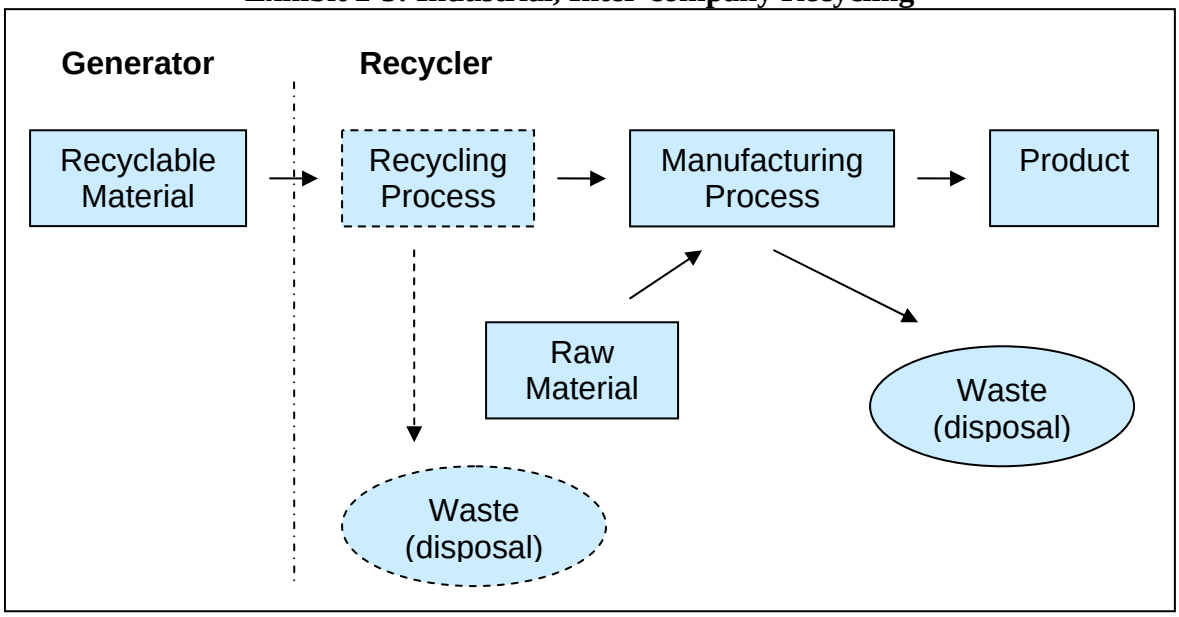
2.3. Industrial Inter-company Recycling

The second kind of recycling at industrial firms is known as industrial inter-company recycling. In this model, firms use recycled materials, either produced by themselves or outside firms, as an input to their production process. The recycled materials are used as a cost-saving substitute for virgin materials. A diagram of the recycling process as practiced in industrial inter-company recycling is shown in Exhibit 2-5. The industrial firm engages in a manufacturing process, and faces a choice of inputs to that process. The firm can either use virgin or recycled materials for production. To use recycled materials, the firm would first accept recyclable hazardous waste from another firm.[7] The firm would then either use this material directly or put it through a recycling process to produce the needed inputs for its primary production process. The outputs of this recycling process are recycled materials (for use in production), and waste (which must be disposed). The recycled materials would then be used in a manufacturing process,

[7] Commodity brokers can be involved in transactions of hazardous waste. Brokers may be involved only to the extent that they facilitate the transaction, but do not handle hazardous waste themselves in any manner. In some cases, however, brokers do handle hazardous waste (for example, store it until they find a buyer). In those cases, if hazardous wastes are stored longer than ten days, brokers do need to have a RCRA permits.

which generates the firm's product. This manufacturing process results in additional waste for disposal.

Exhibit 2-5: Industrial, Inter-company Recycling



2.3.1. Revenue Structure for Industrial Inter-company Recyclers

As discussed above, the primary revenue source for industrial firms is their product. Inter-company recycling enters into the firm's decision-making process in the determination of the mix of inputs to use for its manufacturing process. Inter-company recycling is thus not something that would generate revenue for the firm, rather it is something that would influence its production costs. The choice of whether or not to engage in inter-company recycling is best viewed as how it would influence the potential costs faced by the firm for its manufacturing process.

2.3.2. Direct Costs for Industrial Inter-company Recycling

The direct costs for industrial inter-company recycling are primarily capital and operating costs as defined above for the previous two models. Industrial firms choose among various production inputs based on their relative costs, assuming profit-maximizing motives by the firm. If the firm needed to set up its own recycling operation (as opposed to obtaining recycled material from another firm) inter-company recycling might involve significant capital costs for the firm. In relation to operating costs, using virgin materials would generally be more expensive than using recycled materials, resulting in lower total operating costs for using recycled materials. The decision of an industrial firm of whether to engage in inter-company recycling involves this tradeoff between capital and operating costs and the differences in cost between using virgin and recycled materials. If the cost savings from using recycled rather than virgin materials are small, the firm might not find it cost-effective to invest in equipment needed to engage in inter-company

recycling. On the other hand, a large divergence between the prices of virgin and recycled inputs would increase the attractiveness of inter-company recycling to the firm.

As discussed with the previous two models, there are additional factors that influence the direct costs of inter-company recycling. One of these factors is transportation costs. The industrial firm would incur transportation costs in acquiring its production inputs, and this could affect its choice among different mixes of inputs. If there were a significant difference in the transportation costs the firm would incur between obtaining virgin materials and recyclable material for use in production, this could be a factor that plays into the firm's input choices. Firms engaging in inter-company recycling would also face increased transportation costs for disposal of the waste from the recycling process. Transportation costs could serve as a disincentive for engaging in inter-company recycling if they were sufficiently high to reduce the cost savings involved in inter-company recycling.

The size of a firm is an important factor in the cost-effectiveness of engaging in inter-company recycling. We expect that economies of scale would be important for firms in their production input decisions. For example, given the significant capital expenditures involved in inter-company recycling, it is likely that these expenditures are more cost-effective for a larger firm that is using a greater quantity of recycled materials as inputs than for a smaller firm. As with industrial intra-company recycling, a general expectation is that the amount of inter-company recycling would increase with the size of the firm.

Lastly, as with intra-company recyclers, the cost of producing heterogeneous goods might also be a factor that affects the industrial firm's choice of production inputs (Harrington et al. 1999; Bailey et al. 2002). Similarly to industrial firms engaging in intra-company recycling, inter-company recycling usually involves adding a secondary production process to the firm's operation. The cost savings that an industrial firm might achieve from engaging in inter-company recycling would need to be balanced by the costs that would be incurred from the diversion of resources and management attention away from the firm's primary production to this secondary line of production. In making profit-maximizing decisions regarding the choice of production inputs, the firm would be expected to weigh these costs, to the extent that they could be known, against the savings that would be realized by recycling onsite to provide production inputs.

2.3.3. Indirect Costs of Inter-company Recycling

Similarly to the other types of recycling, there are also indirect costs associated with industrial inter-company recycling. To the extent that firms could know and predict these costs, they would be factored into the firm's decisions regarding inputs to production. As with the other two models of recycling, the main indirect cost of inter-company recycling involves liability issues. The industrial firm would face potential liabilities from accepting hazardous waste, storing it, and recycling it onsite. Additional liabilities could result from the management of the waste from the recycling process. As discussed above, there is a positive correlation between the net worth of a firm and the amount it stands to lose due to liability issues. Insurance is one possible means by which the firm

could protect itself against liabilities, but insurance would not be expected to cover acts of negligence. The amount of care an industrial firm would place in its recycling process would likely be positively correlated with the size of the firm, since larger firms face greater potential liabilities from their recycling operations (Alberini and Frost, 1999). These liability issues would raise the cost of recycling, and could discourage firms from engaging in inter-company recycling if they viewed the liability costs as being prohibitively high.

Transaction costs are an additional factor of indirect costs for inter-company recycling. The influence of transaction costs on inter-company recycling could be expected to be less than for the other two recycling models since inter-company firms must already deal with other economic agents to obtain their production inputs. Transaction costs could come into play for inter-company recyclers, however, given that switching to using recyclable materials as inputs instead of virgin materials would involve the transaction costs of dealing with additional firms. Inter-company recyclers might also face transaction costs from dealing with an outside agent for disposing of waste generated during the recycling process. The amount of these transaction costs would likely be related to the degree to which waste from the recycling process can be managed along with the waste from the firm's production process. If the waste from the recycling process involves transacting with a separate firm, these additional transaction costs could prove to be a significant factor in the firm's choice of whether to engage in inter-company recycling.

2.3.4. Model of Industrial Inter-company Recycling

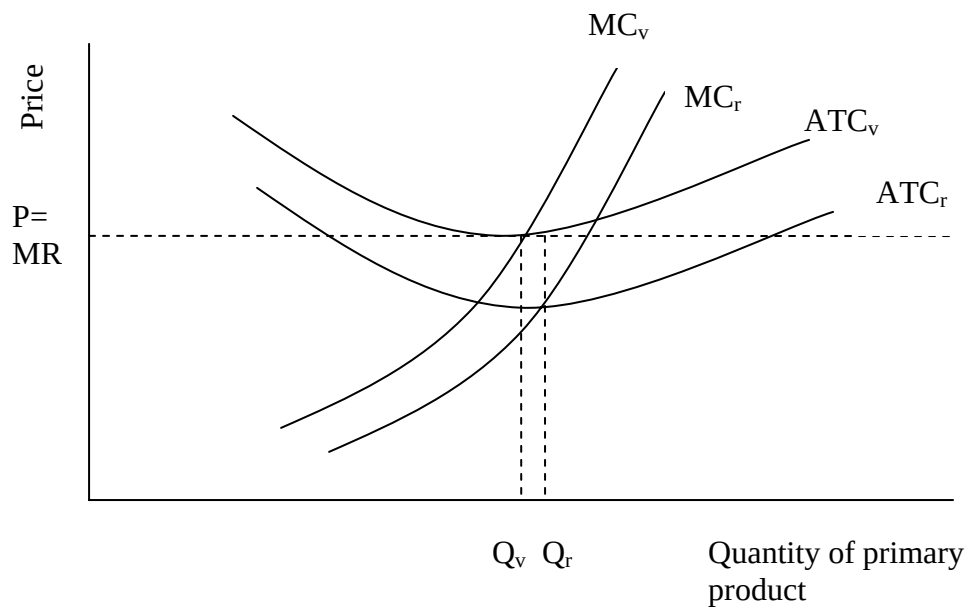
This section presents a formal model of industrial inter-company recycling in relation to the firm's production decisions for its primary manufacturing process. Inter-company recyclers are in the business of producing a primary product Q, which is sold on the market at the prevailing price P. The firm's production costs are modeled below in Exhibit 2-6. The firm faces a variety of decisions in the production of Q, one of which is the mix of inputs used in production. The firm has a choice of either using virgin materials for the production of Q or replacing virgin materials with recycled materials.[8] Depending on the material and the production process, recycled materials could be obtained from a recycler and used directly, or recyclable materials could be obtained from a generator and put through a recycling process by the firm for further use in production. The firm's choice of using virgin or recycled materials as inputs to production will depend on the relative costs of each kind of input. The exhibit below depicts a situation where the cost of using virgin materials is higher than the cost of using recycled materials. The production process using virgin materials is represented by the average total cost curve (ATC_v) and the marginal cost curve (MC_v). When using virgin

[8] It is important to note the simplifying assumptions in the situation presented in this model. The actual input choices of a firm would likely be a mix of both virgin and recycled material, and not exclusively one or the other. For example, it is possible that recycled materials may be lower quality for production, and that some virgin materials would need to be used as production inputs alongside recycled materials. The firm interested in using recycled materials could substitute them for some quantity of virgin materials, but there would still be some virgin materials expected to be used in their production process.

materials as inputs, the firm will produce Q_v units of output, which are sold at the market price P.

For the situation depicted in the exhibit, the firm could reduce its costs by using recycled materials as inputs. These materials would either be obtained from a generator and used directly in production or put through a recycling process by the firm (with waste generated as a byproduct) and then used in production of Q. Since this is a lower-cost option for the firm, using recycled materials would shift its average total cost and marginal cost curves down to ATC_r and MC_r. At these new lower cost curves, the firm would be able to produce a greater quantity of their product, represented by Q_r, which can be sold at the market price P.

Exhibit 2-6: Model of Inter-company Recycling



ATC_r – Average total cost of production using recyclable materials
ATC_v – Average total cost of production using virgin materials
MC_r – Marginal cost of production using recyclable materials
MC_v – Marginal cost of production using virgin materials
MR – Marginal revenue of the firm
P – Market price of primary product
Q_r – Quantity of product when recycled materials are used as inputs
Q_v – Quantity of product when virgin materials are used as inputs

2.4. Market Failures

According to economic principles, the market for recycled materials from hazardous waste would, ideally, result in the production of the socially optimal amount of recycled materials. This amount would be reached according to the intersection of what producers are willing to supply to the market and what consumers are demanding. The suppliers of recycled materials (commercial and industrial firms) adjust their production of recycled materials based on price signals received from the market. Problems arise, however, when markets do not operate properly and fail to provide these appropriate signals to producers and consumers. For recycling, the result is production of an amount of recycled material that differs from what the market would indicate as socially optimal, with either too much or too little recycled materials being produced (van den Berg and Janssen, 2005). There are several different ways in which market failure could enter into the hazardous waste recycling market. This section introduces some of these issues and illustrates how they could result in sub-optimal outcomes.

2.4.1. Imperfect Information

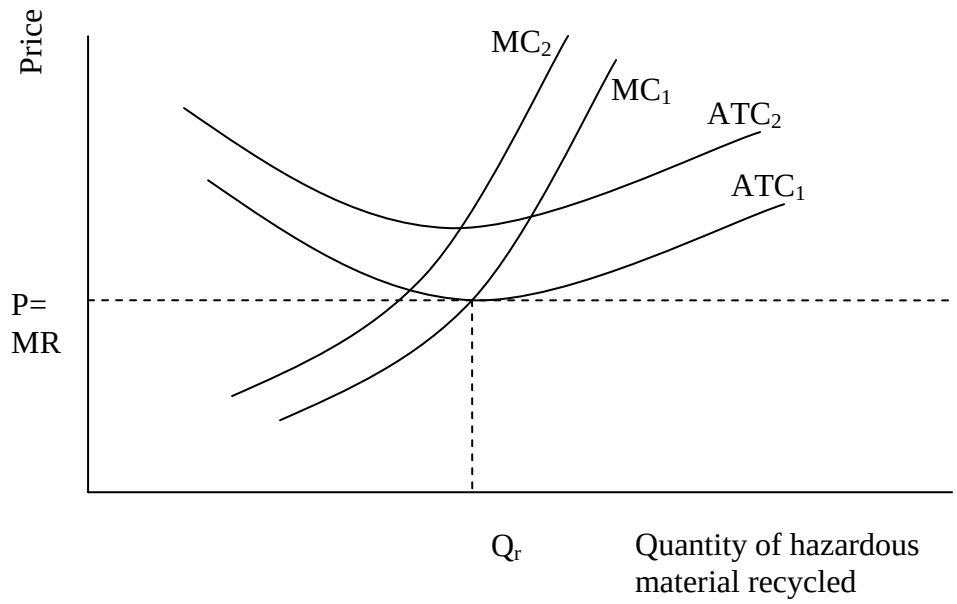
One source of market failure in hazardous waste recycling occurs when firms have imperfect information on either the costs or revenues associated with producing recycled materials from hazardous waste. On the cost side, commercial and industrial recyclers may have imperfect information on to the costs of producing recycled materials. Imperfect information could arise from a variety of factors. One example is that firms that accept waste from an outside source for recycling may be misinformed as to the composition or characteristics of the waste they receive. If, for example, the waste it receives requires more processing than it was expecting, the recycling costs of the firm would be higher (McLaren and Yu, 1997). Costs could also be higher than expected if the firm did not properly educate itself on the processes involved in recycling hazardous waste in a safe and compliant manner before entering into the business. The complex regulatory framework associated with hazardous waste recycling could also play a role in firms having imperfect information on their potential costs for recycling hazardous waste. On the revenue side, commercial and industrial recyclers may have imperfect information on the demand for their products. If the demand for their final product is more elastic (i.e., more price sensitive) than the recyclers have expected, for example due to the availability of substitutes, any attempt to pass the costs onto consumers will result in lower total revenues than they have anticipated.

Imperfect information would influence firms differently in the short and long run. Starting with the case of commercial recyclers, imperfect information would prevent the firm from correctly interpreting the full costs associated with recycling hazardous material in a proper manner. If the commercial recyclers underestimated the costs associated with recycling, they would erroneously enter the market and would have an incentive to produce too much recycled materials even when the market should have given them different signals. This situation is shown in Exhibit 2-7 below. The original market conditions are shown where Q_r units of recycled materials are produced by the commercial recycler by operating on their perceived cost curves (ATC_1 and MC_1), which would fall below the actual costs of producing the recycled materials in a responsible manner (ATC_2 and MC_2). If, for reasons such as increasing regulation, the commercial recycler were forced to operate on the cost curves that reflect the true costs of recycling in a responsible manner (ATC_2 and MC_2), they would make different production decisions in the short and long run than if they were operating on their perceived cost curves (ATC_1 and MC_1). In relation to long–run decisions, the firm would not have entered the market if it had acted on the basis of the true cost curves (ATC_2 and MC_2), since there is no point at which their average total costs (ATC) are below their marginal revenue for producing recycled materials ($ATC_2 > MR = P$).

