Implications of Regulation and Policy on Economics of Vehicle Recycling

by

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Abstract

Technology forcing regulations, as a tool used by policymakers, often face skepticism and scrutiny by stakeholders who may be adversely affected by their implementation. In the case of the European Union's impending End-of-Life Vehicle Directive, high recycling targets initiated controversy over additional costs and who should be responsible for these costs, in addition to the targets' technology feasibility. A technical cost model was developed to address some of these concerns and uncertainties. The model included four major or potential economic operators or technologies involved in the recycling phase of vehicles.

The models were used to test two major categories of implementation scenarios: incremental vs. radical. Results showed that an incremental scenario that introduced "end-of-pipe" technology is most cost-effective and can potentially achieve the Directive's targets. However, a radical scenario, though costs are higher, may stimulate the creation of an integrated remanufactured parts market. A cost model, such as this one, can be useful in examining the economic feasibility of impending regulations requiring technology development and develop cost-effective paths for implementation.

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Table of Contents

Table of Figures

Table of Tables

1 Overview

In 1997, the European Commission put forth a controversial proposal for managing end-of-life vehicles (ELVs) in the EU. This Directive was meant to encourage two complementary strategies of avoiding waste by improving product design and increasing recycling and reuse of waste[1]. Under major opposition from industry, it has taken three years for the Directive to progress through the labyrinth of EU legislation and now awaits approval of final amendments. While several of the EU's member states had previously adopted similar directives, this new proposal's larger scope would have greater impact on automakers and all economic operators within the recycling infrastructure. Industry stakeholders, including automakers, suppliers, and recyclers[1], fear the worst in terms of increased costs, major market distortions, and exiting of key economic operators if all requirements of the ELV Directive become mandatory. Furthermore, stakeholders are questioning technology feasibility, implementation, enforcement, and legality of retroactive responsibilities. These questions are not unique to this particular issue but are indicative of any policies attempting to capture external costs through use of "Extended Producer Responsibility" principles and technology forcing. As such, these legal instruments may be necessary tools in achieving some greater societal goal. Nevertheless, fairly evaluating these tradeoffs require knowledge of these policies' actual implementation costs. In order to address some of these questions in a systematic, transparent manner, my thesis examines economic implications of the ELV Directive case through the use of technical cost modeling, scenario testing, and stakeholder assessment. We will also discuss how such a policy might push stakeholders to innovate and, perhaps, drastically change the current market structure in a cost effective manner. This thesis attempts to highlight key economic and technical factors that may offer alternative solutions or change of focus for stakeholders.

The key points in the Directive that alarm industry stakeholders most are specific recycling targets, recyclable material content in vehicle design, drastic reductions and recovery of certain hazardous chemicals, and producer bears "all or most of the" costs for

[1] Recyclers refer to economic operators involved with the recycling and disposing of ELVs, mainly addressing dismantlers, shredders, nonferrous separators, and, to some extent, new technology entrants.

achieving the goals. The Directive sets specific recyclable content and recycling targets for automakers to meet by 2006 and 2015. While current recycling levels hover around 75% by weight (due to metal content), the Directive will require that material recycling/recovery must be increased to 80/85% by 2006 and to 85/95% by 2015. This means "all" ELVs must be reused and/or recycled to a minimum of 80% and reused and/or recovered to a minimum of 85% by 2006. Clear distinctions exist for these terms, namely that even if certain materials or parts cannot be *recycled*, they should be *recovered* for energy recovery or future processing so as not to enter landfills[2].

Additionally, exact details such as whether vehicles made before the Directive (retroactive) must also be recycled at target levels are still in dispute[3]. Furthermore, the European Commission is adamant that the last user shall not bare the cost of disposal. Due to expected increases in cost to meet recycling targets, automakers/dealers are mandated to bear all or most of the burden of any additional costs in order to push producers to design for disassembly, recycling, and hazardous material reduction/elimination. At the same time, producers will be responsible for actual recycling and recovery when vehicles enter the existing recycling infrastructure.

From the point of view of industry stakeholders and producers, they fear the Directive may affect the normal mechanisms of the market and artificially support an unprofitable, inefficient recycling system without a growing secondary materials market. Vehicle owners will eventually pay for any added costs through higher vehicle prices[2]. The ELV Directive also creates conflicts with other regulatory goals automakers have agreed to meet, such as fuel economy, emissions reductions, and vehicle safety which makes these goals even more technically difficult[3]. In addition to these external issues, automakers need to address internal corporate goals such as, manufacturability, affordability, performance, and market appeal. With these mounting concerns, it is

[2] "Reuse" shall mean any operation by which components of end of life vehicles are used for the same purpose for which they were conceived. "Recycling" shall mean the reprocessing in a production process of the waste materials for the original purpose or for other purposed excluding the processing for use as fuel or as other means of generating energy. The reason for this definition of recycling lies with the necessity to clarify that the burning of fuels obtained by chemically recycling plastic components is not to be considered a form of recycling. "Recovery" shall mean any of the applicable operation provided for in Annex II B to Directive 75/442/EEC. "Energy recovery" shall mean the of combustible...waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat.

[3] For full legislative history, refer to appendix.

important to understand the overall strategic implications of such a mandate in economic, technological and political terms and what each stakeholder's role is for its success.

This thesis attempts to address some of these issues by adopting technical modeling tools commonly employed at the Material Systems Lab. The models draw upon cost and efficiency characteristics of four key economic operators in the industry: disassemblers, hulk shredders, nonferrous separators, and emerging ASR separators. By using technical cost models and scenario analysis, we can form an economic basis for examining tangible costs for stakeholders and important market drivers: additionally, external costs and benefits, such as land filling avoidance gains, contributes to overall determination of feasibility and acceptability. The concept of marginal costs for incremental improvements will also be explored.

Since information related to ELV recycling has been, in part, US oriented (in terms of operational, technical, and pricing data) we will refer occasionally to the functions of US recyclers and will need to modify data to suit European standards and costs. Slight discrepancies should not pose a problem because their overall market structures are consistent. While the political system and priorities of the EU differ somewhat from that of the United States, such a Directive will have impact on all international auto producers and suppliers who conduct business in Europe. Additionally, in a larger scope, if this Directive proves successful, in the eyes of regulators, for reducing waste, increasing recycling, and forcing drastic changes in vehicle design, implementation in the US may be in the foreseeable future. On the other hand, some might argue that the Directive might stagnate upon implementation like other waste management legislation, notably plastics recycling set by member states where “public intervention” has not been enough to stimulate market demand or zero-emission vehicles mandated by California law.

2 Background

From the point of view of the EU government, recycling is crucial in achieving global sustainability by reducing the amounts of primary materials used in the economy and diverting materials from entering landfills[4]. In addition to promoting sustainable use of resources, the EU governments perceive recycling to promote social employment and professional reintegration. In fact, some studies conclude that it creates 5 to 7 times the number of jobs than for incineration and 10 times more than landfilling. The EU Commission estimates employment within the recycling sector to be around 350,000[5]. Additionally, the amount of secondary raw materials that the recycling industry provides to the manufacturing industry is increasing, driven by either cost or regulation. The existing statistics[4] show that at least 50% of paper and steel, 43% of glass and 40% of nonferrous metals produced in the EU are currently produced from recycled household (post consumer) and industrial (post production) waste materials. Other materials such as plastics and rubber are also being recycled, though at a much lower rate, due to technical and market barriers[6]. In order to understand the issues and limitations surrounding recycling and its regulation, we first must examine the recycling infrastructure currently existing in the EU and its associated market forces.

2.1 Recycling Infrastructure in EU

Recyclable materials like metals, and to a lesser extent, paper have achieved recognition as commonly traded, profitable commodities on the world market. They complement the use of virgin materials in cases such as steel production using electric arc furnace (EAF) or paper and cardboard produced with significant recycled content. In these cases, it is quite economical for producers to use recovered materials to lower energy and raw material costs. Energy consumption for primary materials production versus secondary materials differs significantly and leads to beneficial cost reductions. For example, remelting of secondary aluminum (26 MJ/kg) consumes only ~14% of energy relative to production of primary aluminum(190-200 MJ/kg) and electric arc furnaces using secondary steel (18 MJ/kg) consumes only 45% of the energy used in primary steel production with blast oxygen furnaces (40 MJ/kg)[7]. However, for polymers, the energy and cost benefits for recycling are less notable, making incineration for energy recovery a more economical option.

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[4] Statistics are recognized by the European Commission to be inconsistent and fragmented due to unstructured data reporting and collection.

Important factors for successful recycling schemes include quality of feedstock and maturity of a secondary materials market and infrastructure. In discussing quality of feedstock, the feed streams can be segmented into post- production and post-consumer wastes. Post-production waste, because of its limited points of origin, is generally characterized as clean, fairly homogeneous, and, therefore, easily recycled. However, most recycling problems stem from post-consumer wastes whose heterogeneity and numerous points of origin create logistical and technical complexities that create major barriers to full implementation[8].

Recycling in Europe also can be classified into two sectors based on maturity of their market; traditional or emerging. Historically, the recycling industry shows different levels of consolidation for the sectors involved. The traditional market-driven recycling industry deals mostly with high-grade wastes and secondary materials, supplying close to half of the input to steel, nonferrous metals, paper and glass industries. In contrast, there are emerging sectors, based on the recovery of mixed materials, such as plastics, rubber and tire recycling, oil, batteries, and wood that face various levels of barriers for efficient market operation. In these sectors, recycling suffers from competition with low price virgin materials, relatively high collection costs, and barriers such as market rejection, competition with energy recovery options (incineration) and lack of reliable statistics and market transparency as noted by the EU Commission.

> *On the demand side, the competitiveness of recycling is limited by a lack of preference for recyclable and secondary materials on behalf of processing industries, due to their technical properties, limited applicability and /or negative image. Furthermore, recycling is likely to be hampered by the lack of pertinent industrial standards, or even by the tendency for some standards or specifications to ignore or discriminate against recycled materials or products.*
>
> *The lack of transparency is revealed primarily by the fact that there is an almost total absence of economic indicators and statistics in the short term. An illustration of this fact is that it is not often easy to find a representative price for these materials, except outside the market[5] (in the case of scrap iron, for instance, the price commonly used as the reference price is the American composite price). The scant number, not to say the*

[5] This point will be evident later when estimating materials values for cost modeling.

total lack of technical specifications and joint test protocols, or ones which are widely recognized, is a major factor in the fragmentation of this market.

The implementation of recycling objectives in the context of an environmental policy has given rise to situations where the activity of recycling is not profitable unless some direct or indirect public intervention takes place. The basic question is therefore as follows: is it possible for these objectives to be reached with a recycling industry operating according to market rules? It can be stated that, if markets function correctly and in conditions of maximum efficiency and minimal costs, recycling may become profitable in an increasing number of cases.[9]

The emerging sectors face these uncertainties of profitability and proper market functions and, therefore, require public intervention to subsidize their existence in the mean time. In this manner, many have questioned whether the internalization of costs through public intervention, such as deposits, fees, or taxes, are worth the benefits from recycling that are achieved[10].

2.2 End-of Life Vehicle Recycling Infrastructure

As for ELV recycling, historically, this sector has been considered a mature industry supported by established materials markets. Its key economic operators include:

1. **Dismantlers** accept vehicles from last owners/users and remove valuable components from the vehicles. Then, they send remainder of the vehicles, called hulks, to shredders.
2. **Shredders** take hulks and chop them into small pieces to recover ferrous and nonferrous metals.
3. **Nonferrous separators (*heavy media separators*)** further sorts nonferrous metals. *Not all nonferrous metals are processed.*

Discarded ELVs reached 8 million units in Western Europe in 1999 and is forecasted to grow up to over 12 million by 2015[11]. The statistics of ELV recycling far surpass the recycling averages mentioned earlier since over 90% of all ELVs are delivered to dismantlers for disposal and 75% of materials from those vehicles are recycled. Currently, a strong and mature metals recovery system is the primary reason for the 75%-80% recycling rates for ELVs. The remaining fraction, known as automotive shredder residue (ASR), contributes 2-2.5 million tons of hazardous waste annually to landfills. Though the overall fraction of ASR relative to total waste produced in the EU is small, ASR represents up to 10% of the total amount of hazardous waste generated yearly in the EU[12]. Emerging sectors in recycling are expected to deal with the problems associated with the recovery of materials from ASR and with infrastructure implementation for mixed plastics, oils, and contaminated materials in a market-driven fashion. However, as mentioned previously, most of these operators currently need support in the form of "public intervention" since these materials often have negative value at this time. The sorting of plastics of different compositions and other nonmetallic materials represents one of the biggest difficulties for achieving growing recycling targets in recycling ELVs. In fact, the main factor of competitiveness for the entire chain will be sorting of parts and materials. It is in hopes of fostering this emerging industry (and, thereby, keeping ASR out of landfills) that the EU has sought to intervene by mandating ELV recovery targets.

The current and expected growth in ELVs recycling rates, as a consequence both of voluntary agreement and the EU Directive, will evolve according to the degree of success in:

1. the development of collection infrastructures with mandatory obligation to give-back ELVs to authorized facilities,
2. the set up of dismantling, sorting and treatment processes (i.e. automatic sorting processes and shredder technologies - which will require high capital investments),
3. the efforts to develop information on dismantling technologies,
4. the development of new markets for nonmetallic recyclables.[13]

3 EU's Recycling Mandate

The EU's ELV Directive and similar environmental policy are grounded in several principles derived from the European Community Treaty, other international treaties, and fundamental policy principles. From the level of the Community Treaty, the Treaty establishes authority to create Community-wide mandates and, within its environmental programmes, there is reference to develop efforts with industry and consumers "towards sustainability" in production and consumption[14]. In addition, an underlying philosophy of the EU's environmental stance is associated with a principle from the 1992 Rio Conference for a "precautionary approach," which compels participating nations to address potential threats of damage despite lack of full scientific certainty[15]. In the case for waste prevention, some may argue that the potential costs outweigh the benefits of the ELV mandate but the EU feels it is important to limit landfilling of hazardous materials and promote sustainable resource use. Furthermore, in regards to mandating recycling and waste reduction, the EU attempts to employ two additional principles: one principle is "public intervention," whereby externalities are incorporated into the cost of recycling, and the other principle is "extended producer responsibility" (i.e. the polluter-pays principle), so recycling solutions will not become unattractive for consumers to participate. All these principles provide a basis for the ELV Directive and other similar policies.

With the "precautionary principle" and "public intervention principle" in mind, the 5th Community Framework Programme (1998-2002)[6] in the field of Environment and Sustainable Development places great emphasis on the need to modify both methods of development, including production, and consumer behavior[16]. Along these lines, waste prevention is the priority objective of the ELV Directive, followed by reuse, recycling, or recovery of ELVs so as to reduce the disposal of waste[17]. The term prevention differs from reduction because it implies modifications are necessary even before vehicles enter the waste stream. The latter statement regarding waste disposal is analogous to "end-of-pipe" pollution control in chemicals and energy industries where abatement of waste is conducted through recycling or recovery. It is commonly accepted that prevention through change of process or product in the conception phase should be the preferred strategy over abatement in the end-of-life (pipe) phase [18] [19]. Therefore, the

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[6] *The Fifth Framework Programme (FP5) defines the European Union's strategic priorities for Research, Technological Development and Demonstration activities for the period 1998-2002. FP5 has been conceived to help* ***solve problems*** *and to respond to* ***major socio-economic challenges*** *such as increasing Europe's industrial competitiveness, job creation and improving the quality of life for European citizens. Emphasis is placed throughout on the process of innovation to ensure the output of EU research is translated into tangible benefits for all.*

structure of the ELV mandate is designed to steer producers to reduce waste through recyclable designs by placing the burden of cost of recovery on the them[20].

3.1 Policy Rationale

The EU, under the Community Treaty, has authority to create regulation to which all member states must adhere. Associated with the Treaty are Community Programmes which provide guidance in policy making. The ELV mandate falls under the heading of goals for sustainable development through changing behavior of industry and consumers.

> ***[Article 8] Programme "Towards Sustainability"***
> *Sustainable production and consumption patterns*
>
> *The Community will further develop its efforts to facilitate and enhance innovation in industry in relation to sustainable development and promote awareness and changes in behaviour by industry and consumers with a view to moving towards more sustainable patterns of production and consumption[21].*

In addition to goals for sustainability, the EU is compelled to create regulation to protect the environment from serious threats through their agreement to the precautionary principle. The principle was defined first at the 1992 Rio Conference on the Environment and Development, during which the Rio Declaration was adopted: its Principle 15 states that:

> *"in order to protect the environment, the precautionary approach shall be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".[22]*

Within the EU's policy on recycling, the notion of "public intervention" is necessary in cases where recycling has negative value or low market appeal. In such cases, altering market forces is justifiable when environmental externalities are accounted for[23]. This has been evidenced in recycling programs such as Germany's "Green Dot" financing program where a producer buys a sales license for every piece of packaging it sells in Germany[7]. Unfortunately, as a result of the Green Dot program, packaging recycling

[7] The money is then allocated to waste haulers, waster sorters, and post consumer plastics recycling programs. However, soon after implementation, the effort to capture external costs though the "Green Dot" program was costing 4

costs in Germany became two to three times higher than the material value itself. Some may argue that the level of avoidance may not have been worth its cost[24].

Finally, the Directive makes reference to the "producer pays" or "extended producer responsibility"[8] principle where the burden of capturing external costs falls to the producer, as with the above "Green Dot" program. In this way, consumers will not be discouraged from participating in recycling activities and the producer is motivated to change product design to facilitate more cost effective recycling practices and resource conservation[25].

By setting targets for recycling and recyclability and employing this "producer pays" principle, the ELV Directive is also a technology forcing policy. Ashford talks about how setting environmental standards may force stakeholders to implement either incremental (adopt or adapt existing technologies or processes) or radical (developing new technologies or processes) innovations in meeting those standards. However, Ashford points out that policy can stimulate change in producers only if they have willingness, opportunity, and capacity to change[26]. We will use these points in discussing stakeholders roles in implementation and technology options.

3.2 Policy Description

> *The Proposal is designed firstly to preserve and improve the quality of the environment and secondly to ensure the functioning of the internal market and avoid distortions to competition. To this end, it establishes measures on the prevention of waste from vehicles (including restrictions on the use of hazardous substances in new vehicles), on the collection of vehicles as well as their treatment, recycling and recovery. The Proposal is based on the 'producer responsibility' principle.[27]*

The ELV Directive has undergone several revisions and amendments as a result of negotiations between industry, the European Council, and the European Parliament.

DM/kg of material when fair market prices for these materials range from 1-2 DM/kg. This translated to about 2 billion DM spent for 750,000 tons of waste avoidance. Using landfilling fees of 200 DM/ton[1], which may or may not capture externalities of land consumption, landfill avoidance amounts to 150 million DM.

[8] Using the principle of EPR, product manufacturers are responsible for the total life-cycle environmental impact of their products, from raw materials extraction and manufacturing to use and disposal. The aim is to encourage producers to prevent pollution and reduce resource and energy consumption at each stage of product's life cycle. A variety of tools can be employed: partnership agreements between stakeholders, product labeling, government procurement policies, deposit-refund systems, product take-back programs, design-for-recyclability, leasing systems, and life-cycle management programs

Similar programs had been initiated at the national level by several countries including Germany, Sweden, the Netherlands, and France[9], but a Community-wide framework was necessary to ensure coherence between national approaches to attain the ultimate objectives[28]. Under EU procedures, the proposal for a directive was initiated by the European Commission on 9 July 1997. In its first reading by Parliament on 11 February 1999, Parliament approved the Commission's proposal subject to 45 amendments. The Commission presented its amended proposal on 28 April 1999, with which the European Council adopted a common position. The Commission then presented an amended proposal on 1 October 1999. During the secondary reading by Parliament on February 3, 2000, the Directive was approved subject to additional amendments. On March 16, 2000, the Commission accepted in full, in part, or in principle thirteen of the thirty-two amendments adopted by the Parliament. The amended proposal awaits reexamination by the Council[29].

Key contentious points that have been amended and reenacted included levels of recyclability, recycling, recovery, and reuse; policy effective date; bearer of burden of any added costs; and retroactive application of the law on vehicles currently in existence. In the most recent amendments following Parliament reading and Commission review, the major points include [30] [31]:

1. The article stipulates that reuse and recycling must be 80% by weight per vehicle by 2006 and 85% by 2015. Additionally, recovery must be 85% by 2006 and 95% by 2015 (Article 7(2a&b)). However, recyclable content of a vehicle must be 85% by weight and 95% recoverable content by 2005 (Article 7(4)) .
2. Member States should ensure that producers meet all or a significant part of the costs of implementing measures for delivery of ELVs to authorized treatment facilities (Article 5 (4)).
3. It should not cost the last holder and/or owner to deliver the ELV to an authorized treatment center (Amendment 1, Recital 7).

[9] The history of the initiative can be traced back to France's program in 1994. Their efforts were based on a voluntary framework that involved automakers and auto dismantling industry. The National Council of Automobile Professions (CNPA) launched the "Green Plan" in 1992 beginning with an establishment of a network of collection points for wastes. The second phase of the program enabled salvage companies to be certified "Green" if certain requirements were fulfilled, including training, pollution prevention measures, and compliance with technical specifications. Striving to keep ahead of regulations, France's auto dismantling industry voluntarily agreed to a goal of 95% valorization by the end of the century[1]. Here is arguably an example of industry initiative without much government intervention.