Since the firm cannot leave the industry in the short run, operating at the higher set of cost curves will force the firm to either shut down or operate at a loss. As discussed above, the choice among these activities would be determined by the firm's ability to cover its variable costs in the short run. If producing recycled materials still generates revenue above the firm's average variable costs, it will continue to operate in the short run to reduce losses, and then close down in the long run. The firm may have an

incentive in the short run to reduce costs in whatever way it can to lower its cost curves and thus its financial losses. One strategy for reducing these losses could be to continue to accept hazardous materials and the revenue stream associated with that activity, while cutting costs by engaging in improper waste management. The incentives for these activities would be particularly high if the fee the firm receives for accepting hazardous waste is high compared to the price it receives for the sale of its output. The firm may view mismanagement of waste as attractive if it believes it can avoid the true costs involved with properly handling or disposing of the materials.

Exhibit 2-7: Imperfect Information for Commercial Recyclers



ATC_1 – Firm's perceived average total cost of producing recycled materials
ATC_2 – True average total cost of producing recycled materials
MC_1 – Firm's perceived marginal cost of producing recycled materials
MC_2 – True marginal cost of producing recycled materials
Q_r – Quantity of recycled material produced with firm's perceived costs

It is important to note that imperfect information not only influences the firms that are in the hazardous waste recycling market, but it also influences which firms choose to enter the market in the first place. Misperceptions about the costs, or the potential damages, of hazardous waste recycling would create a bias as to the type of firms that enter the market. This would result in more firms entering the market that are misinformed about the true costs involved with hazardous waste recycling. This phenomenon, known as adverse selection, is a commonly identified source of market failure (Boardman et al. 1996).

In addition to firms that enter the market with erroneous information about the costs of recycling, there could also be a segment of the market characterized by the firms that entered intending to ensure their costs are low by ignoring adequate standards of care and potential liability costs. The size of the fee for accepting waste in relation to the revenue for selling recycled output would likely be an important factor in prevalence of this activity. If the acceptance fee is the dominant revenue source for commercial recyclers, they could have more incentive to focus on accepting hazardous waste and less incentive to focus on actually producing recycled output in a compliant manner. To the extent that these firms ignore liability costs and safe production practices, they would be able to set their acceptance fees lower than firms operating in a compliant manner, resulting in more hazardous waste flowing to these firms and more potential mismanagement of wastes.

Imperfect information can also influence industrial firms in their decisions to recycle hazardous waste onsite. A similar situation as shown in Exhibit 2-7 above could occur with industrial recyclers (either intra-company or inter-company) if their perceived costs for recycling hazardous waste were lower than the true costs. The industrial firms, however, face a different situation than commercial firms due to being able to substitute away from producing recycled materials onsite if the costs become prohibitively high for them to do so. The industrial firms may thus have less incentive to mismanage their waste, and may also be less inclined to do so due to the liability issues discussed above. Industrial recyclers also do not have incentives to store or stockpile their waste since they do not receive any revenue from accepting waste. It would thus be expected that imperfect information on the costs of recycling hazardous waste would encourage industrial intra-company recyclers to substitute away from onsite recycling to other waste management options, and would encourage industrial inter-company recyclers to substitute away from onsite recycling to increased use of virgin materials in production.

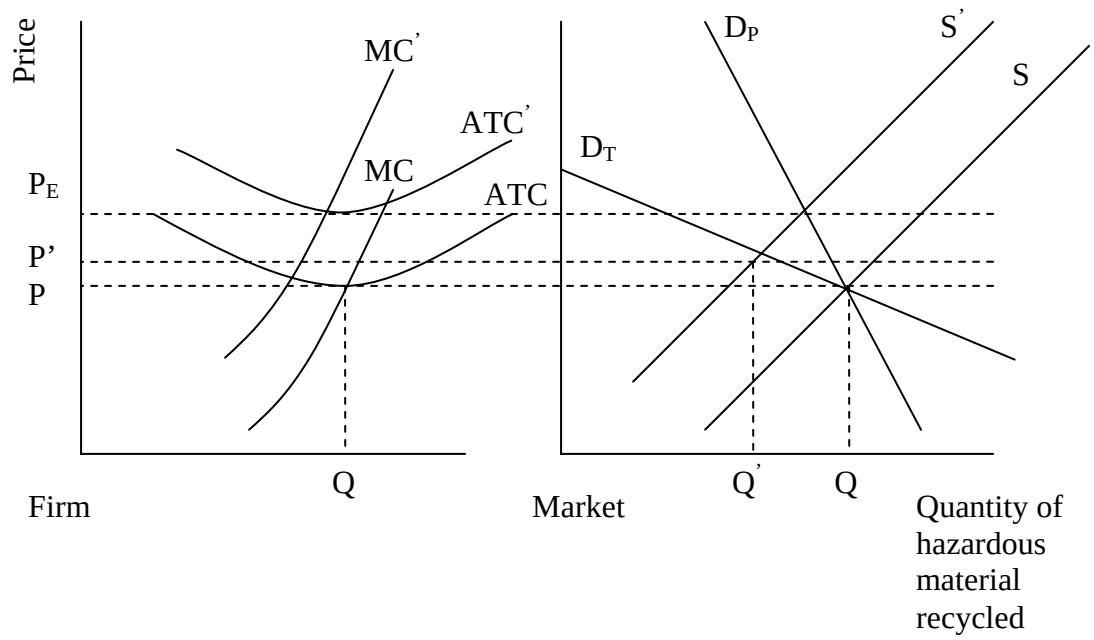
Even if recyclers, either commercial or industrial, were well informed about the true costs of running the recycling business before entering the market, they may find themselves in the situations depicted above if they had imperfect information about the price elasticity of demand for their final product, and thus their ability to cope with increases in production costs. Price elasticity of demand indicates how responsive demand for a product is to a change in its own price. The more responsive demand is (i.e., more elastic), the greater will be a change in demand in response to a given change in the price. Goods with close substitutes and low transaction costs associated with switching between substitutes have a more elastic demand.[9] When faced with an increase in production costs, recyclers may decide to pass some or all the incremental costs onto their customers. The effect that this action will have on their total revenues will depend on the price elasticity of demand for their product. Exhibit 2-8 illustrates this point for commercial recyclers. The original market conditions are depicted where the commercial recycler produces Q units of recycled goods at the market price of P. If the commercial recycler perceives the market demand curve to be relatively inelastic (D_P), he will expect to pass a large share of any increase in his production costs onto his consumers and still operate

[9] Other factors that influence the price elasticity of demand are the degree of necessity for consuming the good, the time period allowed for the price to adjust, and consumption patterns (e.g., peak demand vs. off-peak demand).

profitably. The increase in the production costs are illustrated by the upward shift in the commercial recycler's cost curves (MC' and ATC') and by the upward shift in the market supply curve (S'). The true demand (D_T), however, is fairly elastic. The increase in the price of recycled goods will lead to a larger decrease in the quantity demanded than the commercial recycler has anticipated. With the market price of P', the commercial recycler will continue to operation in the short run only if he can cover his variable costs, otherwise he will shut down. In the long run, we would expect the commercial recycler to exit the market (since P'< ATC').

If faced with increasing operating costs and elastic demand for their final product, profit-maximizing industrial recyclers would shift to a different waste management option. Industrial intra-company recyclers may substitute away from recycling to other waste management options, while industrial inter-company recyclers may substitute away from recycling to increased use of virgin materials in the production (assuming that the forces driving the costs of recycling hazardous wastes have smaller or no effect on the use of virgin materials).

Exhibit 2-8: Uncertainty in the Demand for Recycled Products



ATC – Firm's average total cost of producing recycled materials
ATC' – Firm's average total cost of producing recycled materials after the increase in the production costs
MC – Firm's marginal cost of producing recycled materials
MC' – Firm's marginal cost of producing recycled materials after the increase in the production costs
D_P – Perceived market demand curve for recycled materials (relatively inelastic)
D_T – True market demand curve for recycled materials (relatively elastic)
S – Market supply curve
S' – Market supply curve after the increase in the production costs
P – Market price of recycled material
P' – Market price of recycled material after the increase in the production costs
P_E – Expected market price of recycled material after the increase in the production costs
Q – Quantity of recycled material produced
Q' – Quantity of recycled material produced after the increase in the production costs

2.4.2. Externalities

Externalities are common sources of market failure, which occur when the welfare of one agent (such as a firm or household) is affected by some other agent without permission or compensation. Externalities can either be positive, where the action adds to the agent's welfare, or negative, where the action detracts from it. Negative externalities often exist for pollution and other environmentally degrading activities undertaken by individuals and firms, and they occur when the costs of the environmentally degrading action to society is not reflected in the private costs faced by the agents undertaking the activity (Kolstad, 2000).

The potential influence of negative externalities on the hazardous waste recycling market is illustrated in Exhibit 2-9 below. The graph on the left represents a typical firm (either industrial or commercial), and the graph on the right shows the market supply and demand curves for recycled materials.[10] The market supply curve represents the summation of the supply curves of all the individual firms that supply recycled materials. As discussed above, the supply curves of these firms are determined by their marginal costs for producing various units of recycled materials. Marginal costs are based on the direct and indirect costs of the firm. The production costs of a firm that considers only its private costs are shown as the lower set of cost curves, ATC_P and MC_P. Alternately, the production costs of a firm that considers social as well as private costs are shown as the higher set of cost curves on the graph, ATC_S and MC_S. Two different market supply curves result from the choices of firms. The lower market supply curve, denoted as S_P, represents the supply of hazardous materials as determined by the private costs of the individual firms. The higher market supply curve, denoted as S_S, represents the market supply when firms also consider the social costs of their business. As discussed earlier, the firm is considered to be a price taker, and equates its marginal cost with its marginal revenue, or the price of its output. The prevailing market price for recycled materials, and thus the resulting quantity produced, is determined from the intersection of the market demand curve (D_M) and the market supply curves.

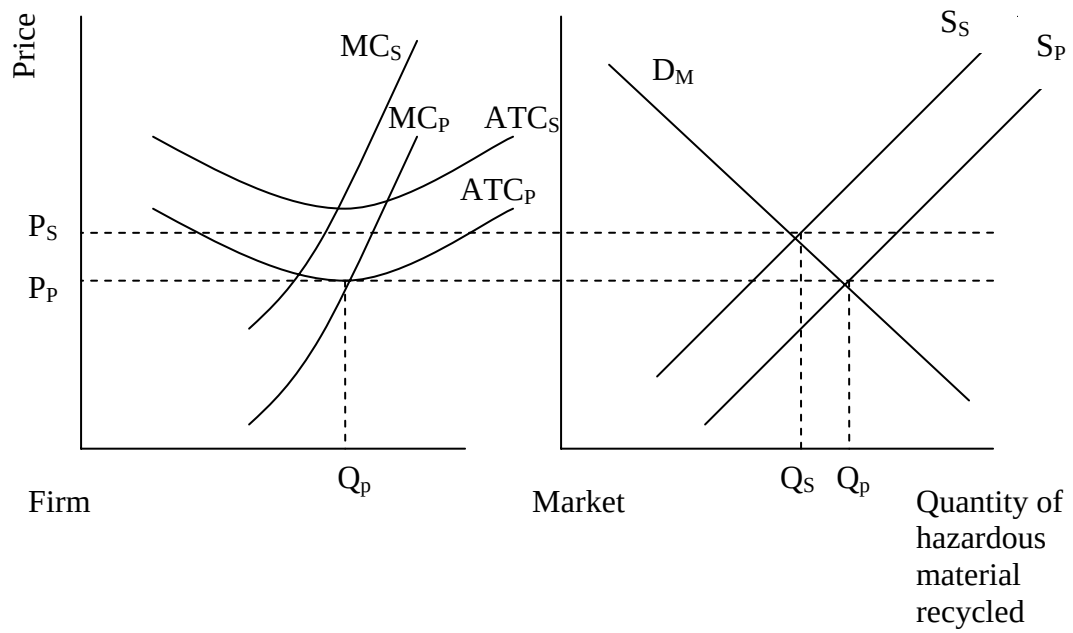
A negative externality occurs in the hazardous waste recycling market when the social costs associated with producing the recycled materials (e.g. environmental damage, human health risks) are not being accounted for by the firms in their production decisions (Gottinger, 1991a). Since firms are operating in a competitive environment, considering only their private costs is often the only rational profit-maximizing response for firms. Any move by a firm that increases its costs relative to the competition will put them at a disadvantage, so firms cannot be expected to consider social costs if they are not forced to do so. For the firms, considering only their private costs means operating on the lower set of cost curves on the graph to the left. The result of firms not accounting for the social costs when determining the level of output is that a larger amount of recycled material is produced than is socially optimal in terms of the damage resulting from recycling activities. If firms consider only their private costs, then Q_P units of recycled materials are produced at a market price of P_P with external costs of the firm being shifted to society.

If firms instead accounted for the social costs of their production decisions, the result would be a reduction in the amount of recycled materials that are supplied by firms, and also a higher price for them (since they would be produced in a more compliant manner). This new price and quantity of recycled materials would be set where the new social cost supply curve (S_S) intersects the market demand curve. The result would be that Q_S units of recycled hazardous materials would be supplied at a price of P_S. Exhibit 2-9 illustrates

[10] The graph of the firm in Exhibit 2-9 could represent either a commercial or industrial facility. For the sake of simplifying the graph, the marginal revenue for the firm is shown as equal to the price of the recycled materials, as opposed to the price plus the acceptance fee as it would be for a commercial firm. This simplification does not affect the relevant analytical points to be gained from the graph.

the situation where the firm will exit the market at the new price P_S since the market price will not cover its recycling costs (P_S<ATC_S). The difference between the two price amounts (P_S – P_P) represents the per-unit amount of the negative externality that is imposed on society by recyclers of hazardous waste failing to account for the external social costs of their activities when making their production decisions.

Exhibit 2-9: Negative Externalities in the Hazardous Waste Recycling Market



ATC_P – Firm's perceived average total cost of producing recycled materials
ATC_S – True (social) average total cost of producing recycled materials
MC_P – Firm's perceived marginal cost of producing recycled materials
MC_S – True (social) marginal cost of producing recycled materials
D_M – Market demand curve for recycled materials
S_P – Market supply curve as determined by the firm's private costs only
S_S – Market supply curve as determined by the true (social) costs
P_P – Price of recycled material as determined by private supply curve
P_S – Price of recycled material as determined by true (social) supply curve
Q_P – Quantity of recycled material produced with private supply curve
Q_S – Quantity of recycled material produced with true (social) supply curve

3. Discussion and Conclusion

Increased understanding of the economic forces that influence hazardous waste recycling can contribute to our knowledge of how firms will factor recycling into their production and waste management decisions. These issues were explored through economic models of hazardous waste recycling as practiced by commercial, industrial intra-company, and industrial inter-company recyclers. This paper also suggested key characteristics that were hypothesized to influence hazardous waste recycling behavior. We divided these characteristics into those that are potentially observable from data on a firm or the market for recycled products, and those that are by nature unobservable. In conclusion, we revisit these characteristics and summarize what has been learned about these characteristics through the economic modeling of different kinds of hazardous waste recycling.

3.1. Discussion of Observable Firm and Market Characteristics

In this section, we discuss how characteristics potentially observable through firm and market data could influence firm recycling behavior. These characteristics are the value of the recycled product, the stability of prices and the net worth of the firm.

- Value of the recycled product: The value of the recycled product is an important determinant of a firm's revenue structure, and is hypothesized to influence hazardous waste recycling behavior. For all three models of hazardous waste recycling, we would expect a recycling market with a high value product to have a higher likelihood of optimal recycling outcomes than a recycling market with a low-value product. With a high value recycled product, firms are likely to exercise greater care in handling recyclable hazardous waste, since spillage or leakage of waste represents a loss of input material and thus results in lower revenues from selling the final product. In cases where recycling firms receive an acceptance fee for taking in recyclable hazardous waste, such as the case with some commercial recyclers, the acceptance fee becomes a much more prevalent factor in the firm's revenue structure when the recycled product has a low value. In such cases, firms may have an incentive to accept a greater quantity of recyclable waste than they could properly manage. For intra-industrial firms, the value of the product would serve as a strong incentive for proper management of the recycled material. A similar argument holds for inter-company recyclers that are using a recycled product or hazardous waste generated from an outside source as an input to their production. If the recycled product has a high value, we would expect that the industrial inter-company recyclers would exercise greater care in their recycling process and the handling of the recycled product.

- Stability of prices: Stability of prices in both the inputs and outputs of hazardous waste recycling is another characteristic that is hypothesized to influence hazardous waste recycling as practiced by the three different models. When prices are stable, firms can more easily adjust their production in response to the price signals they receive from the market. They are thus less subject to sudden

upsets to their revenues or costs which could force them to operate at a short or long-term loss. For firms that are recycling to produce a marketable output (i.e., commercial and industrial intra-company firms), stable prices for the recycled good help the firm to know that it can expect a return from recycling that justifies it entering the market and can recover the investment costs. Commercial firms, for example, use tolling agreements to protect themselves from price instability. For industrial inter-company firms (and in some cases intra-company firms), stable prices help the firm to judge whether the expense of setting up a recycling operation to generate a product for use as a substitute input in the production of their final output is justified.

- Net worth of the firm: Liability issues are the major contributor to indirect costs of commercial and industrial firms. Liability issues affect firms differently due to many factors. One of these factors, the net worth of the firm, is hypothesized to be an important indicator of whether hazardous waste recycling would be expected to produce optimal or sub-optimal outcomes. For commercial and both kinds of industrial firms, liability issues would be expected to have greater prominence for firms that have a higher net worth and have an established history in the industry. If a firm has the potential to take a large loss due to liability issues, it would be expected to protect itself against this risk through careful and compliant practices and possibly through insuring against liability risks. Apart from protection against liability risks, commercial firms may operate in a careful manner in order to attract business. Due to secondary liability issues, industrial firms may examine the liability history of commercial firms and prefer to send waste to those that have a good record of complying with the environmental and safety regulations. Firms that have a higher net worth have more to lose from liability issues and thus have a greater incentive to invest in careful waste management practices. These firms thus would be expected to be more likely to practice recycling in an environmentally safe manner and also to insure against possible liability risks. While many factors contribute to optimal hazardous waste recycling outcomes, having a high net worth is one potential indicator of this result for firms.