4. Member States are responsible for setting up a system for collection of ELVs and requiring a certificate of destruction as a condition of deregistration (Article 5 (1)(2)(3)).
5. The presentation of destruction is a condition of deregistration of ELVs and is presented to holder and/or owner by a treatment facility or dealer/producer/collector on behalf of treatment facility. (Temporary deregistration without presentation of a certificate shall be allowed)
6. Hazardous chemicals including lead, mercury, cadmium, and hexavalent chromium shall not become shredder residue, incineration, nor be disposed of in waste dumps. In addition, these heavy metals will be only used in certain applications as regulated (Amendment 4, Recital 10). Vehicles placed on the road 18 months after initiation of Directive shall not contain the above chemicals unless otherwise specified for particular applications by Annex II (Article 4(2)(a)).
7. In addition to above chemicals, a list of components (Annex 1) are to be stripped from ELVs before further treatment (Article 6(3)).
8. Vehicle manufacturers are responsible for providing authorized facilities with all requisite dismantling information and use common component and material coding standards (Amendment 5, Recital 22)
9. Member States are responsible for dealing with noncompliance (enforcement).

4 Stakeholders' Positions

The key stakeholders affected by this Directive will be automakers/producers, parts suppliers, materials suppliers, recyclers, and vehicle owners. The member states, of course, also play an important role in the success of this Directive since they are responsible for ensuring and enforcing implementation. Within the government, the changing of political appointees to the European Commission can also have an impact on the degree or fervor given to the topic at hand[32].

Why producers? Ryden has proposed two divisions to analyze which stakeholders have the potential to alter a system most significantly. His first division is between primary and secondary actors. A primary actor can influence other parties in the performance of their activities, while a secondary actor is limited by the activities of other parties and, especially, can be influenced by the primary actor. According to these definitions, the primary actors connected with ELVs are automakers and consumers, while recyclers and suppliers are secondary actors. Ryden's second division is between static and dynamic policy steering instruments. A static policy can be characterized by objectives and clear definitions and goals, which in this case targets consumers and recyclers in the form of, for example, certificates of deregistration and environmental adherence standards for operations. On the other hand, producers and suppliers face more dynamic steering mechanisms where the goals are set but how to proceed in achieving those goals are not defined clearly. In this framework, automakers face the largest responsibility, as primary actors, for the success of the Directive and the most risk in its implementation to meet dynamic goals (see Table 1).

Table 1: Division of Stakeholders

	Primary Actors	Secondary Actors
Static Policies	Consumers	Recyclers
Dynamic Policies	Automakers	Suppliers

In fact, automakers have been raising the greatest objection to the Directive, despite regional voluntary agreements already in existence, because of fear of enormous costs in attempting to meet the standards and while still maintaining other conflicting design goals they face[33]. Recyclers also have voiced concern regarding market distortions and the potential collapse of certain operators, if and when automakers begin to take dominance[34] [35]. Though the Directive specifies that safety and environmental regulations should not be compromised and member states must ensure that market distortions do not arise, these are in fact arguments being raised by stakeholders[36]. The Directive does not describe how these safeguards are to be created, leaving member states to deal with the policy mechanisms.

4.1 Automakers/Producers Position

Producers are questioning the ELV Directive in several manners. In a report by the European Automobile Manufacturers Association (ACEA)[10], the organization points out that the Directive "includes demands which do not provide clear environmental benefit,

[10] Association des Constructeurs Européens d' Automobiles: Its creation was based on a clear consensus among its members concerning the need for effective representation. This role has expanded with the advent of the Single Market, the growing importance of EU legislation and action for all member countries and the wider European and global presence of ACEA member companies.

which seriously affect the normal mechanisms of the market, and which potentially have a severe impact on the automobile industry and its suppliers due to possible restrictions in product design and configuration[37]." The report also explains that the ACEA welcomes environmental requirements for ELV treatment but claims the problem does not lie with producers. They support only two provisions within the Directive; namely, 1) certification of dismantlers and shredders for operating environmentally appropriate facilities and procedures and 2) a certificate of destruction to solve the problem of abandoned vehicles. ACEA implies that the remainder of the mandates are unnecessary, since there are many voluntary programs existing in various member countries which have more cooperative approaches for all stakeholders, including last owner of vehicles. "The voluntary self-commitments assumed by industry and supported in most cases by national governments should receive a fair chance for their implementation[38]."

The prospect of having to bear the majority of costs in increasing recyclability of vehicles and increasing post consumer recycling has provoked vehement objections from leaders in the car industry. The Commission, however, insists manufacturers must bear full costs of recycling if the directive is to have the desired effect of changing production practices for new vehicles and preventing an increase in abandoned vehicles[39]. Additionally, current wording of the Directive also gives the car industry "retroactive" responsibilities in recycling vehicles built after 1980, including those built before the enactment of the Directive. One industry estimate, based on recycling cost of euros 150 per car and an estimated 150 million vehicles currently on the roads, places the cost to industry at euros 23 billion[40].

By burdening automakers with the full (or a majority) of the cost for recovery, automakers claim market distortions can manifest in the form of inefficient operators and/or entry of producers into the dismantling market, pushing out small/medium-sized enterprises (SMEs). Environmental certification of facilities may prove to be too high a burden on some portion of the 20,000 fragmented dismantlers dispersed in member states. Furthermore, though it appears that last owner does not pay, his/her new car purchase price would be inflated due to transfer of costs for recycling from producer to consumer.

The industry argues that an increase in vehicle price can in turn either delay disposal of existing old, inefficient vehicles or force buyers to purchase another used, inefficient vehicle instead of a new vehicle.

The industry also points out that other environmental objectives such as lightweighting will be hindered by mandatory recyclability levels coupled with limited incineration of plastics. Lightweighting of vehicles for reduction of fuel consumption has caused a gradual shift of automotive components from denser metals to plastics and composite materials, an increase of 26% between 1980-1994, which has helped to reduce overall vehicle weight by 6% in the same period [41]. Due to the heterogeneous plastics content in automobiles and the difficulties associated with sorting, automakers may be forced to turn back to metals which, although heavier, are easier to recycle. Furthermore, lightweighting goals also have increased the use of composite[11] materials which may contaminate noncomposite plastics streams in post-consumer recycling.

In addition to environmental design conflicts, the European automakers face a difficult task of controlling material content directly due to the increasing design role of suppliers. The industry uses such a wide variety of materials in the production of vehicles that no actual accounting of materials input is conducted until after vehicles are built[42]. The complexity of material types can be attributed to several factors including lightweighting, design aesthetics (product marketability), and manufacturability. Within manufacturing, automakers admit not knowing the full composition of their own vehicles due to subassemblers and/or suppliers having an increasing role in the definition of parts. About 2/3 of a vehicle's value comes from sub-assemblers and suppliers. This trend of outsourcing will continue as manufacturers delegate more and more of the responsibilities of full development of subassemblies to their suppliers. Developers now have the responsibility of choice of materials, according to requirements and cost, which is discussed between the parts manufacturers and the material producers. To a great extent, vehicle manufacturers no longer buy the raw materials directly, except for metals. As

[11] Composite materials are multicomponent materials, usually consisting of a matrix materials with fibers or particles dispersed throughout for increased performance. European automakers have made a concerted effort to use thermoplastics rather than thermosets for easier recycling but this practice is limited to in-plant scrap recycling.

subassemblies become more complex, OEM's are losing control of exact materials entering their vehicles.

In designing for dismantling and recycling, there are actually two separate issues which must be considered. For dismantling, the actual design for simpler interconnection of parts and reduction of number of parts within subassemblies is important. This allows for fast and, preferably, cost-effective recovery in terms of operations cost vs. intrinsic material value. In addition to recovery, material choices are also critical for actual recycling of the material and sorting of polymer mixes. Headway has been made in these two areas but mainly for larger, obvious assemblies such as instrument panels and bumpers[43] [44]. These design goals, however, can not be the determining factor in components design since many other requirements must be taken into account as mentioned previously.

One additional point made by ACEA, the lack of a market and infrastructure for nonmetallic recyclables, remains a major obstacle for the success of market-based, materials recovery. The Directive does not address these points explicitly and offers no solutions for either market creation or material loop closing, except in encouraging integration of recycled materials back into new vehicle components[45]. This will pose a problem for nonmetallic materials’ market values and recycling once recovered through dismantling or post-shredder recovery methods. In a proactive manner, automakers are taking voluntary actions in addressing the issue of creating or expanding a market for secondary materials, especially plastics. For example, Daimler Chrysler officially announced in January of 1999 that all of their suppliers who provide plastic components must have a minimum of 20% recycled content by weight in the products. The minimum shifts to 30% by 2002. This decision is based on the belief that there will be economic benefit to such a change and to spearhead any potential pressures from regulators[46]. This kind of announcement also forces suppliers to take necessary steps in tracking material content and creates a closed-looped market for secondary materials. This is an example of what automakers are willing to do if given an opportunity to align business and environmental objectives. However, closed-loop recycling may not be sufficient for creating a market for ASR.

In the end, car companies are arguing that cooperative and voluntary recycling efforts between government, automakers and recyclers already exist in fourteen European countries. Within these countries, the burden of cost is shared among vehicle owners, recyclers and automakers[47]. Automakers prefer to rely on voluntary efforts rather than policy push methods for achieving recycling goals.

4.2 Recyclers' Positions

Recyclers are concerned over the ELV Directive mainly out of fear of further market distortions on top of those caused by regional regulations already in place We can imagine the roles of dismantlers and shredders/nonferrous separators, which were once separate, may now converge due to implementation of mandatory material recovery in the pre-shredder stage. Transactional prices and materials prices will play a large role in the profitability and survival of individual operators in this sector. One example of the interplay between regulations, material prices and cost is evidenced by a perceptible increase in abandoned vehicles in Nottingham City, Great Britain.

> *Nottingham City Council spokesman, Chris Bailey, reports that abandoned vehicles are becoming an expensive problem in his area, since market conditions forced local dismantlers' yards to offer £10 or less for old vehicles. He explained: "Until last summer only 10 to 20 cars would be abandoned every month, now we are receiving 100 reports a month. In a further twist, the company we use to collect and dispose of the cars could previously cover their costs through the scrap value, now the Council is having to pay disposal fees of £30-£40 per vehicle."... Bryan Brewer, Chief Executive of the Motor Vehicle Dismantlers' Association was not surprised by the report. "This confirms what the trade associations have been warning of for the last nine years: the increasing costs of regulation make it uneconomic to handle vehicles at the low end of the market. The reliability of modern cars means that the demand for spare parts is lower, so dismantlers are left reliant on the material value of a vehicle. Unfortunately, there is a smaller proportion of metal in modern vehicles, and given the current market conditions, they are sometimes not worth handling for value alone."[48]*

In this situation, the cost of disposal was picked up by the city council since it was not economical for dismantlers to pay for low value vehicles. While this problem will be partially solved through mandatory certificates of deregistration, the negative value inherent in the vehicle itself will still need to be covered either though expensive hulk prices--which will create major market distortions downstream--or subsidies from producers. Without such interventions, dismantlers will not remain profitable for long.