3.2. Empirical Evidence for Observable Firm and Market Characteristics

In order to provide further information and support of the ideas expressed in this theoretical analysis, we conducted an in-depth empirical analysis of five selected, commonly recycled hazardous wastes. The original goal of the empirical analysis was to test the various hypotheses that are presented in the theoretical analysis. However, limitations on the availability and quality of data prevented us from conducting these empirical tests. The empirical analysis of the five hazardous wastes was instead used to provide information on the characteristics of markets for these materials that increase our understanding of how market forces shape behavior for the different recycling models laid out in this paper. In this section, we use information on the characteristics of these markets to show how it supports or refutes the conclusions drawn above on the

potentially observable characteristics of firms. Further detail on the empirical analysis of the five hazardous wastes is provided in Appendix II.

The analysis in this section was done using information on recycling markets for five selected hazardous waste materials, four of which are regulated by EPA as hazardous waste.[11] These materials were selected by EPA to *illustrate* market conditions for different hazardous waste recycling models. Although all of these materials have significant rates of recycling, they are neither representative of all hazardous wastes nor should the recyclers of these wastes be considered representative of the recycling models with which they are associated. Information on environmental damage cases associated with recycling activities involving the selected hazardous waste materials was collected as part of a separate EPA report titled "An Assessment of Environmental Problems Associated with Recycling of Hazardous Secondary Materials" (EPA, 2006).[12]

In Exhibit 3-1 below, the five hazardous wastes are characterized by recycling model. Three of the materials are characterized by a commercial recycling model, and two each have characteristics of the two different industrial recycling models. Since spent pickle liquor occurs both at commercial and industrial firms, this material is listed under two different recycling models. We then use information from the empirical analysis of the five hazardous waste materials to provide further evidence on the characteristics that we hypothesize have an influence on hazardous waste recycling behavior.

Exhibit 3-1: Type of Recycling for Five Selected Hazardous Wastes

Type of Recycler	Material
Commercial recycler	Spent Pickle Liquor Spent Solvents Used Empty Drums
Industrial intra-company recycler	Spent Pickle Liquor
Industrial inter-company recycler	Used Lead-Acid Batteries Brass Dust

3.2.1. Value of the Recycled Product

The value of the recycled product is hypothesized to influence hazardous waste recycling behavior, with a high-value product being one potential indicator of a recycling market which produces optimal outcomes. In contrast, a low-value product is a characteristic that could possibly increase the likelihood of sham recycling, where firms engage in recycling primarily to receive the acceptance fees for waste and do not have a genuine interest in recycling the waste. Characteristics of the recycling markets for the five selected hazardous waste materials are presented below in Exhibit 3-2, including a proxy measure for the acceptance fee for the waste and the market values for the virgin and/or recycled product. A comparison of the proxy acceptance fee and the value of the product

[11] "RCRA empty" drums are not regulated by EPA as hazardous waste.

[12] Conducted as part of EPA's effort to revise the current "definition of solid waste" under RCRA, the study's goal was to identify and characterize as many cases of environmental damage as possible that have attributed to some type of hazardous material recycling activity and have occurred after 1982.

provides an indication of markets for which the value of the product could be low as compared to the acceptance fee a recycler would receive for accepting waste. In the used lead-acid battery and brass dust recycling markets, the value of the final recycled product is likely significantly higher than the acceptance fees. Thus, the recycled products in these markets could be considered high value, and the acceptance fees for waste would not be a dominant revenue source for the recyclers in these markets.[13]

For spent solvents, however, comparison of the proxy acceptance fee and the product value suggests that spent solvents could possibly be considered a low-value product, with recyclers generating their primary revenue from the acceptance fees. While this difference in acceptance fees and product value could be an indicator of sub-optimal recycling outcomes from solvents, other empirical evidence refutes the notion that recycled solvents are a low-value product. One way to determine if a product has value is if it displaces another valuable product. Based on communications with solvent recyclers, there is a legitimate market for recycled solvents (such as auto repair shops), which is an indication of the value of the product, given that recycled solvents are displacing virgin solvents for some uses. Additionally, there could be other reasons why a comparison of the acceptance fee and the product value would not be an accurate representation of a recycled product having a high or low value. If, for example, the solvent recycling process had high costs and several drums of spent solvent were needed to produce one drum of regenerated solvent, the recycler would need to charge a high acceptance fee just to cover its costs. The divergence between the acceptance fee and the value of the recycled product is then just an indicator of high recycling costs and not of a low-value recycled product. Additionally, it should be noted that the proxy acceptance fee shown for solvents may overestimate the real acceptance rate due to the fact that spent solvents have an alternative use to recycling (use as substitute fuels). In times of high oil prices, spent solvents which can be used as substitute fuels would likely have a significantly lower acceptance fee than the one presented in the exhibit, and recyclers may even be willing to pay to accept them.

[13] We use landfill disposal fees as a proxy for acceptance fees.

Exhibit 3-2: Product Value and Acceptance Fees

Material	Used Lead-Acid Batteries	Brass Dust	Spent Pickle Liquor	Spent Solvents	Used Empty Drums
Proxy Acceptance Fee (2002)[1]	$160/ton	$160/ton	$114/drum	$114/drum	NA
Recycled Product	Lead	Zinc	Pickle Liquor	Regenerated Solvents	Reconditioned Drums
Dominant Consumers	Battery Manufacturers	Zinc Mills	Steel Mills	Auto-repair shops, dry cleaners	Manufacturers of low to mid value goods
Product Value (2002)	$953/ton[2]	$845/ton[3]	NA	$35/drum[4]	$80[5]

Note: All values are in constant dollars. NA – information not available.
1) Based on the Environmental Technology Council survey data. The proxy acceptance fee is a landfill disposal fee.
2) Market price for lead from the US Geological Survey.
3) Market price for zinc from the US Geological Survey.
4) Estimated price for regenerated solvents, calculated as the weighted average of estimated prices for trichloroethylene, methyl ethyl ketone and perchloroethylene. The weighted price of virgin solvents is $54/drum.
5) Estimated price for a 55-gallon steel drum based on industry communication.

3.2.2. Stability of Prices

The stability of prices is hypothesized to influence recycling behavior, with stable prices for recycled products being one possible indicator of markets that produce optimal recycling outcomes. With volatile prices, recyclers may face times of reduced profits, or even times where they must operate at a loss. As discussed above, this could serve as an incentive for various kinds of waste mismanagement designed to help firms cut recycling costs. Various factors contribute to price volatility. We would expect that materials predominantly traded on the global market (such as metals) would have higher volatility as a result of changes in exchange rates, trade policies and regulations, and country specific economic conditions.

The 2006 EPA study shows that out of the damage cases found involving recyclers of solvents, batteries and drums, the most common cause of damage was mismanagement of recyclables and/or residuals. We have found evidence that volatile prices may have provided an incentive to recyclers of lead-acid batteries and some solvents to engage in waste mismanagement.

We used historical price information (where available) and producer price indices[14] for selected products to construct volatility indices. The results are presented in Exhibit 3-3. Findings suggest that prices for lead, zinc and solvents are more volatile compared to general measures of volatility, where general measures are defined as average volatility of a basket of related goods (metal and metal products for lead and zinc, and chemicals and allied products for solvents). We would thus expect price volatility to be a

[14] The producer price index (PPI) measures the average change over time in the selling prices received by domestic producers for their output. Source: US Bureau of Labor Statistics.

significant causal factor for damaging behavior for these markets. With prices being relatively unstable, we could conclude that it is likely that some firms may enter these markets in order to make a quick profit in times when there is an upward spike in product prices.

Exhibit 3-3: Price Volatility – Mean and Standard Deviation

Materials	**1970-2002**	**1980-2002**	**1996 - 2002**
Lead[1]	14% (13%)	14% (14%)	5% (3%)
Refined lead	NA	10% (8%)	6% (5%)
Zinc[1]	15% (12%)	15% (10%)	14% (10%)
Refined zinc, slab, dust	NA	13% (8%)	11% (7%)
Barrels, drums, and pails	NA	3% (3%)	1% (1%)
Basic organic chemicals	NA	5% (4%)	3% (4%)
Trichloroethylene[2]	NA	NA	2% (0.5%)
Methyl Ethyl Ketone[2]	NA	NA	9% (7%)
Perchloroethylene[2]	NA	NA	7% (7%)
Metals and metal products	*5% (6%)*	*3% (3%)*	*2% (1%)*
Chemicals and allied products	*5% (7%)*	*3% (4%)*	*1% (2%)*
All commodities	*5% (5%)*	*3% (3%)*	*2% (2%)*

1) Volatility index based on market prices available from the US Geological Survey.
2) Volatility index based on market prices from The Innovation Group, available in "Chemical Profiles" at http://www.the-innovation-group.com/welcome.htm.
Notes:
1) Volatility index is defined as mean of the absolute values of the annual percent change in price.
2) Unless otherwise noted, volatility index constructed using data on the producer price index from the US Bureau of Labor Statistics. Available at http://www.bls.gov/ppi/.
3) Time intervals were selected to make the data from different data sources comparable. For example, price information for trichloroethylene was only available for the period 1996-2002.
4) NA – not available.

Recycling facilities, however, can mitigate, to some extent, the effects from volatile prices. For the lead-acid battery and spent pickle liquor markets, tolling agreements are common, which to some extent protect the recyclers from fluctuations in the price of the final product. The agreements also are likely to have a clause allowing the recycler to adjust the price if the cost of electricity and/or fuel increases, thus providing some protection from increases in production costs. Some hazardous wastes also may have multiple commercial uses which serve as an additional buffer from price volatility of the primary product. Firms that handle wastes with multiple uses have less incentive to stockpile waste since the waste can be diverted to another use if decreases in the price for the recycled product make recycling unprofitable. As shown in Exhibit 3-4, we found evidence of multiple uses, mitigating the effects of price volatility in four of the recycling markets. As discussed above, spent solvents may be used as secondary fuels instead of recycled in periods of high oil prices. For emptied drums, scrapping used drums for metal is an alternative use to reconditioning them. If the price of reconditioned drums

falls, recyclers can sell them for scrap as opposed to stockpiling them until the market recovers. A similar situation exists for spent pickle liquor, which can be used in wastewater treatment if low demand for steel causes a drop in its price. Although lead-acid batteries are currently the only significant use for lead, tolling agreements serve as protection for battery recyclers.

Exhibit 3-4: Multiple Use

Material	Used Lead-Acid Batteries	Brass Dust	Spent Pickle Liquor	Spent Solvents	Used Empty Drums
Is there other commercial use?	Yes, although very small	NA	Yes, water treatments plants	Yes, fuel substitution	Yes, scrap steel

3.2.3. Net Worth of the Firm

The net worth of the firm was hypothesized to be an indicator of optimal recycling outcomes, with low net worth firms having less incentive to engage in careful waste management. Although we were unable to collect data on this issue in the empirical analysis, we did find some evidence supporting this hypothesis in our communications with industries in the recycling markets for the five selected materials. In the steel industry, for example, secondary liability issues were mentioned as a concern by firms in terms of sending spent pickle liquor to commercial firms for regeneration. Representatives at two large steel firms mitigated the potential secondary liability risk by periodically doing site visits to the commercial recyclers to ensure that their wastes are being handled in a compliant manner. Since, due to the value and the volume of the products sold, these steel mills are likely to have a higher net worth than the commercial facilities recycling their spent pickle liquor, they are concerned about secondary liability. Namely, should a commercial recycler be required to pay for damage it caused by mishandling spent pickle liquor, it will be able to pay only the amount up to its net worth (i.e., the amount that can be generated by selling off its assets). However, if the damage is significantly higher than what the commercial recycler is able to pay, then it is possible that the steel mills may be required to cover the difference.

3.3. Discussion of Unobservable Firm and Market Characteristics

In addition to those characteristics of firms and recycling markets that would be potentially observable, this paper also discussed kinds of market failure that could contribute to sub-optimal hazardous waste recycling outcomes. While the sources of market failure discussed in the paper are important, they do not necessarily correlate directly to observable characteristics of the firm or market.

- Imperfect information: One source of market failure in hazardous waste recycling by commercial and both kinds of industrial firms is imperfect information. If firms lack complete and accurate information about the market for hazardous waste recycling, they may make different decisions regarding their entry into the market or level of production than if they had better information. This can lead to

the phenomenon of adverse selection, where more firms that are misinformed on the market choose to enter it than firms that are well informed. Firms can have imperfect information on both the costs and revenues of hazardous waste recycling. On the cost side, firms can be misinformed about the true costs of operating a recycling operation in a safe and compliant manner. This could result in firms that operate in a less safe or less compliant manner or that have to exit the market, since the true costs of recycling would not allow the firm to operate at a profit. On the revenue side, commercial firms and industrial intra-company recyclers may have incomplete information about the market prices of recycled goods due to lack of market data or unstable prices. Imperfect information on revenues could thus also contribute to sub-optimal recycling outcomes since it could serve as an incentive for firms to try and cut recycling costs by operating in a less safe manner or as an incentive for them to have to exit the market.

- Externalities: Another common source of market failure identified in the paper is externalities, which result when firms only take responsibility for their private costs, and do not account for social costs resulting from their actions. These social costs are treated as external to the firm and are thus passed on to society. Pollution resulting from hazardous waste recycling constitutes an externality if the firm does not pay for the damages caused by the pollution. The decision by a firm to pass some of the costs of its actions onto society rather than internalizing them is a potential cause of sub-optimal outcomes for hazardous waste recycling. This kind of externalities could either result from ignorance on the part of firms of the external damage they are causing, or from deliberate attempts on the part of firms to lower their costs. The result of externalities in the hazardous waste recycling market is a larger amount of recycled materials being produced at a lower price than would result if firms internalized the full costs of their recycling operations.

3.4. Conclusion

Recycling of hazardous waste offers many potential benefits to firms and more generally to society through reducing waste and the use of virgin materials and landfill space. This paper used economic theory to examine cases when these benefits fail to be realized and hazardous waste recycling results in costs to society that outweigh its benefits. Economic modeling of recycling as practiced by three different types of firms provided information on how hazardous waste recycling can result in sub-optimal outcomes, and it also enabled us to identify potentially observable characteristics of firms and markets that are possible indicators of hazardous waste recycling that could generate sub-optimal outcomes. Different kinds of market failures were also discussed in terms of how they can contribute to environmentally destructive behavior. Identifying these sources of market failure can point to potential solutions for the different issues.

Appendix I – Literature Review

Initial searches and reviews of the literature found relatively few articles of interest with a focus on the economics of hazardous waste recycling from the perspective of firm decision-making. While there are many studies in the economics literature relating to recycling, these almost exclusively relate to recycling of non-hazardous waste by households. Existing literature on hazardous waste recycling is mostly focused on economic analysis of different policies to improve hazardous waste management. While these articles provided some useful information about the general market forces that may influence hazardous waste recycling, literature in areas outside economics proved to have the most specific information about the economics of hazardous waste recycling from a firm-level perspective.

Although most of the literature that discussed firm-level recycling decisions was focused on specific industries, a small number of studies discussed these issues in more general terms. One study, for instance, examined the barriers against the recycling of hazardous waste in Canada (Technology Resource, Inc., 1988). Through a survey of firms, the study found that economic issues were the most common barriers against hazardous waste recycling. The economic factors that presented the biggest challenges to recycling were the existence of lower-cost disposal options, the high investment risk for recycling with low payback potential, and small or nonexistent markets for recycled materials. The study also pointed to a number of factors suggesting that firm size may be a crucial determinant of hazardous waste recycling activity, since larger firms have potential advantages in terms of being able to absorb new capital costs and in being able to process a larger volume of hazardous waste (i.e., economies of scale). The study noted that market incentives would be needed to encourage a higher rate of hazardous waste recycling. Incentives should serve to decrease the uncertainty around hazardous waste recycling and increase the rate at which firms receive revenues for their recycled output. Additional roles for incentives would be to provide information to firms to aid in the reduction of capital expenditures, and to increase the demand and marketability of recycled materials. While this study provided a detailed analysis of the economics of hazardous waste recycling, the age of the study and its focus on Canada may limit its relevance to the current state of hazardous waste recycling in the United States.

Another group of studies used economic modeling to characterize the waste management decisions of a representative industrial firm. A common finding of these studies was that, while other factors may play into waste management decisions, profit maximization is the primary framework from which firms make waste management decisions (Gottinger, 1991b; McLaren and Yu, 1997; Alberini and Frost, 1999; Dijkgraaf and Vollebergh, 2003). These studies modeled the waste management decisions of firms as a choice of the least-cost option among different disposal choices. The costs of the various disposal options were modeled as a function of the characteristics of the waste, the firm, the disposal option, and the existing regulatory framework. In making decisions regarding hazardous waste management, studies generally found that firms tend to balance the short-term, certain costs associated with waste management (e.g., transportation,

disposal) with the long-term uncertain costs such as liability (Gottinger, 1991b; Alberini and Bartholomew, 1999).

In understanding the firm-level factors that influence hazardous waste management decisions, it is useful to think of the different categories of costs that play into these decisions. As suggested by Fleet (1993), these costs can be broken down into four main categories, which are thought to vary widely by firm, depending on firm size and aspects of the regulatory climate. These categories include direct costs, which are the main costs associated with production and waste management. A second category is indirect costs, which include regulatory compliance costs (such as monitoring, manifesting and reporting requirements) and costs associated with liability and future risks. Both direct costs and the indirect costs mentioned above can be considered internal costs to the firm. Fleet (1993) stressed that firms should also include other categories of indirect costs in their waste management decisions, such as internal and external indirect costs that are intangible to the firm. One group of these intangible costs is the social cost of waste management choices. A second group of these intangible costs is costs to the firm, such as public perception of the firm's environmental performance. Literature on the economics of hazardous waste recycling is discussed below in relation to these different cost components.

Information on the direct costs of hazardous waste recycling was found from a number of articles discussing recycling within specific industries. Several of these articles compared the direct costs of hazardous waste recycling to the costs of conventional disposal options. For the industries represented in these articles, a general consensus was that the direct costs of recycling hazardous waste were comparable to the costs of disposal. One study, for example, compared the cost of three different disposal methods for fluorescent lamps used in industrial areas (Tansel et al. 1998). In terms of disposal options, it was found that splitting the waste stream into hazardous and non-hazardous waste was a less economical choice than treating the whole waste stream as hazardous waste. A comparison of the direct costs of disposal versus recycling found the costs to be similar ($0.93-$1.19 per lamp for recycling and $0.83-$1.21 for disposal as hazardous waste). Another study found the direct costs of landfill disposal for F006 wastewater treatment sludges from the plating industry in bulk to be the same ($250-$300 per ton) as recycling these materials (Rosenbaum, 1990). This study noted that, while these costs are currently the same, disposal costs will likely rise much faster than recycling costs due the reliance of disposal on dwindling landfill space. Another study came up with very favorable results in comparing the costs of disposal and treatment by offsite recyclers for hydraulic fluids. This study estimated annual disposal costs and recycling costs for used hydraulic fluid from the Naval Air Station in North Island, CA, and found the disposal costs ($5,232) to be almost twice as high as the recycling costs ($2,766). This study cautioned, however, that costs should be considered on a case-by-case basis due to possible variability in disposal and recycling costs (Joint Service P2 Technical Library, 2003).

Another important consideration in the comparison of the direct costs of disposal and recycling options are the benefits associated with the recovered materials. While the

study of fluorescent lamps found disposal and recycling costs were roughly equal, this study stressed that recycling had the added benefit of the recovery and resale of glass, aluminum, mercury and powder (Tansel et al. 1998). A study of used consumer electronic products also highlighted the importance of the material obtained from recycling in the economic attractiveness of recycling to a firm. In comparing the recycling of cell phones and computers, the authors noted that the existence of viable markets for the recovered materials could be what makes recycling an economically viable option for the firm (Bhuie et al. 2004). The importance of the recovered materials was also stressed in the study of wastewater sludges, which noted that the average ton of F006 sludge contains over $200 of recoverable metals and was an economic benefit that could be shared between the generator of the waste and the recycler (Rosenbaum, 1990).

Besides the influence of direct costs on hazardous waste management decisions, some studies stressed the importance of internal indirect costs on the economics of waste management options. Several studies discussed how hazardous waste recycling decreases costs by cutting the indirect costs associated with waste management. A study of recycling metal-bearing hazardous waste found that, while the recycling was not a favorable alternative in terms of direct costs, the reduced regulatory responsibility associated with recycling could make it an economically feasible alternative (Ramachandran, 1993). Although the direct costs of recycling hydraulic fluid were already attractive compared to disposal, the study on this issue noted that the less stringent regulations associated with recycling were an additional economic incentive (Joint Service P2 Technical Library, 2003). The study of wastewater sludge noted that recycling of hazardous waste cut down on future liability since the waste is converted into usable products and does not stockpile in the waste stream. This removal of waste from the regulatory framework removes the future costs that would be needed for monitoring disposed hazardous wastes (Rosenbaum, 1990).

Studies of the economics of hazardous waste recycling also stressed that other external indirect costs are important to consider in waste management decisions. As discussed above, one category of these intangible costs is the social costs associated with hazardous waste management. These costs include potential environmental benefits and potential avoided costs from the extraction of virgin materials and using up additional landfill space (Fleet, 1993; Sigman, 1999). In examining the economics of recycling personal computers, one study concluded that computer recycling was not economically feasible through comparisons of direct costs alone, but that it could likely be feasible if the environmental benefits associated with recycling could be included in the cost analysis (Bhuie, 2004).

Another category of intangible costs that could influence firm waste management decisions is “green image” costs, or the potential influence of the perceived environmental performance of a company on their revenues. While this is a difficult cost to quantify, some studies identified this as an important factor that could influence a firm’s waste management decisions. Both Fleet (1993) and Rosenbaum (1990) stress that these costs could be significant and influence waste management decisions if dollar terms could be applied to them. Needleman (1994) also noted that positive public perceptions

around recycling could influence firms to recycle hazardous waste, even if the recycling process ended up causing more environmental harm than other disposal options.

Appendix II – Empirical Analysis

The main objective of this section is to describe and characterize the recycling markets for five selected hazardous wastes: lead-acid batteries, brass dust, spent pickle liquor, solvents and empty drums. Using publicly available data and information obtained from interviews with trade associations and industry members, the recycling markets for the five materials are discussed in terms of ideas and concepts expressed in the theoretical section. For each of the five selected hazardous wastes, this section provides some background information on waste management options, waste flows, generation and recycling rates, number and characteristics of recycling entities, and the financial data for the recycling of the wastes. Due to data limitations, this section does not present any empirical tests of the hypotheses laid out in the theoretical section.

Several criteria were used for selecting the wastes, including data availability, recycling rates, and characteristics of the recycling markets. The selected five materials are not necessarily representative of all hazardous wastes. Therefore, the conclusions reached in this paper are not necessarily valid for hazardous wastes, industries and markets other than those analyzed here.

A.1 Data Sources

The discussion presented in the empirical section is based on the information from two main sources:

1. Industry (e.g., trade groups and manufacturers), and
2. The 2003 EPA Biennial Reporting System (BRS).

Information from relevant industry sources was obtained via a telephone interview. Industry provided information on the size of the hazardous waste market (in term of the number of recyclers or the amount recycled) and the characteristics of the market. The information was provided voluntarily and was not required to be submitted. The information provided has not been independently verified by EPA.

The BRS contains data on the generation, management, and minimization of hazardous waste. These data are provided to EPA by hazardous waste generators and treatment, storage, and disposal facilities, as required under 40 CFR 262.41 and 264.75. This provides detailed data on the generation of hazardous waste from large quantity generators and data on waste management practices from treatment, storage, and disposal facilities. Data on hazardous waste activities is reported for odd number years (beginning with 1989) to EPA. The BRS data are required to be submitted. In addition, EPA has provided guidance on the forms used to submit these data and how those forms should be completed. Failure to submit this information, and the submission of inaccurate or incomplete information, is punishable by fines or imprisonment.

The information from the BRS is likely to be more accurate and complete that the industry information. The mandatory nature of the data collection process and EPA

guidance are likely to result in a higher quality of information than the industry data. Due to the different data sources and information collection methods for the industry data and the BRS, these data may not completely agree. The industry data, however, are included in this paper because they provide an industry perspective on the specific hazardous waste recycling markets.

A.2. Recycling Markets

A.2.1. Tipping Fees

In the Pollution Prevention Act of 1990, the US Congress established a national waste management policy stating that:

- Pollution should be prevented or reduced at the source whenever feasible;
- Pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible;
- Pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and
- Disposal or other releases into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.[15]

The established national waste management hierarchy induces hazardous waste generators to treat landfill disposal as the option of last resort.

This section presents average tipping fees for two waste management options: (1) reuse through fuel substitution, and (2) disposal. The average fees are based on the survey data collected by the Environmental Technology Council (ETC).

A waste management option available to facilities that generate hazardous waste with high BTU value is fuel substitution, where hazardous waste is used as a substitute for fossil fuels in boilers and industrial furnaces. The ETC data indicate that the average tipping fee for a 55-gallon drum of liquids was, on average, close to $110 per drum in 2004. There is some evidence that, due to high fuel prices in 2005, recyclers are currently either not charging acceptance fees or are even paying generators for hazardous waste that can be used as substitute fuel.[16]

Hazardous waste generators are encouraged to use disposal as the waste management option of last resort. Before being disposed, some hazardous wastes must be treated to meet the land-disposal restrictions contained in 40 CFR 268. Based on the ETC data, treatment activities account, on average, for 30 to 50 percent of the landfill costs for hazardous wastes. For example, in 2004, the landfill fees for landfilling drummed waste without treatment were $99 per 55-gallon drum, while the fees for treatment of drummed waste followed by landfilling were $173 per 55-gallon drum.

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[15] Habicht, H. *Memorandum: EPA Definition of Pollution Prevention.* US EPA, May 28, 1992, available at http://www.epa.gov/ttn/nsr/gen/memo-u.html.
[16] Based on a telephone conversation with Scott Slesinger, of ETC, conducted in January 2006.

Exhibit A-1 presents average tipping fees paid by hazardous waste generators in the period 2002-2004 for the two waste management options. The ETC does not present tipping fees by hazardous waste. The fees may vary greatly depending on the characteristics of wastes, including the BTU value, halogen content, and compatibility with other waste. For example, in 2004, landfill tipping fees for treated drummed waste ranged from $104 to $261 per 55-gallon drum, with the average fee of $173 per 55-gallon drum.

Exhibit A-1: Average Cost of Hazardous Waste Management

	2002	2003	2004
Fuels			
Drummed Liquids ($/drum)	-	$108	$106
Drummed Solids ($/drum)	-	$200	$207
Commercial Landfill			
Debris ($/ton)	$199	$206	$191
Bulk with Treatment ($/ton)	$162	$133	$131
Bulk without Treatment ($/ton)	$83	$76	$89
Drummed with Treatment ($/drum)	$114	$174	$173
Drummed without Treatment ($/drum)	$105	$100	$99
Soil Treated and Landfilled ($/ton)	$139	$134	$133
Soil direct to Landfill ($/ton)	$70	$71	$69

Note: Transportation costs not included. All fees are in 2003 dollars.
Source: Environmental Technology Council (ETC), available at http://www.etc.org/costsurvey8.cfm. Average costs are based on a survey of ETC members.

The data presented in Exhibit A-1 suggest that the landfill tipping fees for treatment and landfilling of hazardous waste were, on average, $140 per ton for treated bulk and soil, and between $100 and $200 per 55-gallon drum for treated drummed wastes in the period 2002 to 2004. We would expect that, on average, the landfill disposal fees for lead-acid batteries, brass dust, spent pickle liquor and solvents were in those ranges in the period 2002 to 2004.

As explained in Section 2 of the paper, the acceptance fees charged by commercial recyclers are expected to be closely related to landfill disposal fees, since commercial recyclers are competing with landfills, and with each other, to obtain waste from generators. We therefore use the landfill disposal fees as a proxy for acceptance fees in the sections below to ascertain whether the acceptance fees or the revenues generated from the sale of recycled hazardous materials is the dominant revenue stream for *commercial* recyclers.

A.2.2. Lead-Acid Batteries

The discussion presented in this section is based on information from two main sources:

1. The Battery Council International (BCI), a trade association of lead-acid battery manufacturers in North America, and
2. The 2003 EPA Biennial Reporting System (BRS).

BCI Data

The information presented in this section was provided by BCI during a telephone interview conducted in November, 2005. This information has not been independently verified by EPA.

The process of recycling a lead-acid battery involves breaking the battery, draining out the acid, separating out the metal, and running the metallic material through a smelting process to melt it and separate the lead from other materials. Lead-acid batteries are a unique industry in that virtually all (99.5 percent) lead batteries are recycled. There are about 15 secondary smelters that obtain used batteries, recover the lead in them using secondary smelting, and sell the lead back to battery companies. Vertical integration is present in the industry, where some battery manufacturers own secondary smelters. Tolling agreements are common in the industry, which involve fixed prices for accepting the lead by recyclers, recycling the lead, and delivering the recycled lead to the battery manufacturers. Such contractual arrangements help shield the recyclers from price volatility. Because the cost of lead accounts for a significant portion of the production of lead-acid batteries[17] and because recycling lead is less costly than producing lead from ore, the battery manufacturers have a big incentive in seeing that battery lead is recovered. The recycling of lead-acid batteries is facilitated by the simple distribution chain between manufacturers and smelters.

BRS and Other Publicly Available Data

The BRS does not explicitly track lead-acid batteries. Facilities handling lead-acid batteries were identified using both waste codes and form codes from BRS. The BRS contains form codes, one of which is "W309 - Batteries, battery parts, cores, casings (lead-acid or other types)." Because this form code can include some batteries that do not contain lead, waste codes were also used. Waste code D008, which indicates that the waste exhibits the characteristic of toxicity for lead, was also used to identify facilities handling lead-acid batteries. We assumed that all waste lead-acid batteries would carry this waste code. Wastes that carried both form code W309 and waste code D008 were assumed to be lead-acid batteries. Exhibit A-2 lists the number of facilities handling wastes carrying this combination of form and waste code by waste handling method.

The BRS data contained information on a total of 71 unique facilities that handled lead-acid batteries, of which 29 were actively involved in some type of waste management and 42 were solely engaged in waste transfer (i.e., transport and/or temporal storage). Of the 29 waste management facilities, seven facilities were engaged in waste transferring in addition to waste management. Recycling was conducted at 14 facilities. Only one of those facilities, a battery manufacturer, was an intra-industry recycler (i.e., the entity both generated and recycled waste). The highest concentration of recycling facilities was in the southern and western regions of the US, with the South, South Central, West, and Midwest regions comprising 85 percent of the total number of facilities engaged in recycling.

[17] BCI indicated that the cost of lead accounts for close to half of the wholesale price of a battery.

Exhibit A-2: Waste Handling Method and Geographic Distribution for 71 Facilities Handling Lead-Acid Batteries (2003)

	Recycling	Disposal	Energy Recovery	Transfer	Treatment	Total
Northeast	1	-	-	5	3	9
Mid-Atlantic	1	1	-	4	-	6
South	3	2	1	7	1	14
Midwest	3	-	-	14	2	19
South Central	3	1	-	11	1	16
West Central	-	2	-	1	1	4
West	3	1	-	7	2	13
Total	**14**	**7**	**1**	**49**	**10**	**71**[1]

1) The total facility count is less than the column summation because some facilities engage in more than one type of waste handling activity.
Source: ICF Analysis, 2003 BRS.

Exhibit A-3 presents data on the amount of lead-acid batteries managed by method. Over 165,000 tons of lead-acid batteries were managed by facilities in 2003, of which 141,000 tons were recycled (or 85 percent of the total waste managed). The BRS data indicate that a single entity dominated the recycling market with over 100,000 tons of lead-acid batteries recycled (or over 70 percent of the total lead-acid batteries recycled).

Exhibit A-3: Waste Management Methods for Lead-Acid Batteries at 29 Facilities (2003)

	Amount Managed				
	Recycling	Disposal	Energy Recovery	Treatment	Total
Total (tons)	141,032	13	2	24,110	**165,157**
Total (percent)	85	<1	<1	15	**100**
Average per Facility (tons)	10,074	2	2	2,411	**5,695**

Note: 55 tons of lead-acid batteries were transferred in 2003. Because activities related to transportation of waste are not considered waste management, information on the amount transported in 2003 is not included in the Exhibit.
Source: ICF Analysis, 2003 BRS.

Exhibit A-4 provides information on the flow of hazardous waste for lead-acid batteries. The first set of columns presents the NAICS codes for the generators of lead-acid batteries that went to recycling facilities, and the second set of columns presents the NAICS codes for the recycling facilities. The exhibit shows that battery manufacturers (NAICS code 335911) generated nine percent of the waste recycled by secondary smelters (NAICS code 331492) in 2003.

Exhibit A-4: Recycling of Lead-Acid Batteries – Flow of Hazardous Waste, by Industry (2003)

Generators	NAICS	Percent of Waste Supplied[1]	Recycling Facilities	NAICS
Storage Battery Manufacturing	335911	9	Secondary Smelting, Refining and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492
Recyclable Material Merchant Wholesalers	42393	7		
Secondary Smelting, Refining and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492	4		
Primary Battery Manufacturing	335912	87	Secondary Smelting, Refining, and Alloying of Copper	331423
Storage Battery Manufacturing	335911	12		
Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492	7	All Other Plastic Product Manufacturing	326199
Hazardous Waste Treatment and Disposal	562211	61	Recyclable Material Merchant Wholesalers	42393
National Security	92811	21		
Space Research and Technology	92711	18		
Battery Manufacturing	335911	100	Battery Manufacturing	335911
Other Chemical and Allied Products Merchant Wholesalers	42469	54	Other Business Service Centers (including Copy Shops)	561439
Audio and Video Equipment Manufacturing	33431	8		
Deep Sea Passenger Transportation	483112	4		

1) Waste supplied by generators in each industry as a percentage of the total waste recycled.
Note: The exhibit presents only the top three industries (in terms of the amount of waste supplied) for which NAICS codes were available. For example, secondary smelters (NAICS code 331492) recycled 133,321 tons of lead-acid batteries in 2003, of which 11,438 tons, or nine percent, were supplied by storage battery manufacturers (NAICS code 335911). Close to 80 percent of waste was supplied by industries for which data on the generators' NAICS codes are not available in the BRS database.
Source: ICF Analysis, 2003 BRS.