Even if dismantlers will not have to cover the full cost of collecting ELVs, there is a further problem in actual disassembly for recycling. The requirements for added parts removal and more careful fluids draining may shift labor resources away from recovering reusable parts, which is the "bread and butter" for dismantlers, and/or increase labor costs through hiring of additional employees. The latter could be considered a benefit as it addresses one of the EU's goals for job creation, though this perspective overlooks the fact that the dismantler may not have the revenue to support the new jobs. In addition, parts removal for materials value will be difficult if no infrastructure exists to sell the recovered components. The national governments or producers will need to establish collection and marketing schemes to be more effective. All this translates to added costs for all stakeholders, including member states and consumers.

On the other hand, dismantlers agree that hazardous wastes should be removed fully and regulated to prevent shredder scrap contamination. In fact, a major dismantler, BMF, has already instituted hazardous fluids removal requirements in all their facilities, ahead of regulations.

> *Shredder Division Chairman, Deryck Robinson explained"The draft European End of Life Vehicle Directive when it becomes law will require hazardous materials to be removed so as not to contaminate subsequent shredder waste from end-of-life vehicles. In our opinion these further measures will also be needed in order to offset the increasingly heavy costs of landfilling non recyclable materials." Motor Vehicle Dismantlers' Association Chairman John Hesketh welcomed the move. "Depolluting vehicles prior to shredding is entirely in line with environmental protection requirements, and highlights the essential role of professional dismantlers in the solution to the End of Life Vehicle problem." Although the costs of handling older vehicles will be increased by this change, John Hesketh hopes that the shredder operators will pass on the added value of the frag feed by increasing the market price. "While some will see this as*

just another expense for dismantlers, the MVDA welcomes the move towards greater professionalism within the industry."[49]

The last point may be contrary to shredders' perspective where "if, as the Commission draft stipulates, the majority of nonferrous metals were to be stripped from end-of-life vehicles before further treatment and the shredding and media separation plants were left with the cost of disposing of worthless residues, the companies would simply become uneconomic[50]." In other words, shredders, though they appreciate the fact that hulks would not be contaminated by hazardous fluids, which lowers disposal costs, they fear their revenues will be impacted by decreased metal content of hulks that have undergone significant dismantling[51]. However, since not all nonferrous metals are being recovered currently, shredders may opt for adding new equipment to recover more nonferrous metals to be sold to nonferrous separators.

Lastly, several ASR separators have emerged who are banking on a potentially profitable business in recovering high value plastics and foams from the ASR stream[52] [53]. Though the technologies are still in pilot plant stages, ASR separators believe the economics are more favorable for sorting ASR rather than dismantling components. There is still the issue of a secondary nonmetallic materials market to consider but, in this sense, they will rely on automakers seeking to close recycling loops and established industries seeking recycled materials as an inexpensive feedstock. Additionally, a large portion of their revenues will be extracted through landfill "avoidance" costs where the shredder and nonferrous separator basically pays an equivalent amount for the ASR material to be processed rather than landfilled. In fact, higher landfilling costs will actually benefit ASR separators as their service becomes more preferable. The problem for ASR separators is that the wording of the ELV Directive gives preferential treatment to pre-shredder dismantling for recycling and, if dismantlers remove most of the high value plastics components, they face the same issue confronting shredders and nonferrous separators of dealing with less valuable material content.

In summary of stakeholders' positions, each stakeholder's interest differs slightly depending on where they are in the value-chain. In some cases, they may also conflict due to their niche roles. For example, emerging ASR separators may prefer less plastics disassembly initially so the material may flow downstream. Additionally, dismantlers fear automakers may be forced into the dismantling business, since the automakers are held responsible for costs, which may cause many SMEs to leave the value-chain. Overall, though, the concerns of all stakeholders remain similar. They have all raised concern over potential market distortions, loss of prevalent SMEs or key regional operators, and lack of infrastructure or market for secondary nonmetallic materials. The following chapter summarizes the overall issues surrounding the ELV Directive.

5 Overall Issues with Recycling Mandate

The controversy surrounding the EU Directive has prolonged its approval as a result of industry opposition and several amendment revision processes. This Directive has raised many issues throughout its approval process. We can examine them in terms of economics, technological feasibility, stakeholder and market acceptance, and policy implementation and effectiveness.

Below are a summary of questions raised by various stakeholders:

Economics
1. What are the additional costs involved in achieving such goals?
2. How are costs tied to the various recycling segments?
3. Who will or should bare these costs? Will there be market distortions as result?
4. How might the market evolve to be economically self-supporting?
5. Will secondary material value be sufficient to support new targets?

Technology
1. What technical shortfalls exist in the current infrastructure to meet goals?
2. Where should technology development be focused (design for recycling or recycling)?

Stakeholders/Market
1. Who are the major stakeholders and what are their motivations?
2. Can and how must current stakeholders evolve to meet such goals?
3. What sacrifices are stakeholders willing to make?
4. Will government need to artificially bolster the mandate's success?

Policy
1. How can the mandate be enforced or generally accepted?
2. How does one interpret the recycling definitions in the mandate and how will the different definitions impact the system?

3. Is retroactive application of the law on existing vehicles legal?
4. Will such a plan falter similar to other technology forcing regulations?

In considering the above uncertainties, the overriding question is whether realizing the EU's policy objectives will outweigh the potential costs to all stakeholders. If costs are too high, even considering externalities, regulation alone may not be able motivate stakeholders' participation. On the other hand, high costs may prompt inefficient businesses to exit the market or alter existing technologies and processes drastically.

Ashford has conducted numerous case studies in examining effects of regulations on technology development. He divides technological responses into three categories: 1) adoption of compliance technology, 2) change in process technology, or 3) product substitution[54]. While a new technology or product substitution may be a more costly method of attaining current environmental standards, it may achieve stricter standards at less cost than adaptation of existing technology. In essence, as Figure 1 indicates, supply curve A represents an existing system that does have lower costs at existing standards, but as we shift to higher standards (creating less risk), the marginal cost is less for supply curve B. This implies that the new technology may be a more attractive option relative to existing systems at higher, more stringent standards. We will consider such implications of new supply curves through economic assessments.

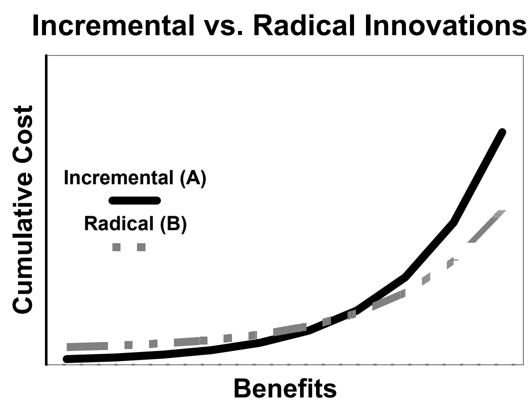

Figure 1: Conceptual Comparison Between Incremental versus Radical Innovations

6 Research Objectives and Methodology

This thesis attempts to understand some of the implications of a technology forcing regulation and, at the same time, address some of the major issues highlighted above. The methodologies used include: technical cost modeling, technology assessment and stakeholder assessment. We have already examined the stakeholder positions and responsibilities in Section 4 and will return later to discuss potential scenarios in meeting the mandate. Our main focus will be using technical cost modeling to assess the potential for new technology adoption.

One standard method of assessing viability is to calculate direct costs to stakeholders. However, this method of examining past costs may not indicate future costs when conditions change or have interactive effects. Furthermore, it is helpful to identify key cost drivers and examine them through scenarios testing. A useful method of addressing these needs is through the construction of a technical cost model where there is transparency in assumptions and methods.

6.1 Life Cycle Cost Modeling

Although the implications of this Directive are complex in nature, we can begin analyzing some of them by building upon technical cost models including those previously developed within MIT's Materials Systems Laboratory (MSL). In this way, an economic basis can be formed to examine tangible costs that stakeholders might face under specific regulatory environments. Additionally, external costs and benefits, such as land filling avoidance gains are considered. The economic descriptions of cost for this particular case are a function of:

1. Vehicle design and material composition
2. Recycling technologies and yields (existing and potential)
3. Recycling definition (e.g., definition of "incineration," by weight of original vehicle or arriving vehicle, etc...)
4. Recoverable materials and components pricing

The European Car Manufacturer Association has quoted estimates ranging from $150-$200 per vehicle under the new standards, while the European Commission counters with an estimate at euros 80(~$85) per vehicle. Additionally, the car manufacturers estimate a combined cost of euros 23 billion to address recycling of existing vehicles. On the other hand, the European Commission estimates implementation cost to be around euros 2.5 billion. While both are relatively high implementation costs, the difference of a factor of 10 is unsatisfactory for real economic cost estimation. The argument lies in the assumptions. With cost modeling, the methodology allows for sensitivity analysis to help determine which variables are key drivers. Once key drivers are determined, we can test how to change economic or pricing policy through scenario testing.

With appropriate economic and policy incentives, such as higher landfill costs or secondary market expansion, the costs may not be as alarmingly high as industry claims. However, an examination of the appropriate incentives are necessary. Some key drivers employed in this cost model are:

1. landfill costs
2. hulk material transfer price
3. secondary material market value
4. existing and potential material content
5. mandatory parts removal versus economically driven recovery
6. increased dismantling versus ASR sorting

There has also been concern raised on the issue of the percentage set for recovery. Since the ELV industry recovers approximately 75% of a vehicle's weight for mature steel and aluminum markets, the remaining required recovery will have to be from emerging recycling operators for secondary polymers. While achieving the next 5% of recovery may still be cost effective, it's important to bear in mind how vehicle recycling will achieve the final required 5% of recovery. This notion of marginal costs can also be discussed using this model.

The model combines four recycling stages. The first step modeled in the cost assessment is dismantling. This is a model created by Dr. Randolph Kirchain of MSL for his PhD dissertation to estimate dismantling costs and degree of recovery[55]. The model is dependent on material values of parts versus their total recovery costs. The model's underlying database retrieval system uses a complex algorithm based on part value, material value, part location, and retrieval time to determine whether each part is economically feasible to retrieve. The second modeled operator is the shredder. It is based on a spreadsheet model developed by Dr. Andrew Chen of MSL for his PhD dissertation[56]. The third modeled operator is a nonferrous separator. The cost model of this operation is based on a synthesis of information from Huron Valley Steel (HVS)[12] and other separators. Lastly, since plastics recovery from ASR will be key to cost, the model includes a recycling system developed by Plastics Recovery International (PRI)[13] using a skin flotation technique for plastics separation and a polyurethane foam recovery system from Argonne National Labs.

6.2 Cost Redistribution Scenarios

Using the modeling tool, it is then possible to assess how the recycling system will perform under various scenarios, including whether the system utilizes either incremental or radical solutions. As mentioned earlier, the underlying concept here is that some innovations may be considered radical at existing standards but may prove cost effective at higher standards while the opposite occurs with developing incremental improvements with the existing system. An analogous situation is innovation to reduce pollution. Typically, "end-of-pipe" scrubbers and pollution abatement solutions are considered incremental changes because nothing changes with the core processes. However, a completely new processing technique might substitute the existing process without producing any pollutants. While this may appear costly initially, its implementation might curtail any future costs of regulations. In light of this; it will be useful to explore these two different scenarios to examine if a radical scenario can better address higher levels of recycling needs.

Before detailing the scenarios to be analyzed, it is first necessary to identify what changes can occur with the existing infrastructure--these being available "incremental" solutions. The EU can opt to encourage increased dismantling through subsidies or tax incentives or

[12] Huron Valley Steel is the largest nonferrous separation operator in the US. Its facilities are vertically integrated from shredding to nonferrous separation to secondary metal remelt.
[13] Plastics Recovery International has been developing a method of separating key, high value plastics from ASR. The company has built a pilot plant for testing.

encourage "end-of-pipe" technology involving ASR recovery. The addition of a few new facilities for ASR recovery should be minor investments relative to a more radical solution for increased dismantling which may require an entire system overhaul. However, it is important to keep in mind that ASR recovery is still in its development stages and will require a sound secondary nonmetallic materials market for its success.

In contrast, the more radical solution that some larger players in the recycling industry are considering is to consolidate the industry both vertically and horizontally. Included in the consolidation could be facilities geared for major dismantling in an assembly line type layout. Additionally, shredders and nonferrous separation can also be located on-site for capturing the remaining materials without added transport and transaction costs. However, this scenario would force many small/medium enterprises (SME's) to exit the market and would also require new investments into greenfield sites. There are already examples of such activities taking place in both Europe and the US which will be discussed later. In addition, the major goal of these mega dismantling facilities will be to recover parts for resale rather than material value alone. The question then becomes how big does the used/remanufactured parts market need to be to sustain such an endeavor?

The table below summarizes the two technological approaches to addressing the ELV Directive goals.

Table 2: Comparison of Incremental and Radical Technologies

	Incremental	**Radical**
Method	"End-of-pipe"	Industry consolidation
Technology Emphasis	ASR recovery	Mass dismantling, vertical integration
Infrastructure	Existing	New with SME's exiting
New Investment	Minor	Major
Market	Secondary plastics market	Secondary parts market

7 Life Cycle Cost Modeling

7.1 Infrastructure Description

As mentioned earlier, the current ELV treatment system contains disassemblers, shredders, and nonferrous scrap separators (see Figure 2). Important in the cost assessment of these will also be landfilling. The system appears to be fairly standard across the regions studied with variations in level of technology and recovery. "In the European Union, the ELV treatment industry is an important economic activity, involving close to 20,000 collectors/dismantlers - mostly SMEs - as well as a few hundred companies operating heavy duty shredders"[57]. The International Bureau of Recycling estimates that there are 220 shredder operators in the EU and about 40 heavy media separators (nonferrous separators)[58]. In addition, entrepreneurial ASR separators are emerging in part due to the potential profitability of the Directive[59].

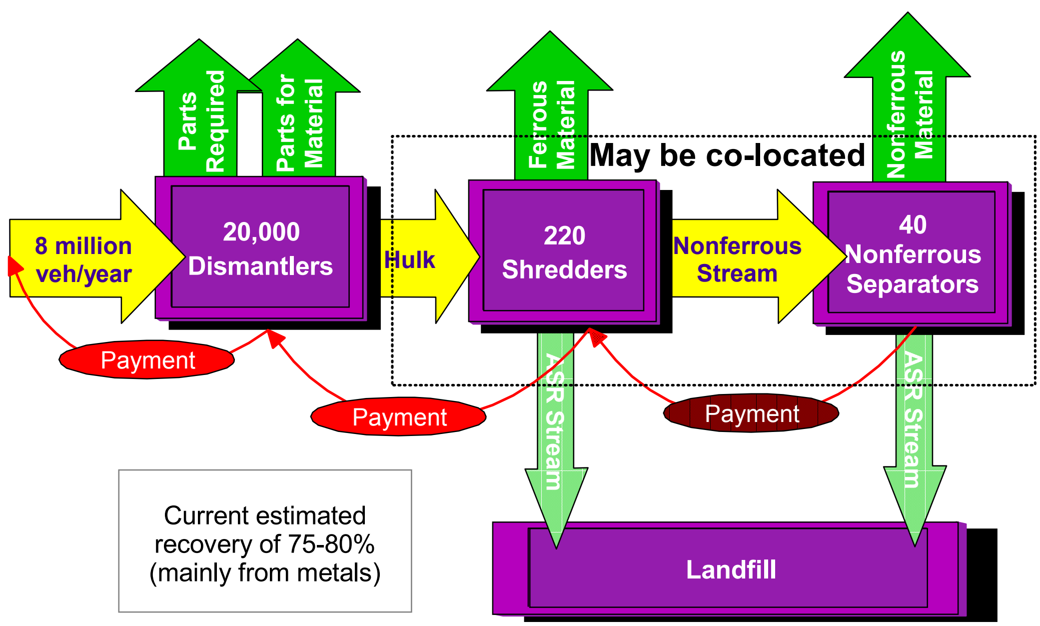

Figure 2: Diagram of recycling infrastructure

7.1.1 Existing Recycling/Recovery Technologies

7.1.1.1 Dismantlers

The typical scenario for recycling of an old vehicle begins with dismantlers. At this step, parts are removed based on resale value or adherence to regulatory and product standards. In a recent survey of US dismantlers for determining level of reuse of ELV parts, the results indicated that a dismantler recovers some part of 21% of vehicles received[14]. Within the 21% of vehicles reused, 12% of them are actually rebuilt for sale and the remaining 88% for parts inventory[60]. Parts resale is the most profitable portion of their operation. The remaining 79% of vehicles are sold as hulks after tires, radiators, batteries, gas tanks, air bag propellants, and fluids are removed as required by shredders and regulators in the US[61]

The dismantling industry is structured slightly differently in Germany where facilities are highly fragmented with lower processing rates and parts are remanufactured by original automakers. With 20,000 facilities dispersed throughout the EU (4000 in Germany), a rough estimate of average vehicles (assuming 8 million vehicles retired per year) processed per facility is approximately:

N_V=*8,000,000 ELV per year*
N_F=*20,000 facilities in Europe*
D_w=*250 workdays per year*
$N_V/N_F/D_w$=***1.6 ELV per day per facility*** *or 8 vehicles per week*

This estimate is inaccurate in the sense that the industry contains a range of facilities from small repair shops to larger, more efficient facilities. The number of facilities in the US is difficult to determine with reports of 6000-12,000 facilities depending on business designation[62]; but, in either case, US facilities combined, though fewer in number, can process approximately the same number of vehicles as in Europe. Additionally, in the US, there is an industry that specializes in remanufacturing parts to be sold directly to repair shops as replacement parts. This offers more flexibility to dismantlers to recover components for sale to remanufacturers[63].

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[14] Remanufacturing is the refurbishing of used parts for sale as replacements parts.

Overall, US dismantling operations have not been recovering parts purely for material value due to profitability, diversity of materials categories, and logistics issues in resale[64]. However, across the Atlantic, due to the threat of regulation, European firms have progressed farther in disassembly for recycling in both product design and disassembly facilities and infrastructure. European automakers have started experimental auto dismantling shops, including Peugeot-Citroen, Renault, BMW, Volkswagen, Audi, and Volvo. The most successful reported facilities are operated by a Dutch company, called de Mosseleaar BV. The Dutch finance the recycling of their cars with a "green fee," a $100 surcharge tacked onto the sticker price of each new car purchased. The facility has recovery rates of over 85% and operates in a large, enclosed structure with proper environmental safeguards[65]. A similar system exists in the US called Comprehensive Automotive Reclamation Services (CARS) and uses the same equipment as de Mosseleaar BV. The company claims it has created a profitable system that does not require subsidies and is supported by the insurance industry as a lower cost solution to parts replacement. CARS reports processing rates of 30,000-40,000 vehicles per year. Volvo, in partnership with ENCRIS AB, is also looking into dismantling ELVs and remanufacturing parts as a profitable avenue for both customer service and environmental benefit[66].

To encourage more disassembly and standardized recovery of materials, the European automakers joined in creating the (International Dismantling Information System) IDIS, which is a compilation of proper treatment and disassembly of ELVs manufactured by 20 different automakers. The CD-ROM from IDIS provides dismantlers with estimates of removal time and procedures for large, high value, easily accessible, nonmetal parts for recycling. While European automakers have provided disassembly data, it is unclear whether dismantlers will follow these suggestions without additional incentives and a better infrastructure to accept the diversity of materials they extract.

It is also important to point out that the dismantling process utilizes virtually no automation and thus is a highly labor intensive process. In the US, ELVs are actually purchased by the dismantlers making this cost actually the largest fraction of a dismantler's total cost. The purchase price, of course, varies by car and from region to region. The transaction also depends on local incentive structures for last owners/holders to turn in vehicles. In the EU, if the producer is held responsible for recycling costs, the dismantler may pass the deregistration costs to the producer to supplement increased labor costs in disassembly.

One last important point for cost modeling is that there may be a correlation between dismantlers' highly fragmented structure with transport and delivery costs. We can hypothesize that it is more convenient for last owners to turn in ELVs to local facilities so transport costs are reduced. Additionally, dismantling occurs at the same point for lower transport or delivery costs since hulks can be stacked 15-20 on a truck, at least in the US. The optimization of facility size and transport costs will prove important in discussions regarding vertical integration and consolidation of dismantling facilities.

7.1.1.2 Shredders and Nonferrous Separators

After disassembly, hulks are flattened and then transported to shredding facilities. There is a transaction cost between shredder and dismantler usually in the range of $30-$95/ton[15] paid by the shredder. The hulks are fed through large hammermill shredders that reduce the car to fist-sized pieces. The shredded material then passes under an air suction region for removal of dust, fluff, foam and other light pieces. Then the shredded stream passes under magnets for ferrous removal. At this point, 95% of the steel from a vehicle is recovered[67]. The remaining nonferrous materials can then be sorted with an eddie current recovery (ECR) system which sorts nonferrous metals from the rest of ASR. In Europe, finer nonferrous separation can occur on the same site as shredders with the installation of additional nonferrous separation equipment. However, often, no nonferrous facilities exist and material is sold to nonferrous separators or landfilled. It has been difficult to conclude the thoroughness of nonferrous metal recovery by European shredders and what the next steps are because of the scarcity of information in published literature.

[15] US Export Yard Buying Prices for Auto Bodies (delivered) from the American Metal Market

In the US, nonferrous recovery efficiency depends on downstream nonferrous separators' requirements for their feedstock and whether shredders have the capability for nonferrous metals recovery. The recovery efficiency varies based on speed of separation and allowable ASR content (see Figure 3). Therefore, the higher the recovery efficiency of nonferrous materials desired, the ASR content within the recovered metal stream also increases. Often the nonferrous separators set a minimum requirement for their nonferrous feedstock which determines the price they are willing to pay for the feedstock[68]. Therefore, even though nonferrous separators buy the material, they act like a monopsony in determining the price they are willing to pay for it. Even if there are no set requirements, shredders are still paid based on nonferrous metal content of a sample of their ASR upon delivery.