Exhibit A-5 presents additional information on the firms that were involved in recycling lead-acid batteries. The most common category was from the "Secondary Smelting, Refining and Alloying of Nonferrous Metal" industry, with a total of nine firms (NAICS code 331492). Firms in this industry recycled 95 percent of the total lead-acid batteries recycled in 2003, with the average recycling rate per firm of close to 15,000 tons. The second highest amount of waste recycled (close to 4,500 tons, or three percent of the total) was recycled by a firm in the "Secondary Smelting, Refining, and Alloying of Copper" industry (NAICS code 331423).

The information on the flow of lead-acid battery recycling materials presented in Exhibit A-4 and the information on the amount of hazardous waste recycled by industry presented in Exhibit A-5 indicate that most lead-acid battery recyclers are *inter*-industry recyclers that receive their waste from firms in industries other than the one in which they

operate. The theoretical model on industrial inter-company recycling (presented in Section 2.3) may best describe market behavior of these entities.

Exhibit A-5: Distribution of Facilities Recycling Lead-Acid Batteries, by Industry (2003)

Industry	NAICS	Total Amount Recycled (tons)	Amount Recycled as a Percentage of the Total	Number of Facilities	Average Amount Recycled per Facility (tons)
Secondary Smelting, Refining and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492	133,321	95	9	14,813
Secondary Smelting, Refining, and Alloying of Copper	331423	4,491	3	1	4,491
All Other Plastic Product Manufacturing	326199	3,192	2	1	3,192
Recyclable Material Merchant Wholesalers	42393	13	<1	1	13
Storage Battery Manufacturing	335911	12	<1	1	12
Other Business Service Centers (including Copy Shops)	561439	3	<1	1	3
Total		**141,032**	**100**	**14**	**10,074**

Note: Totals may not add due to rounding.
Source: ICF Analysis, 2003 BRS.

Exhibit A-6 presents revenue data for each industry that performs battery recycling. The revenue data in Exhibit A-6 includes all revenue for the industry, including revenue not related to battery recycling. For the majority of firms in these industries, recycling is not their primary business. Because revenue data were available for entire industries, and not for individual facilities that perform battery recycling, the data in Exhibit A-6 includes facilities that are not engaged in recycling.

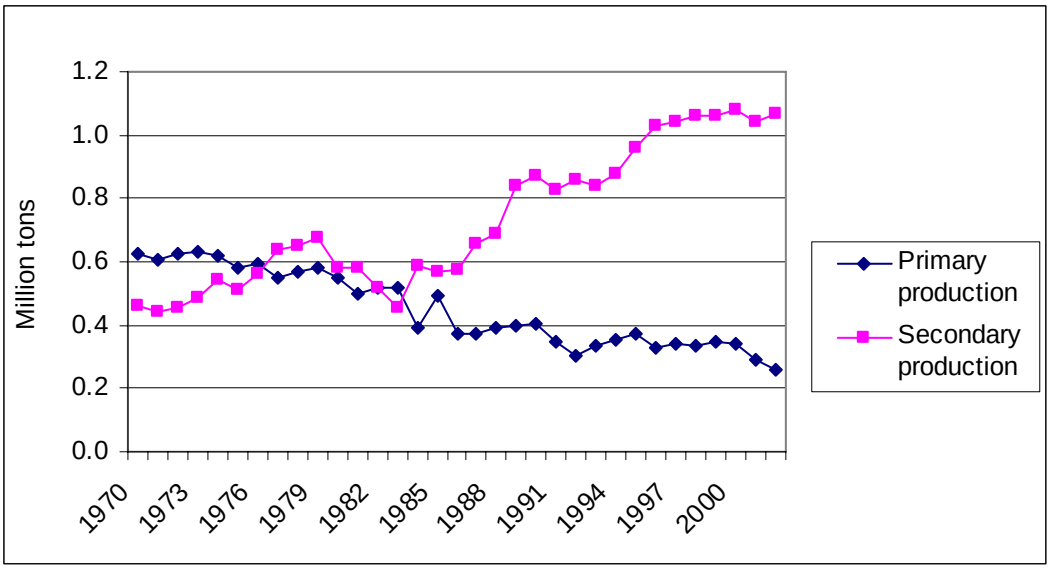
Exhibit A-6: Characteristics of Industries in Which Some Facilities are Engaged in Recycling Lead-Acid Batteries

Industry	NAICS	Total Number of Companies	Percent of Facilities Conducting Recycling[1]	Total Industry Revenue (millions)	Average Revenue per Facility (millions)
Secondary Smelting, Refining and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492	211	4	$2,796	$13.3
Secondary Smelting, Refining, and Alloying of Copper	331423	30	3	$611	$20.4
All Other Plastic Product Manufacturing	326199	6,701	<1	$72,894	$10.9
Recyclable Material Merchant Wholesalers	42393	7,145	<1	$28,207	$3.9
Storage Battery Manufacturing	335911	97	1	$3,415	$35.2
Other Business Service Centers (including Copy Shops)	561439	5,852	1	$6,414	$1.1

1) The percentage is calculated using the total number of recyclers presented in Exhibit A-5.
Source: ICF Analysis, Census 2002, 2003 BRS.

Exhibit A-7 presents information on the level of primary and secondary production of lead. The graph shows an increasing trend in secondary production and decreasing trend in primary production.

Exhibit A-7: Primary and Secondary Production of Lead, 1970-2002



Notes: Primary production – the amount of refined lead produced in the U.S.
Secondary production – the amount of old lead scrap (scrap including, but not limited to, metal articles that have been discarded after serving a useful purpose).
Source: ICF Analysis, United States Geological Survey.

Exhibit A-8 provides information on the amount of lead recovered from scrap. As shown in the table, battery lead comprised the vast majority (about 95 percent) of lead generated

from secondary production in 2002 and 2003. This translates to about 75 percent of total lead produced by both primary and secondary production methods.

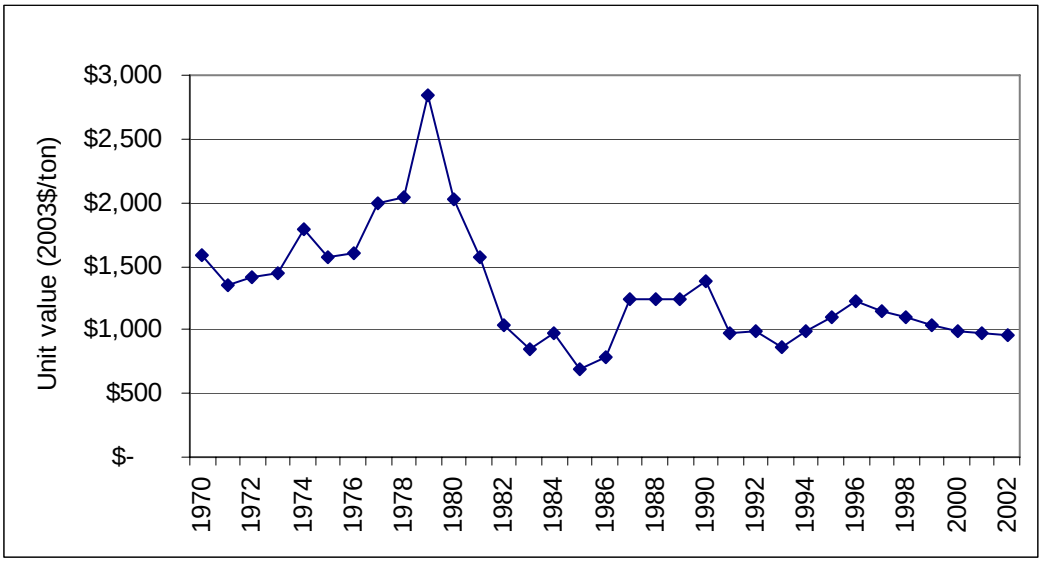
Exhibit A-8: Lead Recovered from Scrap Processed, 2002-2003

Lead Recovered from:	2002	2003
Total New Scrap	42,800	40,900
Old Scrap		
Battery Lead	1,010,000	1,060,000
Other	59,500	48,970
Total Old Scrap	1,070,000	1,110,000
Grand Total	**1,120,000**	**1,150,000**
Battery Lead as a Percentage of Total Old Scrap Production	**94.4%**	**95.5%**

Notes: Metric tons, unless otherwise noted.
Source: ICF Analysis, United States Geological Survey.

Exhibit A-9 presents information on the price of lead over time, with summary statistics presented in Exhibit A-10. The price of lead has declined in real terms over the past 30 years. The average annual price in that period was $1,303 per ton, with a standard deviation of $453 per ton (or 35 percent of the average annual price).

Exhibit A-9: Annual Price of Lead, 1970-2002



Source: United States Geological Survey.

Exhibit A-10: Summary Statistics for the Annual Price of Lead ($/ton)

	1970-2002	1970-1989	1990-2002
Minimum	$698	$698	$862
Maximum	$2,845	$2,845	$1,379
Mean	$1,303	$1,465	$1,053
Median	$1,225	$1,428	$996
Standard Deviation	$453	$513	$136

Note: All values are in 2003 dollars.
Source: United States Geological Survey.

In their 2002 study "Booms and Slumps in World Commodity Prices," Cashin, P. et al. analyzed the monthly data for the period 1957:1 to 1999:8 for 36 primary commodities, including lead. Their analysis of the historical price of lead shows that:

- Price slumps are slightly longer in duration than price booms, with slumps lasting on average 28 months and booms lasting on average 26 months[18];
- The average percentage change in the price of lead during slumps is -47.3 percent, while the average percentage change in the price of lead during booms is 40.8 percent; and
- The probability of a slump (boom) ending is independent of the time spent in the slump (boom).

Exhibit A-11 summarizes the results of the Cashin et al. (2002) study. The results indicate that the price of lead has shorter price cycles than all other metals analyzed in the study. Shorter price cycles may make it harder for lead recycles to forecast demand. The average percentage change in the price of lead during a slump (boom) is very close to the average percentage change for all 36 commodities. The magnitude of a drop in the price of lead (in percentage terms) during a slump, however, tends to be higher than for most other metals the authors analyzed.

Exhibit A-11: Booms and Slumps in the Commodity Prices

	Slumps			Booms		
Commodity	**Duration (months)**	**Average Percent Change in Price**	**Is there Duration Dependence?**	**Duration (months)**	**Average Percent Change in Price**	**Is there Duration Dependence?**
Lead	27.8	-47.3	No	25.7	40.8	No
Aluminum	34.8	-33.3	No	22.5	29.3	No
Copper	34.4	-48.7	No	31.7	46.1	No
Gold	48.6	-35.0	No	29.0	32.9	No
Nickel	43.0	-42.7	No	31.3	39.3	No
Zinc	31.8	-41.2	No	24.1	43.2	No
Average for 36 Commodities	39.0	-46.0	No	29.0	42.0	No

Note: The null hypothesis tested by the authors was that the probability of exiting a slump (boom) is independent of the length of time spent in that phase.
Source: Cashin, P. et al. (2002).

[18] A boom (slump) is defined as a period of generally rising (falling) prices.

Exhibit A-12 presents information on the consumption of lead broken down by various products. As shown in the table, storage batteries accounted for the majority of the consumption of lead (over 80 percent) in both years.

Exhibit A-12: Consumption of Lead by Product (in metric tons), 2002-2003

Uses	**2002**	**2003**
Storage Batteries	1,190,000	1,170,000
Miscellaneous Uses	71,400	71,620
Ammunitions, Shot and Bullets	57,600	48,800
Other Oxides (Including Pain, Glass and Ceramics Products)	51,900	35,700
Other Metal Products	34,800	31,700
Sheet Lead	25,600	24,200
Solder	6,450	6,310
Pipes, Traps, Other Extruded Products	2,250	1,670
Total	**1,440,000**	**1,390,000**
Consumption of Lead in Storage Batteries as a Percent of Total Consumption	**82.6%**	**84.2%**

Source: ICF Analysis, United States Geological Survey.

Conclusions

The following conclusions can be drawn from this empirical analysis:

- Most lead-acid battery recyclers are inter-industry recyclers that receive their waste from firms in industries other than the one in which they operate.
- A high recycling rate of lead from lead-acid batteries and its use in battery manufacturing indicate that recycled lead is freely substituted for lead produced from virgin materials.
- Because recycled lead tends to be less expensive than lead produced from virgin materials, the battery manufacturers have a financial incentive to use recycled lead.
- The price of lead has shorter price cycles compared to the price of aluminum, copper, gold, nickel and zinc. Shorter price cycles may make it harder for lead recycles to forecast demand.
- The average percentage change in the price of lead during a slump (boom) is very close to the average percentage change for primary commodities. The magnitude of a drop in the price of lead (in percentage terms) during a slump, however, tends to be higher than for most other metals.

A.2.3. Brass Dust

The discussion in this section is primarily based on the 2003 BRS data. Some brass dust may not be regulated as a solid waste under RCRA under the exclusion for scrap metal when it is reclaimed [40 CFR 261.4(a)(13)], and would not be reported to the BRS. Thus, the BRS may underreport the amount of brass dust that is recycled. The data sources used for this paper did not contain information on the amount of brass dust that is recycled but not reported to the BRS.

Brass dust recyclers were identified using the following BRS form codes: (1) "W504 - Other sludges from wastewater treatment or air pollution control;" (2) "W505 - Metal bearing sludges (including plating sludge) not containing cyanides;" and (3) "W519 - Other inorganic sludges." Because the BRS does not explicitly track brass dust, the number of brass dust recyclers and the amount of brass dust recycled presented in this study may be under- or over-estimated.

Exhibit A-13 presents the number of facilities that handled (i.e., managed and/or transported) brass dust in 2003, broken down by number of facilities conducting each waste handling method and geographic region. The BRS data contained information on a total of 73 unique facilities that handled brass dust, of which 43 were actively involved in some type of waste management and 30 were solely engaged in waste transfer (i.e., transport and/or temporal storage). Of the 43 waste management facilities, 12 facilities were engaged in waste transferring in addition to waste management.

Exhibit A-13: Waste Handling Method and Geographic Distribution for 73 Facilities Handling Brass Dust (2003)

	Recycling	Disposal	Energy Recovery	Transfer	Treatment	Total
Northeast	2	1	-	6	2	11
Mid-Atlantic	2	-	-	3	4	9
South	-	2	2	8	3	15
Midwest	1	-	1	16	7	25
South Central	1	1	1	5	6	14
West Central	-	1	-	-	2	3
West	1	3	-	4	3	11
Total	**7**	**8**	**4**	**42**	**27**	**73**[1]

1) The total facility count is less than the column summation because some facilities engage in more than one type of waste handling activity.
Source: ICF Analysis, 2003 BRS.

Exhibit A-14 presents data on the amount of hazardous waste managed by method for facilities managing brass dust. A total of 28,233 tons of brass dust was managed by 43 facilities in 2003, with facilities managing 657 tons of waste on average. Treatment was the most common waste management method in 2003, with 26,500 tons of brass dust treated (or 94 percent of the total brass dust managed). Significantly smaller amount (slightly over 500 tons or 2 percent of the total brass dust managed) was recycled in 2003. The average amount recycled per facility was 76 tons.

Exhibit A-14: Waste Management Methods for Brass Dust at 43 Facilities (2003)

	Amount Managed				
	Recycling	**Disposal**	**Energy Recovery**	**Treatment**	**Total**
Total (tons)	534	1,145	66	26,488	**28,233**
Total (percent)	2	4	<1	94	**100**
Average per Facility (tons)	76	143	17	981	**657**

Note: 926 tons of brass duct were transferred in 2003. Because activities related to transportation of waste are not considered waste management, information on the amount transported in 2003 is not included in the Exhibit.
Source: ICF Analysis, 2003 BRS.

Exhibit A-15 provides information on the flow of hazardous waste for brass dust. The first set of columns presents the NAICS codes for the generators of waste that went to recycling facilities, and the second set of columns presents the NAICS codes for the recycling facilities.

Exhibit A-15: Recycling of Brass Dust - Flow of Hazardous Waste, by Industry (2003)

Generators	**NAICS**	**Percent of Waste Supplied[1]**	**Recycling Facilities**	**NAICS**
Storage Battery Manufacturing	335911	92	Secondary Smelting, Refining, and Alloying of Copper	331423
Primary Battery Manufacturing	335912	8		
Storage Battery Manufacturing	335911	99	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492
Vitreous China, Fine Earthenware, and Other Pottery Product Manufacturing	327112	1		
Other Pressed and Blown Glass and Glassware Manufacturing	327212	94	Nonferrous Metal (except Aluminum) Smelting and Refining	33141
Jewelry (except Costume) Manufacturing	339911	100	Testing Laboratories	54138
Bare Printed Circuit Board Manufacturing	334412	3	Hazardous Waste Treatment and Disposal	562211

1) Waste supplied by generators in each industry as a percentage of the total waste recycled.
Notes: The exhibit presents only the industries for which the NAICS codes are available in the BRS database. For example, the nonferrous metal smelting and refining facility (NAICS code 33141) recycled 9 tons of brass dust in 2003, of which 8.5 tons, or 94 percent, were supplied by facilities in the pressed and blown glass and glassware manufacturing industry (NAICS code 327212). The BRS database does not contain information on the NAICS codes for the generators who supplied the remaining waste.
The BRS database does not contain information on the industries that supplied waste to the recycling facility in the primary smelting and refining of nonferrous metal industry (NAICS code 331419). For that reason, the recycling facility with NAICS code 331419 is not shown in the above exhibit.
Source: ICF Analysis, 2003 BRS.

Exhibit A-16 presents additional information on the firms that were involved in recycling brass dust in 2003. The most common category was "Secondary Smelters," with a total of three firms (NAICS codes 331492 and 331423). There was only one commercial recycler managing brass dust in 2003 (NAICS code 562211). The amount managed by that facility was relatively small (six tons). Such a small amount managed could indicate that the commercial recycler may be recycling materials other than brass dust.