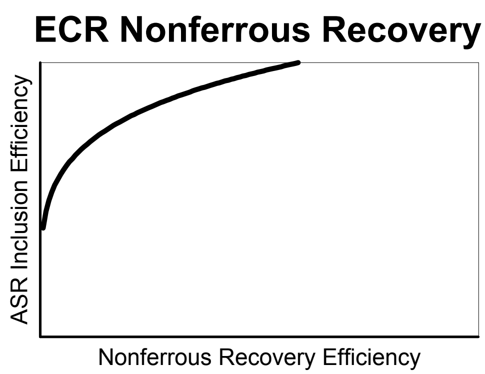

Figure 3: ECR Nonferrous Recovery Efficiency vs. ASR Inclusion Efficiency

Once the nonferrous material is delivered to the nonferrous separator or enters a nonferrous separation step on-site, it is cleaned and processed through a cascade of heavy media separation vessels to separate metals from the remaining ASR[69]. At Huron Valley Steel, magnetite and ferrosilicon slurries are used in addition to water during this step. The separation process is shape dependent so sorting is not absolute. The heavier streams are then passed once again through a series of ECR's to recover aluminum, copper, zinc and brass. The recovery efficiency is dependent on throughput speed and the number of ECR separation steps.

In more technologically advanced facilities, image processors or color sorting is also being used to distinguish between various red metal alloys such as brass versus copper. There have been some attempts to separate aluminum alloys for higher resale value since currently recovered aluminum alloys are mixed and are worth only cast grade prices. If aluminum alloys can be separated into their respective grades, namely wrought automotive aluminum grade, then their value increases. The economics of these last steps are still under debate and should be classified as part of future technologies[70].

7.1.2 Future Recycling/Recovery Technologies

In discussing policies for sustainable development, it was mentioned that technology innovations can occur at two points. The first method is to improve recycling in the post-consumer phase through various recovery and recycling techniques. The other, more effective method is to redesign vehicles for the best recyclability or reuse possible. The latter choice is a necessary but longer term goal. Shorter term developments are necessary for dealing with existing vehicles on the road. Therefore, recycling technologies still need to be developed to prevent materials from entering landfills. Current developments are targeting four areas of the recycling process:

1. Consolidate and modernize dismantling facilities
2. Reduce hazardous materials so ASR does not become contaminated
3. Improve nonferrous recovery efficiency
4. Recover materials from ASR for recycling

The first option of consolidating dismantling facilities has been discussed in the previous section. Effective implementation beyond the few existing pilot facilities will require a cost-effective transportation plan, a growing after-market for remanufactured parts, and/or a growing market for recycled plastics.

The second option is already included explicitly in the ELV Directive. The hope is that ASR can have a nonhazardous waste designation and cause less harm to the environment when landfilled. This option, however, still does not reduce the quantity of waste entering landfills.

The third option of improving nonferrous recovery efficiency requires only incremental improvements in the sense that more nonferrous separation capabilities are added to shredders. Additionally, further separation of red metals and different aluminum alloys through color/image process could increase material values but may not necessarily improve overall efficiency.

For the last point, ASR recovery has been a difficult problem to solve. Some proposed solutions include incineration, pyrolysis, heavy media separation, and density separation. According to the EU Directive, there is a limit placed on the amount of incineration (and pyrolysis[16]) permitted for ASR. In fact, the issue to consider incineration as a form of recovery is still being debated. Automakers want to push incineration as a form of recycling rather than just recovery because of growing plastics content in vehicles. However, policymakers feel this is not a good utilization of resources. In this case where energy recovery is limited, some 15-20% of a vehicle's weight is still left to be landfilled and thus new solutions are needed. The main issues with the remaining suggested techniques have been reparability, purity of recovered streams, cost, and resale value. Most separation technologies have relied on material density for separation using heavy media. However, in the case for plastics, each plastic has ranges of density overlapping with other plastics. This poses a problem for achieving high enough purities in recovered streams for actual reuse. Therefore, others have developed techniques that tap into other distinguishing properties of polymers which will provide better recovery. Several recycling industry players are embarking on such ventures to recover an assortment of polymers from ASR.

One method, developed by Argonne National Labs and is being implemented by Salyp, a Belgium recycler, recovers polyurethane foam (PUR) from ASR to be cleaned and reused at the same grade as virgin PUR. Initial separation of ASR into three product streams of polyurethane foam, thermoplastics, and inorganic fines is accomplished through a two-stage trommel. Of the three product streams, PUR recovery is furthest along in

[16] Pyrolysis is the thermal decomposition of organic materials in an oxygen-free environment. The resulting extracted products can be categorized into three major streams: oil, gas, and solid residue. Gas is used to sustain the pyrolysis process and the solid residue is landfilled. The final usable product, oil, is a form of energy recovery from ASR and is not considered recycling by the EU Directive.

development. The PUR stream, after passing over magnets for ferrous material removal, enters the next stage of cleaning consisting of being resized, washed, rinsed, and dried. Size reduction assists in better results in subsequent steps. The washing step is a two step system with heavy media settling in the first tank followed by a wash of surfactants and detergents. After washing, the foam is squeezed between rollers, dried, and baled. The Argonne PUR foam was converted to carpet underlay which demonstrated reasonably good qualities. Recovery of the remaining two streams of thermoplastics and inorganic fines are still in development but there are discussions of using sink/float methods to sort thermoplastics and using ferrous and silicon oxide from the fines for cement production[71].

An alternative to the sink/float method for thermoplastics has been developed by Okutec. Salyp is incorporating a second process demonstrated by Okutec which uses altered properties of plastics at elevated temperatures based on their softening point. The polymers are not melted only softened and then rolled. Those with like properties mechanically adhere to rollers that apply different pressures and the remaining materials pass through. An infrared drying drum is used to heat the polymers prior to passage through rollers, which Salyp claims is an energy efficient method for temperature application. The setup is analogous to magnetic recovery of ferrous scrap from shredders. Salyp is in the process of building a pilot plant which will go into operations in 2001[72].

Another recycler, Plastics Recovery International (PRI) with support from USCAR's Vehicle Recycling Partnership (VRP), has developed a different process for plastics recovery. The company has already built a pilot facility for testing their skin floatation principle. The skin floatation method targets specific plastics through use of various proprietary plasticizers. Dispersed in a water solution, a plasticizer is mixed with a plastics stream where the plasticizer targets a specific polymer, rendering it hydrophobic by a thin layer of oily coating. Air is then introduced into the bath through air sparges. The air bubbles preferentially attach to the target plastics and promote their floatation. The other plastics remain at the bottom[73].

The entire PRI skin flotation process begins with air aspiration to remove foams and other fluff followed by a standard heavy media separation process to recover any residual metals. In particular, PRI is attempting to recover copper, a high value material, from this step in the process[74]. The remaining stream enters a wet grinder for size reduction and consistency. The ground particles are then sorted in a three stage wash beginning with a high caustic solution and surfactant to remove oil, grease, and adhesives. This is conducted in an elevated temperature bath to insure cleaner plastic flakes. In this step, light plastics naturally float to the top of the wash solution and are skimmed off for rinsing, while heavier plastics sink and enter a series of skin flotation treatments. A counter current method helps to remove fiber lint and foam. The light plastic stream consists of mainly polypropylene (PP), polyethylene (PE), and thermoplastic olefins (TPOs). These are subsequently dried and classified using the air aspiration method. The heavier plastics stream can then be treated in consecutive baths with varying plasticizer treatments depending on the target plastic. Reported recovery purities range from 90-95% in pilot plant tests.

All the ASR recovery techniques are still in their development stages and require full scale-up implementation before actual recovery capabilities and costs can be assessed. Therefore, it is difficult to determine which may be the better technology. Nevertheless, profitable implementation seems probable based on preliminary studies and since PRI's system is already in its pilot plant stage, more data was available for constructing a cost model.

7.2 Models

In addressing the issues highlighted earlier, an extensive cost model was employed to capture the four primary operators within the recycling chain. This approach was necessary in order to answer questions regarding marginal costs for increasing recycling and the effective burden on producers. Furthermore, the cost model sensitivity tests also provides insight into how operators react to materials prices and how prices may effect an entire system. The operators modeled included dismantlers, shredders, nonferrous separators, and ASR separators. It is important to note that ASR separation does not currently exist as a mature, commercially viable process, but will likely play an important role in achieving directive targets. Therefore, the cost model for this process is based on a pilot facility.

7.2.1 Dismantling Model

A dismantler's profitability, as described previously, is dependent mostly on the resale of used parts. When examining the dismantler profitability through hulk and materials sales (i.e. older vehicles with little part value), it is important to keep in mind that dismantlers may still remain profitable since ~20% of vehicles have positive value through spare parts resale. However, since the variation in determining profitability of parts resalers are difficult, the focus is on any resulting changes in their hulk and materials sales portion of their business.

The model employed is capable of simulating several kinds of scenarios. The underlying principle of the model is that disassembly is motivated through economic forces including part resale, material value, or mandatory recovery requirements. As mentioned previously, the algorithm considers the position of each part in a vehicle relative to all other parts that can be removed. It also accounts for all the materials within a larger assembly that has been removed. The component values are compared with total cost or effort for removal to make the decision for actual removal. Anything remaining in the hulk is then sold to shredders at a set price per ton of hulk. In addition to a market driven scenario, we also have a government mandated scenario where certain parts such as batteries, tires, fuel tanks and hazardous fluids must be removed prior to shredding. Lastly, the model is capable of handling the International Dismantling Information System (IDIS) suggestions for removal of parts for material recovery. Infrastructure issues aside, this suggests extra costs for a dismantler that will need to be supplemented through deregistration fees or subsidies from automakers.

7.2.2 *Shredder Model*

This is a straight forward model that calculates costs based on throughput capacity. The equipment and facility cost is based on a regression of several facilities and their throughput rates. We also assume that built into the shredder facility is a eddy current recovery (ECR) system to sort most of the nonferrous materials from ASR. In practice, the recovery efficiency averages only 70-75% among various shredders [75]. However, since the range of capabilities vary widely (i.e. from those SME's who do not have ECR's as part of their shredder system to vertically integrated facilities such as Huron Valley Steel who can recover above 95% of nonferrous materials from a hulk) recovery percentage used in the model for nonferrous material was set to 85% to replicate average facilities with ECR capabilities. Another point to keep in mind is that shredders often process a considerable amount of non-hulk products such as appliances called white goods. Since we are only concerned with the portion that process vehicles, it is assumed that 100% of throughput is hulks. Additionally, shredders have a fair amount of maintenance costs attributed to tool wear, which is calculated based on throughput. Overall the shredder creates three streams of output: ferrous, nonferrous with some ASR contamination, and ASR. Though the perceived purpose of shredders is to recover ferrous material, a majority of shredder income comes from nonferrous materials recovery. In fact, transaction price between shredder and nonferrous separator is key to each of these operator's profitability.

7.2.3 *Nonferrous Recovery Model*

The nonferrous recovery model is derived from information describing Huron Valley Steel (HVS: the US's largest nonferrous separator) as well as various text describing recovery efficiency and technique. Data reported on recovery efficiencies from the 1980's to present day has shifted from around 70% to 98% as HVS has claimed. Therefore, there may be large discrepancies from one nonferrous separator to the next based upon technology used in the sorting process. Built within the nonferrous recycling model are several steps with pieces of equipment that do not necessarily increase in size, but only increase in number of units used to achieve desired throughput. This method is based on the notion that equipment sizes are fairly standard to the industry and increasing capacity is accomplished through addition of new lines. One can choose to override these calculations and enter actual capital costs if desired. In fact, this feature is available for all the operators for easier sensitivity adjustment.

7.2.4 ASR Recovery Model(s)

The ASR recovery model used in this thesis is a hybrid of Argonne's polyurethane recovery and PRI's skin floatation method. With PRI's assistance, the ASR operator represented in this model uses similar process steps and achieves similar recoveries as PRI. Currently, PRI's pilot facility recovers ABS, PP, nylon, and copper as they are some of the higher value materials. However, from previous testing of plasticizers, several additional polymers may be recovered, requiring only added wash tanks[76]. This permits calculation of incremental costs in recovery by adding new tanks. Additionally, since light fluff and foams such as PUR are separated out prior to washing, this stream is modeled to feed into a process similar to Argonne's PUR recovery system, though notably more simplified. The PUR section incorporates part of a PUR recovery model developed previously by Dr. Andy Chang for his doctoral thesis. The cost estimates provided by PRI are based on only ABS, PP, and nylon recovery and capacity is determined by "product output." In the case for PRI, equipment design scales up at 10,000 tons product/year intervals. This was somewhat difficult to resolve when considering additional materials to be recovered. A ratio of PRI specified recoverable materials to all ASR materials was used to calculate "effective input."

8 Input Data

Data used in the model can be separated into the following categories: 1) vehicle parts and properties, 2) operator fixed costs, and 3) operator variable costs. For data category 1, vehicle parts and properties, I used disassembly information gathered by Pavel Zamudio Ramirez of MIT for his thesis based on a composite of two midsize sedans[77]. Additional vehicle profiles contributed by automakers were also used for testing variations of the model. Parts data were treated for compatibility with MSL's disassembly model. Included in the process was an effort to group parts into subassemblies which can then in turn be grouped as part of a full assembly. In this way, if a large assembly is designated as preferred for removal by the algorithm, then all the parts and their materials are accounted for. Furthermore, a "precedence table" was also created for all the parts indicating which parts must be removed immediately prior to accessing a given part. This designation allows the disassembly program to recognize that, for example, when a tire is to be removed for recycling, one must remove the wheel hub and rim before obtaining the actual tire itself. However, if the algorithm decides that removing the entire wheel and tire assembly from the car is more cost effective, then that would be the economic approach. The parts data themselves include material type, weight, and resale value, if any.

Since some data sets for vehicles provided information for too many parts for reasonable assessment, fasteners and parts weighing less than 100 g were included in the modeling as an aggregated part that can never be disassembled. Some may argue that fasteners and "small" components may end up as part of disassembled parts rather than in subsequent processes for recovery and is lost from the system. However, since over 95% of fasteners are steel, it was assumed that if they are not left on the vehicle after disassembly, the recycling processes used to recover disassembled parts will use magnetic methods to extract ferrous pieces. As for the small components, there is a high probability they remain within the car and can be accounted for in an aggregated manner following disassembly since the entire vehicle is shredded and its components become indistinguishable. Lastly, some grouping of materials was necessary to create bounds on the assessment. Refer to Appendix VI for details.

Unfortunately, due to the large undertaking of preparing vehicle data into appropriate formats, only one vehicle has been completed in time for thesis writing. The smaller vehicle size is more representative of average European vehicles than the larger sedans used in Ramirez's and Kirchain's study.

The second group of data is fixed costs. This includes all capital, overhead, and maintenance expenditures that exist regardless of utilization of facilities. Capital costs include both equipment and building investments. These estimates are based on either industry standards, estimates provided by industry members, or regressions based on different size facilities. More likely than not, this is not the exact cost of a facility but provides a fair starting point for a base case.

The third group of data is variable costs. In this category, we find rate based variables such as labor, utilities, material, landfilling, and transport costs. These variables are derived from the amount of materials processed and utilization of facilities. Material costs are based on prices posted on US RecyclingNet website, American Metals Market, and index prices (refer to Appendix V for more details). In cases where prices are not available, such as many engineering polymers, an assumption was made that the price of secondary material was half that of virgin material. These different prices can be varied accordingly in the model for policy testing. Transport costs are also important in determining facility size and degree of vertical integration. Likewise, landfilling cost is also key to scenario testing. Labor, utilities, and transport costs can vary according to regional differences (refer to Appendix VII for detailed input data).

9 Scenarios, Sensitivities, and Discussion of Results

Once the model was developed, it was tested in three steps. First, to properly test the effectiveness of the model, specific variables were isolated and examined for how their variance might influence costs and profitability. Secondly, a base case was created for all "three" vehicles in order to verify variance of costs based on material content. Third, different scenarios incorporating results from sensitivity analysis and policy mandates were tested for impact on system cost and profitability. Additionally, scenarios were built to test the potential benefits of industry consolidation both vertically and horizontally. Either strategy would require radical changes to the existing infrastructure and how transactions are conducted. Finally, in assessing profitability, it is critical to discuss the implications of an overall profitable system where a particular link is not profitable versus an ideal system where all operators are profitable.

9.1 Sensitivities

Since there is considerable interdependence of variables within the model, it was necessary to test several key drivers and assumptions to determine their effect on costs. These analyses also provide a treatment of the dependence of the results based on questionable assumptions. Costs and profitability were found to be especially dependent on the following factors:

- Material prices (transaction costs)
- Landfill prices
- Transportation cost (cost and distance)
- Effect of subsidies

First of all, facilities were assumed to operate at or near their optimal, or most cost effective, capacity utilization and size of facilities were derived from industry standards. However, we do not assume fully dedicated facilities, since in reality, all the operators are involved with different recovery activities, such as automobile parts recovery for resale, and recovery activities from other sources, such as shredding appliances or processing other post-consumer wastes. This assumption of non-dedication provides more moderate estimates on potential size of facilities and distribution of fixed costs.

First of all, transaction price of hulks between shredder and dismantler can affect each operator's profitability significantly. The logic is that if a shredder pays too little for hulks, the dismantler is motivated to recoup his expenses through removal of more expensive components, which then decreases high-value materials going to shredders and reduces his profitability. On the other hand, if dismantlers demand too high of a price for hulks, the shredder may not be profitable at all and will not purchase the hulks, leaving dismantlers with either further component dismantling or lower hulk prices. The first issue that arises from differing hulk prices is highlighted in Figure 4, where lower hulk prices motivate higher extraction of valuable materials leaving post-dismantlers with less valuable materials to process. The "appropriating" of materials by dismantlers lowers the profitability of shredders to the point that the operations become not feasible at high hulk prices (See Figure 5). Likewise, if not paid enough, dismantlers lose out also and will either pay less to owners for ELVs or decide not to collect abandoned/unwanted vehicles. Therefore, there is a fine market range where profitability is balanced so both operators can function. However, note that recovery is not optimized in the situation where profitability is

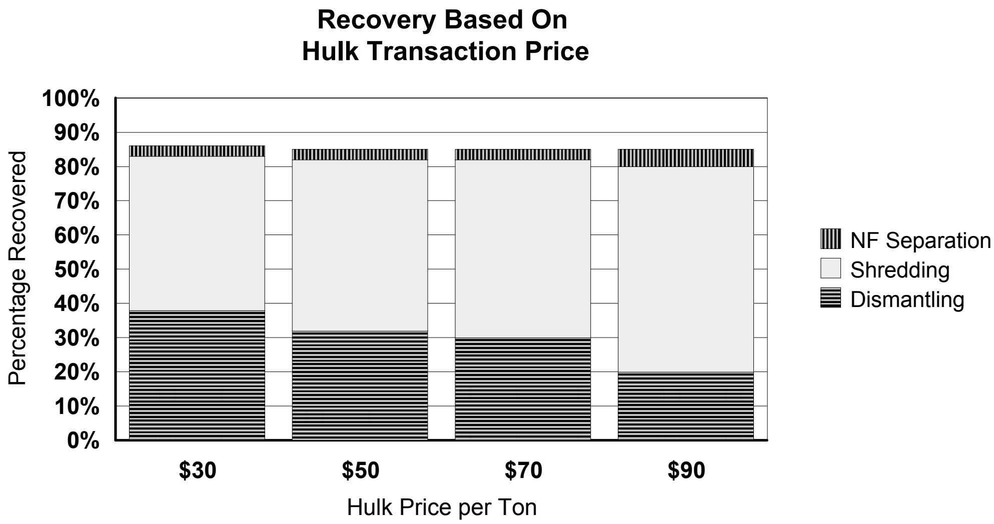

Figure 4: Recovery by Various Operators as a Result of Differing Hulk Prices

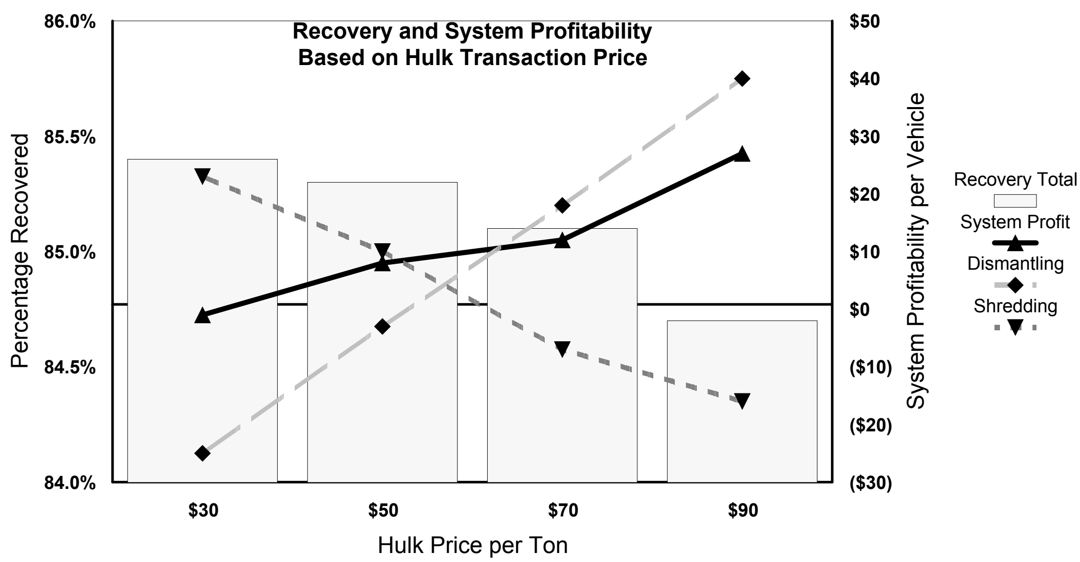

Figure 5: Profitability of Operators Depending on Hulk Price and Impact on System Recyclability

Moving downstream, nonferrous operators face similar difficulties in balancing transfer pricing, but the picture here is less clear since not all operators participate in this transaction. In Europe, conflicting accounts of the current infrastructure give rise to inconclusive evidence regarding technological capabilities of shredders and the transactions between shredders and nonferrous separators. By some accounts, there is active post-shredder presorting of nonferrous materials at shredder sites which translates to higher resale value of the nonferrous stream to separators. However, there are also numerous shredders without this capability because of their small facility size and available capital. It is unclear whether the unseparated ASR stream is sold to nonferrous separators for reclaim. One hypothesis for this lack of complete development of the nonferrous separation market is the presence of limits deriving from high transportation costs and landfill costs.