The information on the flow of brass dust materials presented in Exhibit A-15 and the information on the amount of hazardous waste recycled by industry presented in Exhibit A-16 indicate that most brass dust recyclers are *inter*-industry recyclers that receive their waste from firms in industries other than the one in which they operate. The theoretical model on industrial inter-company recycling (presented in Section 2.3) may best describe market behavior of these entities.

Exhibit A-16: Distribution of Facilities Recycling Brass Dust, by Industry (2003)

Industry	NAICS	Total Amount Recycled (tons)	Amount Recycled as a Percentage of the Total	Number of Facilities	Average Amount Recycled per Facility (tons)
Secondary Smelting, Refining, and Alloying of Copper	331423	384	72	1	384
Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492	127	24	2	64
Nonferrous Metal (except Aluminum) Smelting and Refining	33141	9	2	1	9
Testing Laboratories	54138	7	1	1	7
Hazardous Waste Treatment and Disposal	562211	6	1	1	6
Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	331419	1	<1	1	1
Total		**534**	**100**	**7**	**76**

Source: ICF Analysis, 2003 BRS.

In terms of average annual amount recycled, brass dust recycling activity is dominated by three secondary smelting plants. Based on the 2003 BRS figure, these three secondary smelting plants appear to have over 96 percent of the recycled brass dust market, with the market share of the top plant being over 72 percent. All other things being equal, we would expect the price of a product to be higher in a market dominated by a few firms than in a market with a large number of firms. Given the average annual amount

recycled, it is highly unlikely that the hazardous waste treatment and disposal facility (NAICS code 562211) is exclusively engaged in recycling brass dust.

Exhibit A-17 presents data on all facilities managing brass dust in a specific industry, including both facilities engaged in recycling and those that are not. The majority of the firms were not involved in recycling as their primary business. For the one firm in the hazardous waste treatment and disposal industry (NAICS code 562211) recycling is assumed to be its primary business.

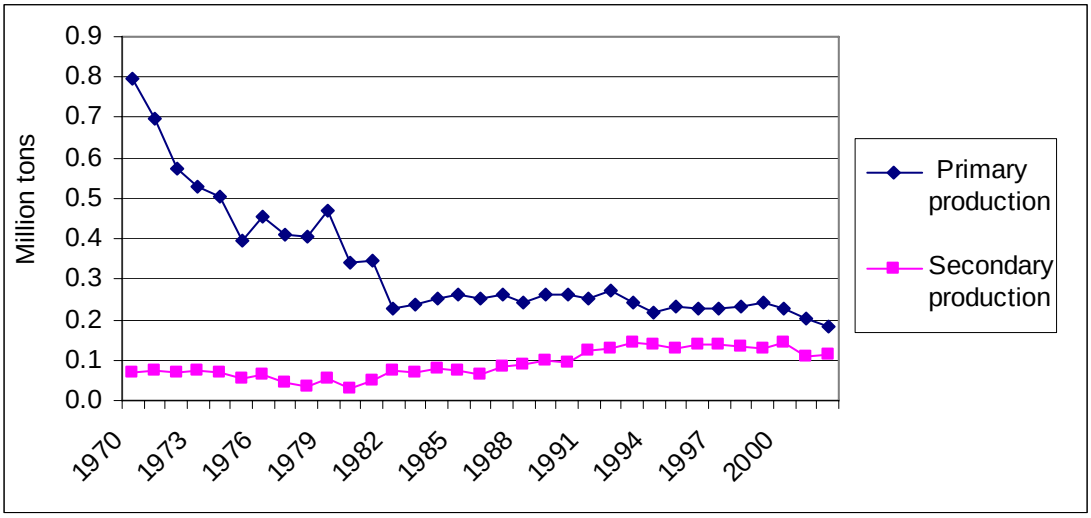
Exhibit A-17: Characteristics of Industries in Which Some Facilities are Engaged in Recycling Brass Dust

Industry	NAICS	Total Number of Companies	Percent of Facilities Conducting Recycling[1]	Total Revenue (million)	Average Revenue per Facility
Secondary Smelting, Refining, and Alloying of Copper	331423	30	3	$611	$20.4
Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492	211	1	$2,796	$13.3
Nonferrous Metal (except Aluminum) Smelting and Refining	33141	11	9	$2,615	$237.7
Testing Laboratories	54138	5,948	<1	$8,794	$1.5
Hazardous Waste Treatment and Disposal	562211	696	<1	$3,466	$5.0
Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	331419	153	1	$2,246	$14.7

1) The percentage is calculated using the total number of recyclers in each industry presented in Exhibit A-16.
Source: ICF Analysis, Census 2002.

Exhibit A-18 shows trends of primary and secondary production of zinc over time. Roughly two thirds of the zinc supply is produced from ore (primary production), and the remaining third is produced from scrap and residues including brass dust (secondary production). The majority of zinc used in the US is imported. In 2002, for example, 0.3 million tons of zinc were produced domestically, while almost 0.9 million tons were imported.

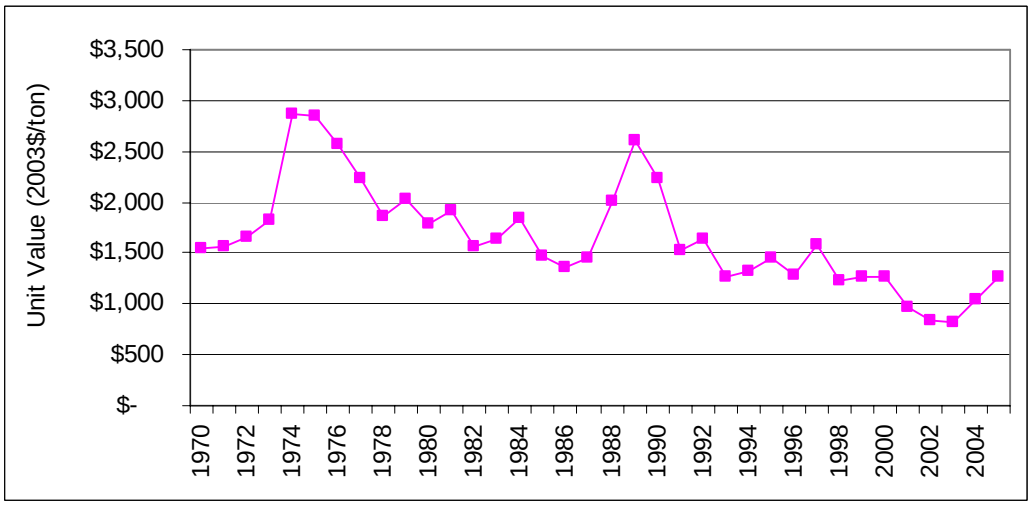
Exhibit A-18: Primary and Secondary Production of Zinc, 1970-2002



Source: ICF Analysis, United States Geological Survey.

Exhibit A-19 shows the annual price of zinc from 1970 to 2005, with summary statistics presented in Exhibit A-20. The price has exhibited a decreasing trend in real terms over the past 35 years. The average annual price in that period was close to $1,657 per ton, with a standard deviation of $513 per ton (or about 31 percent of the average annual price).

Exhibit A-19: Annual Price of Zinc, 1970-2005



Source: United States Geological Survey.

Exhibit A-20: Summary Statistics for the Annual Price of Zinc

	1970-2005	1970-1989	1990-2005
Minimum	$827	$1,368	$827
Maximum	$2,867	$2,867	$2,243
Mean	$1,657	$1,933	$1,311
Median	$1,565	$1,833	$1,266
Standard Deviation	$513	$461	$343

Note: All values are in 2003 dollars.
Source: United States Geological Survey.

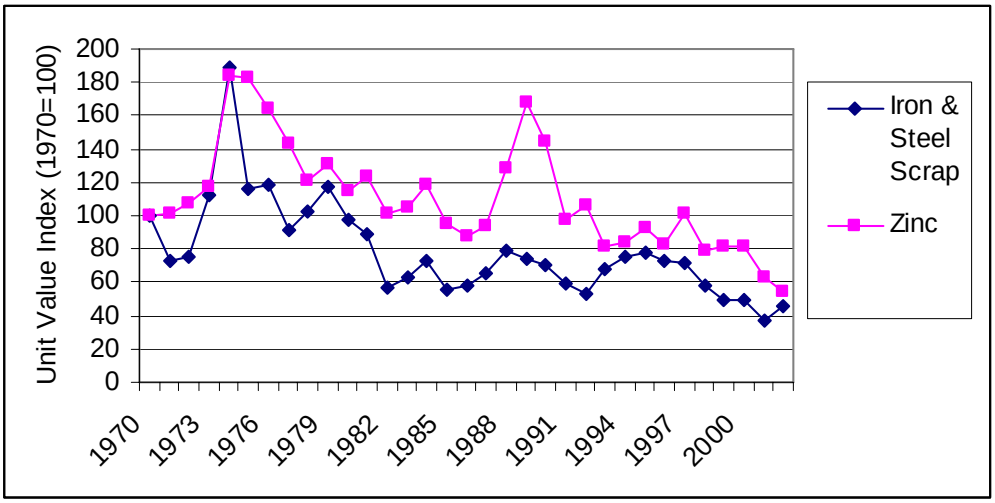
As discussed in the theoretical section of the paper, one of the factors that affects the acceptance fee is the availability of other disposal options in the area. If generators were indifferent between sending their waste to a landfill versus a recycler, we would expect the acceptance fee to be somewhere between $100/ton and $150/ton in the period 2002-2004, the period for which the landfill tipping-fee data are available (see Exhibit A-1). Given the high price of zinc, however, commercial recyclers may set the acceptance fee significantly lower than the landfill tipping fee to induce brass-dust generators to choose recycling over disposal. Thus, we would expect that the dominant revenue source for *commercial* brass dust recyclers is the revenue generated from the sale of zinc rather than the revenue generated from acceptance fees.[19]

The data on the commodity prices presented in Exhibit A-21 show that slumps in the price of zinc are, on average, eight months longer than booms in the price of zinc (32 and 24 months, respectively). This means that any period of a relatively high zinc price is followed by a longer period of a relatively low zinc price. The price of zinc has shorter price cycles than all other metals presented in Exhibit A-21, except lead. The average percentage change in the price of zinc is -41.2 percent during slumps and 43.2 percent during booms. The average change in the price of zinc during a slump (boom) is close to the average price change across 36 primary commodities (measured in percentage terms). The probability of a slump (boom) ending in the world zinc market is independent of the time spent in the slump.

Roughly three quarters of the supply of zinc is used in the iron and steel industry, with the rest being used in the rubber, chemical, paint, and agricultural industries. We would therefore expect that a main driving force behind the price of zinc is the supply and demand of iron and steel. Exhibit A-21 shows that the price of zinc has fluctuated historically with the price of iron and steel. The correlation coefficient for the price of the two materials is 0.75, indicating that the price of zinc is strongly influenced by the price of iron and steel.

[19] Although this is an important point, we should note that, based on the BRS data, commercial recyclers recycle a very small amount of brass dust.

Exhibit A-21: Price Index of Zinc Compared to Price Index of Iron and Steel, 1970-2002



Source: United States Geological Survey.

Conclusions

The following conclusions can be drawn from this empirical analysis:

- Most brass dust recyclers are inter-industry recyclers that receive their waste from firms in industries other than the one in which they operate. Only about one percent of the total amount of brass dust recycled in 2003 was recycled by commercial recyclers.
- Roughly three quarters of the supply of zinc is used in the steel and iron industry.
- A low recycling rate of brass dust indicates that recycled zinc is not freely substituted for zinc produced from virgin materials.
- There is asymmetry in the duration of zinc price slumps and booms, with slumps lasting, on average, eight months longer.
- The average change in the price of zinc during a slump (boom) is very close to the average price change across 36 primary commodities (measured in percentage terms).

A.2.4. Spent Pickle Liquor

Pickle liquor is an acid solution used to clean and condition steel in various steelmaking processes. Through re-use in the steel pickling process, the metals content in the solution builds up causing the solution to lose its desired chemical properties (i.e., to become "spent"). Thus, spent pickle liquor needs to be processed (i.e., regenerated) before it can be used again in steelmaking processes. Spent pickle liquor is considered hazardous waste (K062) by EPA and regulated under RCRA.

The discussion presented in this section is based on information from two main sources:

1. US Steel and Mittal Steel, US steel manufacturers, and

2. The 2003 EPA BRS.

US Steel and Mittal Steel Data

Unless otherwise noted, the information presented in this section was provided by US Steel and Mittal Steel during a telephone interview conducted in November, 2005. The information provided has not been independently verified by EPA.

Waste Management Options. There are three main options for spent pickle liquor. These options are disposal, reuse, and recycling, which is commonly referred to as regeneration.

- *Disposal.* Before the enactment of RCRA, it was a common industry practice to dispose of spent pickle liquor into lagoons. After RCRA labeled the material as a hazardous waste, deep-well injection became the most prevalent waste management option. Disposal is a common management method for spent pickle liquor largely due to cost and regulatory issues. It is often the cheapest option and also the simplest option for companies that are concerned about the regulatory issues around reusing it. It is thought, though, that cost does not totally drive these issues, as some companies would likely be willing to incur higher costs to recycle due to wanting to be perceived as environmentally sensitive. Based on the most recent industry data, 19 percent of generated spent pickle liquor was disposed of.

- *Direct Use*. Spent pickle liquor is used as a substitute for certain chemicals, with one example being use as a chemical additive at wastewater treatment plants. Some reusable products also result from the regeneration process. Based on the most recent industry data, 18 percent of generated spent pickle liquor is used in wastewater treatment plants.

- *Regeneration.* Prompted to some degree by environmental concerns, there has been a move to regeneration of spent pickle liquor within the steel industry.[20] In the early 1980s, approximately two percent (or 28 million gallons) of spent pickle liquor was recycled.[21] Regeneration is currently the most widely used waste management option, with over 60 percent of waste (or 114 million gallons) regenerated (AISI, 2005). The regeneration process is carried out both by commercial and intra-industry recyclers.

[20] In the process of regeneration, the water is cooked off and the iron is precipitated out. Fresh acid is then added to it so that it can be reused for pickling.
[21] Ferrante, J.G. and Sage, S.H. Spent Pickle Liquor in the Steel Industry: Finding the Path to P2. *Pollution Prevention Review*, Spring 1999.

Exhibit A-22: Spent Pickle Liquor – Industry Management (2004)

Total Generated	Total Regenerated	Direct Use WWTP Chemical	Use as Product Ingredient	Deep Well Injection
186,403,516	113,667,701	34,081,116	15,422,220	35,232,479

Note: All values are expressed in gallons.
Source: American Iron and Steel Institute, Memorandum to EPA, 2005.

Recycling Market. The steel industry is both a producer of spent pickle liquor and a main consumer of regenerated pickle liquor. Steel companies vary in whether they do regeneration onsite or offsite, with larger steel companies traditionally having regenerating facilities on one of their sites. Currently, there are no more than ten K062-regenerating facilities operating in the US.

K062-regeneration has relatively large capital cost requirements. The capital costs for building a spent acid regeneration plant can be as much as $30 million. High start-up costs indicate that economies of scale are needed to recover the investment. It is therefore a common practice for a regeneration plant to serve more than one steel mill, whether it is commercially owned or operated by a steel company. For the same reasons, the most economical way for a small steel company to regenerate its spent pickle liquor is to send it offsite.

The need to gain economies of scale by regenerating a greater quantity of spent pickle liquor than used in its own production implies that regeneration would likely need to be treated as a separate production process within a steel company. For example, because the consumers of finished steel products and regenerated pickle liquor are not the same, a steel company with a regeneration plant would likely need to develop two supply channels. This need to divert resources from its main operation (i.e., making steel) may discourage a steel company from operating a generation plant onsite. A steel company may find it more profitable to concentrate on making steel and outsource K062-regeneration.

Multi-year tolling arrangements are common in the industry. Such contracts benefit steel mills to the extent that they offer some protection from price fluctuations and a guarantee of a stable supply of fresh acid solution. Such contracts, however, give the industry less flexibility in switching between waste management options when, due to market conditions, other waste management methods become more economically favorable. For example, market conditions in the chemical industry may drive down the price of virgin pickle liquor, a byproduct of that industry, making it more cost effective for steel mills to use virgin acid solution instead of regenerated pickle liquor.[22]

The production of steel and regeneration of spent pickle liquor are both energy-intensive processes. Energy is a significant cost factor in the regeneration process since regeneration plants are designed to run continuously. Multi-year tolling arrangements

[22] The price per ton of virgin pickle liquor may not be directly comparable to the price per ton of regenerated solution, since, due to their different acidity levels, different quantities are needed to pickle a ton of steel.

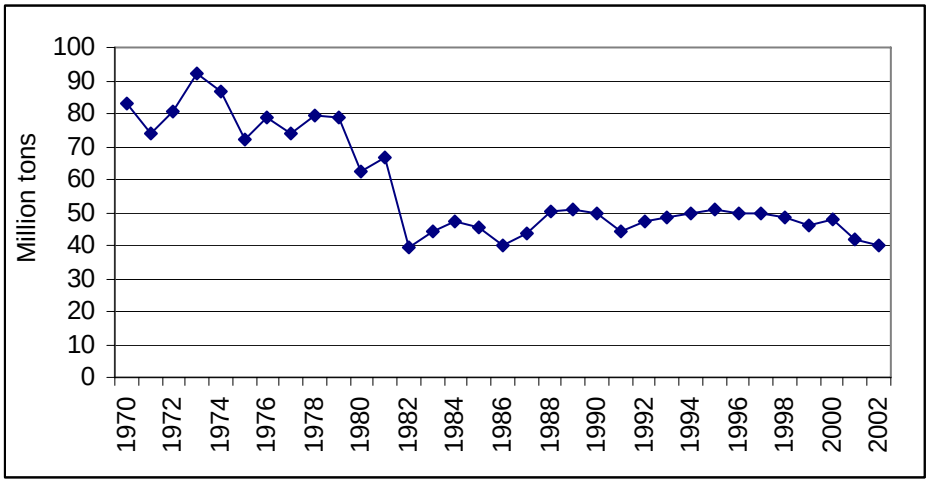
usually have a provision that allows for adjustments in electricity prices. With a multi-year tolling arrangement in place, a generator (i.e., steel mill) pays a regenerating facility for pickle liquor, the cost associated with the regeneration of spent pickle liquor, and transportation costs. Whether the generator pays commercial and inter-industry recyclers to take their spent pickle liquor or gets paid for it depends, in addition to market conditions, on transportation costs. Generators must usually pay if they are located far away from commercial and inter-industry recyclers.

Generators of spent pickle liquor also may send it to facilities for direct reuse. Depending on market conditions, entities using spent pickle liquor as a direct input (e.g., wastewater treatment plants) may pay the generators for the wastes.

Because spent pickle liquor is considered hazardous waste, environmental and health and safety regulations must be observed during its management. As a way of minimizing potential future liability, steel producers visit commercial recyclers that handle their spent pickle liquor on a regular basis to ensure they are handling the wastes properly.

The production level of the steel industry is the main driver of the market conditions for pickle liquor. Exhibit A-23 shows that the domestic annual production of iron and steel decreased significantly in the 70s, from 83 million tons in 1970 to 62 million tons in 1980. In the period 1981 to 2002, the production levels varied between 40 and 50 million tons per year. The average annual production in that period was about 47 million tons, with a standard deviation of 5.7 million tons (or twelve percent of the average annual production in that period).

Exhibit A-23: Iron and Steel Production, 1970 – 2002



Source: United States Geological Survey.

BRS and Other Publicly Available Data

The discussion in this section is based on the 2003 BRS data. Facilities handling spent pickle liquor were identified using both form codes and waste codes from BRS. The following BRS form codes were used in the selection: (1) "W101 - Very dilute aqueous

waste containing more than 99% water (land disposal restriction defined wastewater that is not exempt under NPDES or POTW discharge);" (2) "W103 - Spent concentrated acid (5% or more);" (3) "W105 - Acidic aqueous wastes less than 5% acid (diluted but pH <2);" (4) "W110 - Caustic aqueous waste without cyanides (pH >12.5);" and (5) "W113 - Other aqueous waste or wastewaters (fluid but not sludge)." In addition, waste code K062, which indicates that the waste exhibits the characteristic of toxicity for spent pickle liquor, was also used to identify facilities handling spent pickle liquor. We assumed that all waste spent pickle liquor would carry this waste code.

Exhibit A-24 presents the number of facilities that handled (i.e., managed and/or transported) spent pickle liquor in 2003, broken down by waste handling method and geographic region. The BRS data contained information on a total of 34 unique facilities that handled spent pickle liquor, all of which were actively involved in some type of waste management. Of the 34 waste management facilities, 10 facilities were engaged in waste transferring in addition to waste management.

Exhibit A-24: Waste Handling Method and Geographic Distribution for 34 Facilities Handling Spent Pickle Liquor (2003)

	Recycling	Disposal	Energy Recovery	Transfer	Treatment	Total
Northeast	-	1	-	2	2	5
Mid-Atlantic	-	-	-	2	5	7
South	-	3	-	1	2	6
Midwest	-	3	-	4	5	12
South Central	-	1	1	1	3	6
West Central	-	-	-	-	-	-
West	-	-	-	-	2	2
Total	**-**	**8**	**1**	**10**	**19**	**34**[1]

1) The total facility count is less than the column summation because some facilities engage in more than one type of waste handling activity.
Source: ICF Analysis, 2003 BRS.

Exhibit A-25 presents data on the amount of hazardous waste managed by method for facilities managing spent pickle liquor. A total of 281,733 tons of spent pickle liquor was managed by 34 facilities in 2003, with facilities managing 8,287 tons of waste on average. The vast majority of spent pickle liquor (233,433 tons or 83 percent) was disposed. A significantly smaller amount (slightly over 48,301 tons or 17 percent of the total waste managed) was treated in 2003.

The BRS data indicate that no recycling of spent pickle liquor was conducted in 2003. The industry data, however, indicated that a significant amount of recycling is being conducted. One potential reason for underreporting of spent pickle liquor recycling in the BRS could be that this waste is commonly reported as another applicable waste code in the BRS, as this waste is typically corrosive and contains metals. Facilities reporting spent pickle liquor to BRS may be using the code for wastes that are corrosive (D002) or one of the codes for wastes that are considered toxic due to the presence of metals.

Exhibit A-25: Waste Management Methods for Spent Pickle Liquor at 34 Facilities (2003)

	Amount Managed				
	Recycling	**Disposal**	**Energy Recovery**	**Treatment**	**Total**
Total (tons)	-	233,433	39	48,301	**281,773**
Total (percent)	-	83	<1	17	**100**
Average per Facility (tons)	-	29,179	39	2,542	**8,287**

Note: 154 tons of spent pickle liquor were transferred in 2003. Because activities related to transportation of waste are not considered waste management, information on the amount transported in 2003 is not included in the Exhibit.
Source: ICF Analysis, 2003 BRS.

Conclusions

The following conclusions can be drawn from this empirical analysis:

- Industry data indicate that most spent pickle liquor recyclers are commercial recyclers, as individual steel mills may not produce enough spent pickle liquor on a continuing basis to operate a recycling unit efficiently.
- High start-up costs indicate that economies of scale are needed to recover the investment. These characteristics imply that regeneration would likely need to be treated as a separate production process within a steel company.
- Like lead-acid battery recyclers, the main supplier of spent pickle liquor and the main consumer of the recycled spent pickle liquor are in the same industry, which simplifies the supply chain.
- Industry data indicate that, in 2004, about 60 percent of spent pickle liquor was regenerated and used in the steel industry.
- Because spent pickle liquor is considered a hazardous waste, environmental and safety concerns are high. As a way of minimizing potential future liability, steel producers visit commercial recyclers that handle their spent pickle liquor on a regular basis to ensure they are handling the wastes properly. Although such visits would increase the current operating costs of steel mills, they could help reduce their future liability risks.
- The iron and steel production has been relatively stable in the period 1980-2002, which would imply, all other things equal, that the demand for pickle liquor in that period was relatively stable as well.

A.2.5. Solvents

This study is primarily interested in industrial solvents used in dry cleaning of fabrics, and cleaning and degreasing of metal. As solvents are reused in industrial processes, they lose their cleaning/degreasing properties (i.e., become spent). Some spent solvents are considered hazardous waste by EPA and regulated under RCRA.

The discussion presented in this section is based on information from two main sources:

1. Safety-Kleen, a US commercial recycler of industrial solvents, and

2. The 2003 EPA BRS.

Safety-Kleen Data

Unless otherwise noted, the discussion in this section is based on the information provided by Safety-Kleen during a telephone interview conducted in November, 2005. The information provided has not been independently verified by EPA.

Safety-Kleen is the largest US commercial recycler of spent solvents. It operates more than 200 service and recycling centers throughout the North America.[23] The company recycles about 21 million gallons of solvents per year, with the majority being mineral spirits. Its primary customers are auto repair shops and other small business that use solvents.

A small part of Safety-Kleen's business is done through tolling agreements, likely because such arrangements are impractical for small quantities of solvents it collect from its main customer base. Its dominant business strategy is to collect spent solvents from its customers and supply them with regenerated solvents. Its wide geographic presence of collection and recycling centers enables Safety-Kleen to gain from economies of scale while minimizing transportation costs.

Solvent recycling involves capital and operating costs which may deter some small generators form recycling onsite. For example, in addition to a RCRA permit, an onsite recycler would need to have a trained person to oversee recycling process and make sure that regulations are being followed.

Commercial recyclers mostly get paid to accept spent solvents from their customers (unless the virgin solvent is very valuable, in which case the recycler may pay for spent solvent). The acceptance fee is dynamic and can change quickly. These fluctuations would likely be harder for smaller, more specialized companies to handle. The acceptance fee also is correlated with fuel costs where spent solvents are commonly being used as fuel substitution. The price for recycled solvents, although relatively stable, has been eroding over time most likely due to over-capacity in the industry and downsizing related to waste and waste handling in the late 1990's. Market prices for recycled solvents have a regional component, since demand and transportation costs vary. The price for recycled solvents is not always lower than the price of virgin solvents.

BRS and Other Publicly Available Data

The discussion in this section is primarily based on the 2003 BRS data. Solvent recyclers were identified using both the form codes and the waste codes from BRS. The following BRS form codes were used: (1) "W202 - Concentrated halogenated (e.g., chlorinated) solvent;" (2) "W203 - Concentrated non-halogenated (e.g., non-chlorinated) solvent ;"(3) "W204 - Concentrated halogenated/ non-halogenated solvent mixture; and (4) "W219 -

[23] Hoovers, available at http://www.hoovers.com/safety-kleen-systems,-inc./--ID__11287--/free-co-factsheet.xhtml.

Other organic liquid." The following BRS waste codes were used: (1) F001 – Carbon Tetrachloride, Methylene Chloride, Trichloroethane, Perchloroethylene (Tetrachloroethylene), and Trichloroethylene; (2) F002 – Chlorobenzene, O-Dichlorobenzene, Methylene Chloride, Trichloroethane, Perchloroethylene (Tetrachloroethylene), Trichloroethylene, Trichlorofluoromethane, and Trichlorotrifluoroethane; and (3) F005 – Benzene, Carbon Disulfide, 2-Ethoxyethanol, Isobutanol, Methyl Ethyl Ketone, Pyridine, and Toluene. Wastes that carried any combination of the above listed form codes and waste codes were assumed to be solvents.

Exhibit A-26 presents the number of facilities that handled (i.e., managed and/or transported) solvents in 2003, broken down by waste handling method and geographic region. The BRS data contained information on a total of 426 unique facilities that handled solvents, all of which were actively involved in some type of waste management. Of the 426 waste management facilities, 235 facilities were engaged in waste transferring in addition to waste management. The BRS data indicate that 153 entities were engaged in recycling of spent solvents in 2003. Of the 153 entities, 27 were commercial recyclers (3-digit NAICS code 562).[24]

Exhibit A-26: Waste Handling Method and Geographic Distribution for 426 Facilities Handling Solvents (2003)

	Recycling	Disposal	Energy Recovery	Transfer	Treatment	Total
Northeast	25	2	6	19	7	**59**
Mid-Atlantic	20	1	10	20	9	**60**
South	32	-	16	46	12	**106**
Midwest	36	-	25	46	14	**121**
South Central	12	4	15	63	17	**111**
West Central	11	1	4	19	4	**39**
West	17	1	7	22	7	**54**
Total	**153**	**9**	**83**	**235**	**70**	**426**[1]

1) The total facility count is less than the column summation because some facilities engage in more than one type of waste handling activity.
Source: ICF Analysis, 2003 BRS.

Exhibit A-27 presents data on the amount of hazardous waste managed by method for facilities managing solvents. A total of 1,033,615 tons of solvents was managed by 426 facilities in 2003, with facilities managing 2,426 tons of waste on average. The vast majority of solvents (694,170 tons or 67 percent) was used as a substitute for fossil fuels in boilers and industrial furnaces. This practice is especially common in chemical and cement industries. Significantly smaller amount (slightly over 107,000 tons or 10 percent of the total waste managed) was recycled in 2003. The average amount recycled per facility was 700 tons.

[24] SRI Consulting estimated that there were 32 commercial recycling companies at the end of 1997 (SRI Consulting, 1998).

Exhibit A-27: Waste Management Methods for Solvents at 426 Facilities (2003)

	Amount Managed				
	Recycling[1]	**Disposal**	**Energy Recovery**	**Treatment**	**Total**
Total (tons)	107,465	19,894	694,170	212,086	**1,033,615**
Total (percent)	10	2	67	21	**100**
Average per Facility (tons)	702	2,210	8,363	3,030	**2,426**

1) Solvents recycling may include some or all of the following activities: phase separation, batch distillation, thin film evaporation and fractional distillation (SRI Consulting, 1998).
Note: 174,672 tons of solvents were transferred in 2003. Because activities related to transportation of waste are not considered waste management, information on the amount transported in 2003 is not included in the Exhibit.
Source: ICF Analysis, 2003 BRS.

Exhibit A-28 provides information on the flow of hazardous waste for solvents. The first set of columns presents the NAICS codes for the generators of waste that went to recycling facilities, and the second set of columns presents the NAICS codes for the recycling facilities.

Exhibit A-28: Recycling of Solvent - Flow of Hazardous Waste, by Industry (2003)

Generators	NAICS	Percent of Waste Supplied[1]	Recycling Facilities	NAICS
Pharmaceutical and Medicine Manufacturing	32541	27	Hazardous Waste Treatment and Disposal	562211
Pharmaceutical Preparation Manufacturing	325412	21		
Medicinal and Botanical Manufacturing	325411	7		
Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	332812	2	Materials Recovery Facility	56292
Rolling and Drawing of Purchased Steel	33122	1		
Fabric Coating Mills	31332	1		
Paint and Coating Manufacturing	32551	100	Paint and Coatings Manufacturing	32551
Paint and Coating Manufacturing	32551	67	Other Chemical and Allied Products Merchant Wholesalers	42469[2]
Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	332812	17		
Adhesive Manufacturing	32552	6		
Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing	32613	100	Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing	32613

1) Waste supplied by generators in each industry as a percentage of the total waste recycled.
2) The NAICS code recorded in the BRS database was not valid (NAICS code 42269). After checking the company's name and activities, we determined that the appropriate NAICS code was 42469.
Note: The exhibit presents only the top three industries (in terms of the amount of waste supplied) for which NAICS codes were available. For example, the hazardous waste treatment and disposal facilities (NAICS code 562211) recycled 33,504 tons of solvents in 2003, of which 9,209 tons, or 27 percent, were supplied by facilities in the pharmaceutical and medicine manufacturing industry (NAICS code 32541). Close to 20 percent of waste was supplied by industries for which data on the generators' NAICS codes are not available in the BRS database.
Source: ICF Analysis, 2003 BRS.

There are three main types of commercial recycling arrangements. They are: toll recycling, speculative recycling and commercial waste brokers. In a toll recycling arrangement, a recycler collects spent solvents from a generator, recycles them and returns regenerated solvents to the generator. With speculative recycling arrangements, a recycler collects spent solvents from generators, recycles them and sells them on the market as regenerated solvents. If the value of a virgin solvent is high, a recycler engaged in speculative recycling is likely to pay the generator for the spent solvent. Wastes also can be handled by commercial waste brokers. A broker facilitates trade

between generators and recyclers and/or facilities which use waste as a feedstock. In some cases, brokers may warehouse spent solvents until they find a buyer.[25]

Exhibit A-29: Distribution of Facilities Recycling Solvents, by Industry (Top Five Industries; 2003)

Industry	NAICS	Total Amount Recycled (tons)	Amount Recycled as a Percentage of the Total	Number of Facilities	Average Amount Recycled per Facility (tons)
Hazardous Waste Treatment and Disposal	562211	33,504	31	24	1,396
Materials Recovery Facility	56292	21,498	20	2	10,749
Paint and Coatings Manufacturing	32551	12,150	11	15	810
Other Chemical and Allied Products Merchant Wholesalers	42269	10,844	10	1	10,844
Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing	32613	4,791	4	3	1,597

Source: ICF Analysis, 2003 BRS.

The BRS data indicate that 107,465 tons of solvents were recycled in 2003, of which 53 percent was recycled by commercial recyclers.[26] The commercial recycling market was dominated by two facilities in 2003; one recycled close to 11,000 tons and the other recycled over 9,000 tons of solvents. The data presented in Exhibit A-28 and Exhibit A-29 indicate that at least 15 percent of the total amount of solvents recycled in 2003 was recycled by intra-company recyclers (NAICS codes 32551 and 32613).

Exhibit A-30 presents revenue data for each industry that performs solvents recycling. The revenue data in Exhibit A-30 includes all revenue for the industry, including revenue not related to solvents recycling. Because revenue data were available for entire industries, and not for individual facilities that perform solvents recycling, the data in Exhibit A-30 includes facilities that are not engaged in recycling.

[25] Michigan Department of Environmental Quality. 1998. "Considerations in Selecting a Commercial (Off-site) Solvent Recycling Service." *Fact Sheet.*

[26] In addition to the commercial recyclers presents in Exhibit A-29 (NAICS codes 562211 and 56292), the BRS data indicate that additional 1,660 tons of solvents (or two percent of the total amount recycled in 2003) were recycled by commercial recyclers with the NAICS code 56221.

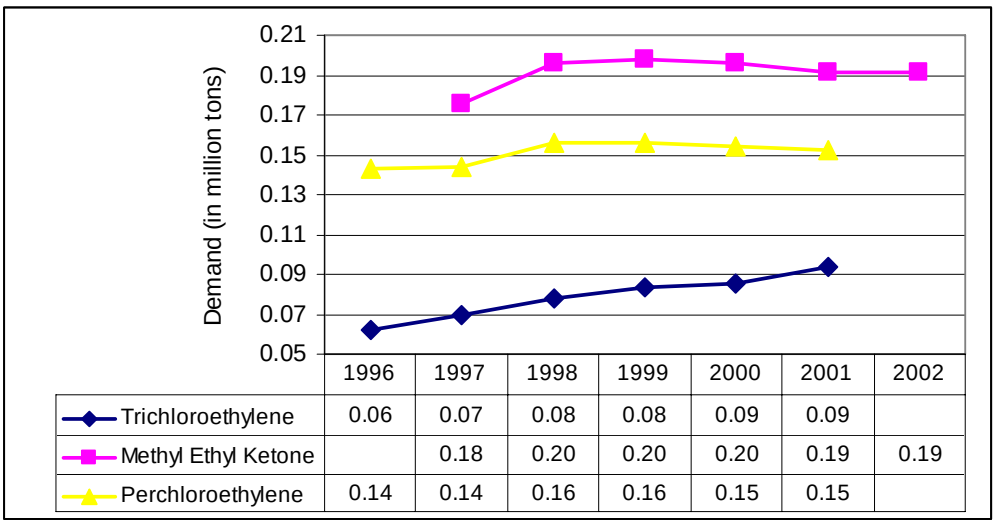
Exhibit A-30: Characteristics of Industries in Which Some Facilities are Engaged in Recycling Solvents

Industry	NAICS	Total Number of Companies	Percent of Facilities Conducting Recycling[1]	Total Industry Revenue (millions)	Average Revenue per Facility (millions)
Hazardous Waste Treatment and Disposal	562211	696	3	$3,466	$5.0
Materials Recovery Facility	56292	838	<1	$1,835	$2.2
Paint and Coatings Manufacturing	32551	1,409	1	$19,257	$13.7
Other Chemical and Allied Products Merchant Wholesalers	42269	11,117	<1	$88,065	$7.9
Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing	32613	294	1	$2,314	$7.9

1) The percentage is calculated using the total number of recyclers presented in Exhibit A-29.
Source: ICF Analysis, Census 2002, 2003 BRS.

The exhibits below illustrate demand and prices for production of virgin trichloroethylene, methyl ethyl ketone, and perchloroethylene for the period 1996 to 2002.[27,28]

Exhibit A-31: Demand of Virgin Trichloroethylene, Methyl Ethyl Ketone, and Perchloroethylene (1996 – 2002)



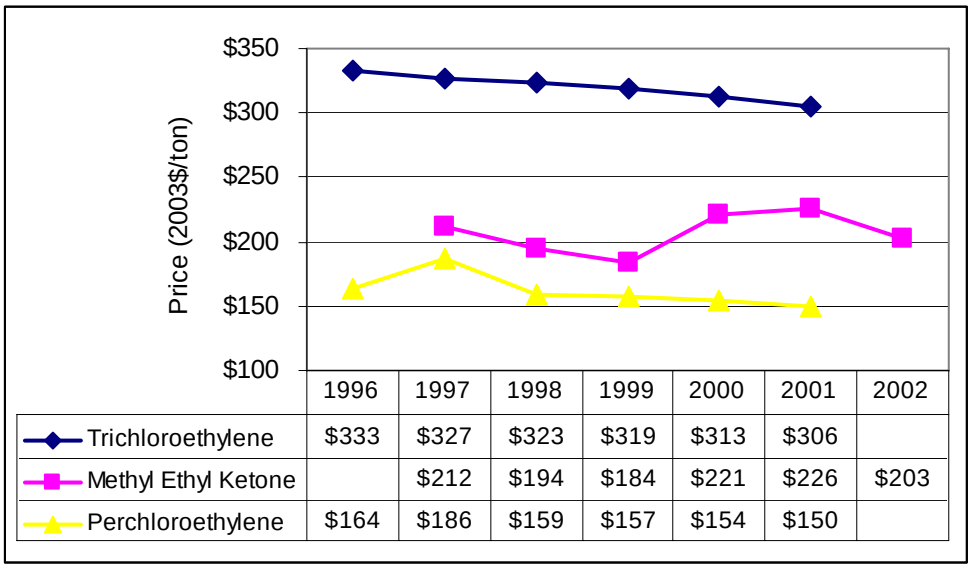
	1996	1997	1998	1999	2000	2001	2002
Trichloroethylene	0.06	0.07	0.08	0.08	0.09	0.09	
Methyl Ethyl Ketone		0.18	0.20	0.20	0.20	0.19	0.19
Perchloroethylene	0.14	0.14	0.16	0.16	0.15	0.15	

Notes: (1) Demand equals production plus imports minus exports. (2) Empty cells indicate years for which data were not available. (3) Data were converted from pounds to tons.
Source: The Innovation Group, available in "Chemical Profiles" at http://www.the-innovation-group.com/welcome.htm.

[27] Comparable data for recycled solvents were not publicly available from the same source.
[28] Uses: *Trichloroethylene* - hydrofluorocarbon intermediate (67%); metal degreasing (30%);miscellaneous (3%). *Methyl ethyl ketone* - coatings solvent (55%); adhesives (14%); chemical intermediates (7%); lube oil de-waxing (6%); magnetic tapes (5%); printing inks (4%); miscellaneous (9%). *Perchloroethylene* - chemical precursor (65%); dry cleaning (15%); metal cleaning and vapor degreasing (10%); miscellaneous (10%) (Source: The Innovation Group).

The price of trichloroethylene decreased in real terms in the period from 1996 to 2001 (in nominal terms, the price was constant). The price of perchloroethylene also decreased (in real terms) over the same period. There was, however, a one-year spike in the price in 1997. The price of methyl ethyl ketone was the most volatile of the three solvents.[29] Caution should be exercise when drawing conclusion based on these data as they are available only for a short period of time and thus may not be representative of the historical prices.

Exhibit A-32: Price of Virgin Trichloroethylene, Methyl Ethyl Ketone, and Perchloroethylene (1996 – 2002)



	1996	1997	1998	1999	2000	2001	2002
Trichloroethylene	$333	$327	$323	$319	$313	$306	
Methyl Ethyl Ketone		$212	$194	$184	$221	$226	$203
Perchloroethylene	$164	$186	$159	$157	$154	$150	

Note: Data for methyl ethyl ketone for 1996 were not available. Data for trichloroethylene and perchloroethylene for 2002 were not available.
Source: The Innovation Group, available in "Chemical Profiles" at http://www.the-innovation-group.com/welcome.htm.

Exhibit A-33: Summary Statistics for the Annual Price of Virgin Trichloroethylene, Methyl Ethyl Ketone and Perchloroethylene (1996 – 2002)

	Annual Price (2003$/ton)		
	Trichloroethylene	**Methyl Ethyl Ketone**	**Perchloroethylene**
Minimum	$306	$184	$150
Maximum	$333	$226	$186
Mean	$320	$207	$162
Median	$321	$207	$158
Standard Deviation	$10	$16	$13

Note: All Values are in 2003 dollars. Source: ICF Analysis, The Innovation Group.

Exhibit A-34 presents the prices for virgin and reclaimed trichloroethylene, methyl ethyl ketone, and perchloroethylene in 1997. The data indicate that, on average, reclaimed solvents were 30 to 65 percent less expensive than virgin solvents in that year. We

[29] We defined volatility as the standard deviation of the annual percent changes.

combine these data with the information presented in Exhibit A-32 to estimate the price of reclaimed solvents for one of the years for which we have a proxy for the acceptance fee. The calculations, presented in Exhibit A-35, are based on a simplifying assumption that the difference between the price of a reclaimed and virgin solvent (in percentage terms) stayed constant.

Exhibit A-34: Price for Virgin and Reclaimed Trichloroethylene, Methyl Ethyl Ketone and Perchloroethylene (1997)

	Price in $/gallon		Price of Reclaimed Solvent as a Percentage of Price of Virgin Solvent
	Reclaimed	Virgin	
Trichloroethylene	4.00 – 5.44	7.93	50% - 69%
Methyl Ethyl Ketone	2.10	3.09	68%
Perchloroethylene	2.69 – 4.71	7.40	36% - 64%

Source: SRI Consulting, 1998.

Exhibit A-35: Estimated Price for Reclaimed Trichloroethylene, Methyl Ethyl Ketone and Perchloroethylene (2001)

	Formula	Trichloroethylene	Methyl Ethyl Ketone	Perchloroethylene
Price of Virgin Solvent in 2001 ($/ton)	A	$306	$226	$150
Price of Reclaimed Solvent as a Percentage of Price of Virgin Solvent	B	69%	68%	64%
Derived Price of Reclaimed Solvent in 2001 ($/ton)	C = A*B	$211	$154	$96
Derived Price of Reclaimed Solvent in 2001 ($/gallon)	D = C/[1/(density/ 120)* 2,200]	$1.17	$0.47	$0.59
Derived Price of Reclaimed Solvent in 2001 ($/drum)	D * 55	$64	$26	$32

Note: Density of trichloroethylene = 1,460 Kg/m^3; density of methyl ethyl ketone = 805 Kg/m^3; density of perchloroethylene = 1,622 Kg/m^3.

We estimate that the price of reclaimed trichloroethylene was $64 per a 55-gallon drum in 2001. That amount is significantly lower than the proxy acceptance fee of about 112$/drum.[30] The difference between the price of regenerated solvents and the acceptance fee is even more pronounced for the other two solvents. These results indicate that some commercial recyclers may have generated more revenue from the acceptance fees than from the sale of regenerated solvents in 2001.

[30] As explained in Section 3.2.1, we use the landfill disposal fees as a proxy for acceptance fees. We hypothesize that the landfill disposal fee for "drummed with treatment waste" in 2002, the earliest year for which we have data, approximates the acceptance fee for a 55-gallon of spent trichloroethylene in 2001.

Conclusions

The following conclusions can be drawn from this empirical analysis:

- Over 50 percent of the total amount of solvents recycled in 2003 was recycled by commercial recyclers. At least 15 percent of the total amount of solvents recycled in the same year was recycled by intra-company recyclers.
- The commercial recycling market is dominated (in terms of the amount recycled) by a single recycling firm.
- Some commercial recyclers may generate more revenue from the acceptance fees than from the sale of reclaimed solvents.

A.2.6. Drums

The discussion presented in this section is based primarily on the information received during a telephone interview with a representative from the Reusable Industrial Packaging Association (RIPA), conducted in November, 2005. Based on availability, data from other sources were used to support or verify the information received from the RIPA.

Drums are used for transporting chemical products, and can be made out of steel or plastic. The main product in the drum industry is the 55-gallon drum. There are roughly 40 million steel drums manufactured every year and roughly the same amount that are reconditioned for reuse.

Exhibit A-36: Number of Drums Reconditioned Annually

Container Type	Number of Drums Reconditioned (in millions)
Steel Drums	31.2
Plastic Drums	8.3
IBCs	0.5
Total	40.0

Note: IBC - intermediate bulk containers.
Source: EPA, Preliminary Data Summary for Industrial Container and Drum Cleaning Industry, June 2002.

Waste Management Options. Two main waste management options for handling used empty drums are reconditioning and scrapping.

- *Reconditioning*. The drum reconditioning industry is dominated by commercial reconditioners who handle only "RCRA empty" drums. To be considered "RCRA empty," a used drum needs to have less than one inch of product remaining in it. Drums meeting this standard are outside of RCRA jurisdiction, i.e., they are not considered hazardous waste by EPA. Drums that are not "RCRA empty" are returned to the generator. One factor that determines whether it is cost effective to recondition a drum is its condition. Damaged drums that cannot be reconditioned to a specific standard are sold to a scrap yard.

- *Scrap*. Used steel drums may be scrapped for metal rather than reconditioned. Drums that are damaged are more likely to be scrapped. Thinner drums are more likely to get damaged and thus less likely to be reconditioned. The trend in the drum manufacturing industry has been to reduce the thickness of drums. The characteristics of new drums thus affect to some extent the rate at which drums are scrapped. Even when drums are scrapped, a reconditioning facility will wash it before selling it to a scrap yard.

Recycling Market. Drum reconditioning involves significant capital costs, as there is very specialized equipment used to clean out drums. Most drum reconditioning is done by commercial facilities whose primary business is industrial container and drum cleaning (i.e., rather than manufacturing of drums or products transported in drums). More than half of the container and drum cleaning facilities also engage in transportation equipment cleaning. EPA estimates that there are close to 300 industrial container and drum cleaning facilities.

Exhibit A-37: Total Number of Industrial Container and Drum Cleaning (ICDC) Facilities

Type of ICDC Facilities	Number of Facilities	Small Business
Non TEC Facilities	118	60%[1]
TEC Facilities	173	30%[2]
Total	291	42%[3]

1) The Reusable Industrial Packaging Association (RIPA) estimate; size cutoff unknown.
2) EPA estimate with a threshold of less than 5 million in annual revenue.
3) Weighted average.
Note: TEC - transportation equipment cleaning.
Source: EPA, Preliminary Data Summary for Industrial Container and Drum Cleaning Industry, June 2002.

There are about 75 companies that are part of the RIPA. These companies have about 120 plants in total. These firms primarily operate by accepting drums, reconditioning them, and then selling reconditioned drums on the market. Tolling agreements are less common in this industry. There has been very little entry or exit in the drum reconditioning market, and most of the companies in the industry have been in operation for several generations. The average reconditioning plant processes about 1,500 to 3,000 drums per day. There are some economies of scale in the industry, as it would be hard to recover costs by reconditioning a small amount of drums. The 3,000 drums per day per facility is likely to be the maximum capacity. At any greater production, the supply of reconditioned drums would likely exceed the demand. This limitation may indicate that most drum reconditioning facilities operate locally.

Larger drum reconditioning facilities are likely to have the equipment (i.e., at least one truck and a few trailers) to offer storage and transportation services to their customers. For instance, a drum reconditioner may leave an empty trailer at a customer's manufacturing site to be used for storing empty drums. Once the trailer is full, the reconditioner will haul the empty drums to its reconditioning facility.

There is a potential liability cost associated with putting a drum on the market that does not meet required safety specifications. Each reconditioned drum must be certified by the reconditioner and thus can be tracked back to him should it fail the Department of Transportation safety test. The failure to meet the test carries a financial penalty. Thus, the reconditioning facilities have an incentive to maintain high quality standards.

Reconditioned drums are about 20 percent less expensive than new ones. To some extent, the difference in price may be explained by the perceived risk of contamination. Specifically, some manufacturers may not use reconditioned drums at all or may not use them for high value products for the fear that there may be waste residue that could contaminate their product. Therefore, reconditioned drums are most often used for lower value products.

A main factor that determines recycling and reconditioning rates is the price of steel. When the price of steel is high, less new steel drums are demanded as consumers shift to less costly options (e.g., plastic drums). Less new drums produced means that there are fewer drums available for reconditioning. The price of steel also determines whether drum reconditioners pay or get paid to accept drums. When the price of steel is high, used drums are more scarce and reconditioners usually pay a small amount to accept them. There is a tipping point in the price of scrap steel at which it is more cost effective for a drum reconditioner to pay for a used drum, wash it, and then scrap it rather than recondition it and sell it on the market.

Conclusions

The following conclusions can be drawn from this empirical analysis:

- Based on the profile of the RIPA members, the drum reconditioning market is likely dominated by commercial recyclers, with daily capacity of 1,500 to 3,000 drums.
- Reconditioners are expected to deal only with “RCRA empty” drums and are thus not regulated under RCRA. Lower regulatory constraints would imply lower operating costs.
- Based on the RIPA information, there has been very little entry or exit in the drum reconditioning market. The relatively constant number of recyclers, all other things equal, would imply that the market is stable.
- Drum-reconditioning rate is affected by the price of steel. There is a tipping point in the price of scrap steel at which it is more cost effective for a recycling facility to sell drums to a scrap yard than to recondition them.
- Reconditioned drums are, on average, 20 percent less expensive than new ones and are mostly used for lower value goods.

A.3. Summary

Exhibit A-38 summarizes recycling market characteristics for the five hazardous wastes.

Exhibit A-38: Characteristics of the Markets for Recycled Materials

Variables	Implications	Used Lead-Acid Batteries	Brass Dust	Spent Pickle Liquor	Spent Solvents	Empty Used Drums
Effect on Price						
Are generator and consumer in the same industry?	If yes, it may be easier for recyclers to forecast demand.	Yes	Yes	Yes	Not necessarily	Not necessarily
Are consumers heterogeneous (in terms of NAICS)?	If yes: - Potentially lower volatility in total demand - Potentially higher marketing costs.	No	No	No	No	Yes
Are tolling agreements dominant?	If yes, recyclers are at least to some extent protected from price fluctuations.	Yes	NA	Yes	No	No
Is there no clear substitute?	If yes, recyclers have more market power, recycled materials have a higher price, and there is less price volatility.	No, virgin lead	No, zinc	No, virgin pickle liquor	No, virgin solvents	No, new steel drums or plastic drums (for some goods)
Is the substitute more expensive?	If yes, it may reduce volatility introduced by substitutes, and the recycled product has a clear market niche for lower-valued uses.	Yes	Yes	Varies	Varies	Yes
Effect on Costs						
Are recycling facilities mainly commercial?	If yes, capital costs or potential liability may be perceived to be too high by potential industrial recyclers.	No	No	Yes	Yes	Yes
Is the market dominated by a few large recycling facilities?	If yes, smaller facilities may need to be innovative to stay in the market or gain market share (i.e., larger facilities may have advantage through economies of scale).	The BRS data indicate that a single facility dominates the market	Yes	Likely	Yes	No

Variables	Implications	Used Lead-Acid Batteries	Brass Dust	Spent Pickle Liquor	Spent Solvents	Empty Used Drums
Does the material fall under RCRA jurisdiction?	If yes, - recycling may be discouraged by the regulatory complexities involved - there are liability implications.	Yes	Some brass dust may not be regulated as a solid waste under RCRA under the exclusion for scrap metal	Yes	Yes	No, emptied drums are supposed to be "RCRA empty"

Note: NA – information not available.

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