Using the base case for Vehicle 3 (which will be described later), the transaction price for nonferrous material stream (i.e. from shredder to separator) demonstrates that if the separator has on-site facilities, he is most profitable charging 0% of the Al price (i.e. No transaction fee) and capturing the sum of the system's profits. To reiterate from the previous chapter, the transaction price for nonferrous material is based on the value of the nonferrous content of the material stream with some discount. In Figures 5 & 6, the X-axis represents the % discount taken off the perceived nonferrous content of the nonferrous stream. For example, if it was found that a particular truckload had approximately 50% nonferrous material content mixed with ASR, than the nonferrous separator may offer to pay for that 50% with some discount for processing expenses.

If the shredder does not have on-site processing capabilities, the range of nonferrous transfer prices within which both nonferrous separator and shredder can be profitable is quite limited and not optimal (meaning the system does not achieve maximum profitability). In Figure 6 where shredders conduct some presorting of the nonferrous stream, only at the crossover of a nonferrous discount of approximately 18% does both operators achieve some level of profitability. This case, of course, changes as nonferrous prices increase. Such an increase effectively shifts the plots of Figure 6 & 7 vertically, creating a range over which both operators are profitable. Additionally, non dedicated NF separators may be willing to pay more to shredders considering they will aggregate material from several shredders and thus process more "vehicles" at one facility.

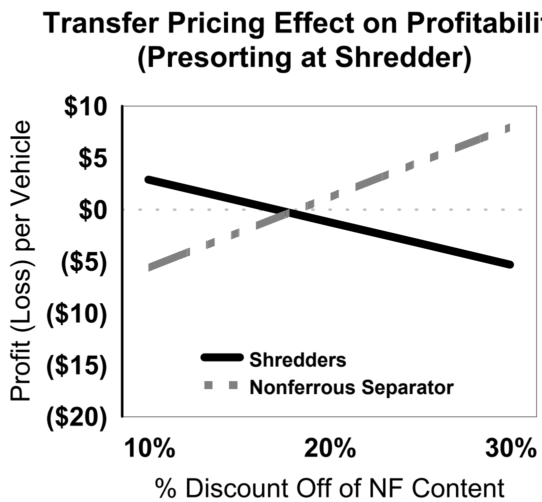

Figure 6: Transfer Pricing Effect on Profitability (Presorting Nonferrous Material at Shredders)

Interestingly, as Figure 7 demonstrates, it is actually more cost effective in Europe for shredders to choose not to conduct preliminary sorting of nonferrous materials from ASR because the relatively high landfill costs can be partially avoided by delivering high quantities of ASR mixed in with nonferrous material. The shredder can accommodate receiving a lower price for the material and still maintain profitability, while the nonferrous separator will be profitable since his costs are also lower for the material despite increased landfilling costs.

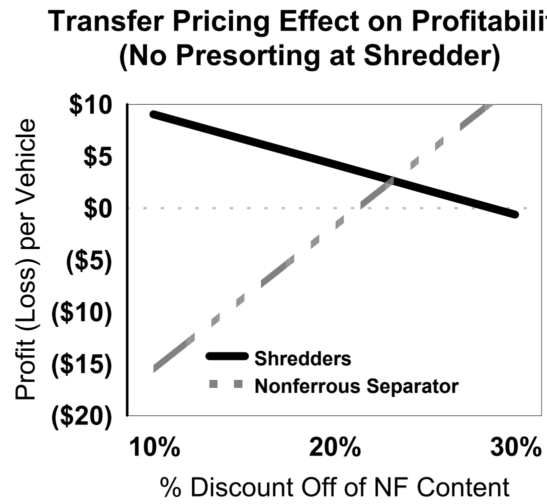

Figure 7: Transfer Pricing Effect on Profitability (No Presorting Nonferrous Material at Shredders)

When considering the potential of ASR separators to be economically incorporated into the existing infrastructure, it is necessary to assume that these businesses will receive payments analogous and equal to landfill tipping fees for the materials which they receive. Essentially, shredders and nonferrous operators are paying for ASR separators to recover material from ASR instead of landfilling the material. As such ,the magnitude of this revenue, as set by prevailing landfill tipping fees is key to establishing separator viability. Using the base case and varying landfill tipping fees (see Figure 8), the model results show that ASR operations are not profitable until landfill costs are near $160/ton. However, NF separators, who have low margins with high volumes, and shredders, whose profitability drops rapidly due to high ASR content of hulks, sees significant losses if forced to pay tipping fees higher than the base case of $160/ton. At prices above $160/ton, ASR operators become profitable but these higher tipping fees put shredders and nonferrous separators into the red. While maintaining a disposal price at $170-$190/ton provides the highest total economic benefits and an economically driven recycling system, lower tipping fees will not provide enough incentive for ASR separation to emerge. Landfill prices that are too low will not motivate post-shredder, ASR separators to enter the market, since the revenue from the sale of the low-value materials is insufficient to help recoup expenses. On the other hand, though higher prices might reflect an incorporation of landfilling externalities, those high tipping fees are likely to create a mass exodus of shredders and nonferrous operators whose margins are already being squeezed by depressed metals prices. Ultimately, this effect may decrease recycling within the overall system, unless a fine balance can be achieved.

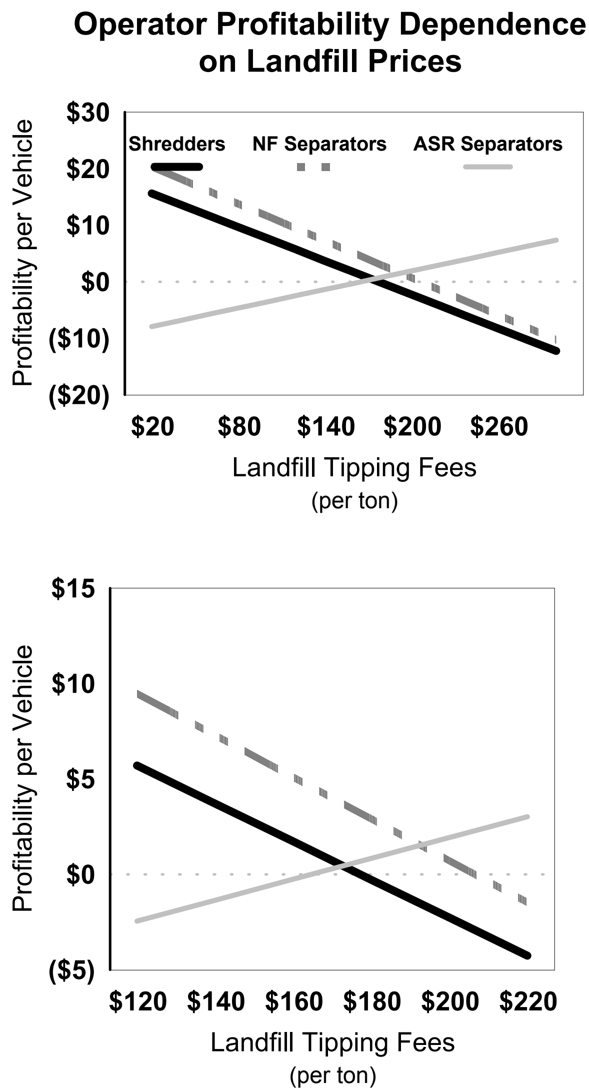

Figure 8: Profitability of Operators Based on Landfill Prices (Especially ASR Separators)

Transport costs also have a significant effect on profitability, especially when the construction of larger processing facilities means they can handle material from greater distances. Two transaction points arise that may cause pressures of unprofitability to new systems. First of all, take the case when dismantling, shredding, and nonferrous separation are consolidated at one facility. While consolidation reduces transport costs between shredder and nonferrous separator, delivery and transport of ELVs is still necessary. In this case, the distance that vehicles must be transported from an ELV drop-off point (either dealer/mechanic's garage/local scrapyard) to a large facility is greater than in the case of smaller, more geographically distributed facility since the larger facility has a greater radius of service and less facilities are needed (see Figure 9).

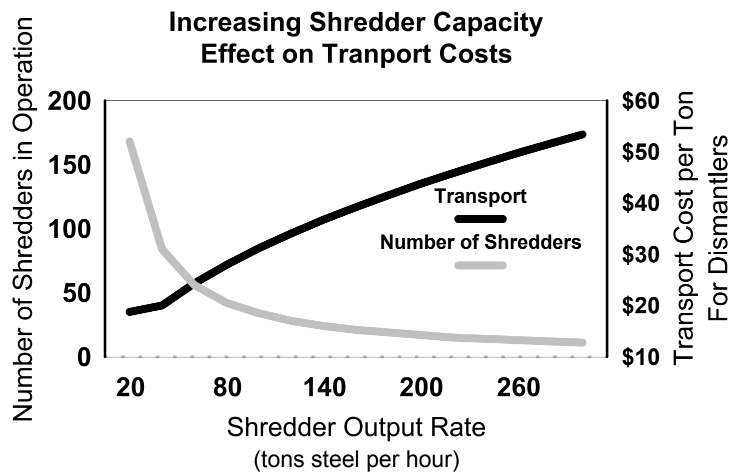

Figure 9: Increasing Shredder Capacity Can Increase Transport Costs

In Figure 10, we see that consolidation of shredders actually do not impact profitability significantly once output exceeds ~35-40 tons per hours. However, dismantlers become less profitable as facilities become larger than 50 tons output per hour due to higher transport expenses. The above graph (Figure 9) projects high increases in transport costs when there are fewer facilities. However, realistically speaking, the total number of facilities should not fall below 100 or the average shredder would be processing material from more than 80,000 vehicles per year. Most of the mega-processing centers are designed to process 30,000-40,000 vehicles per year.

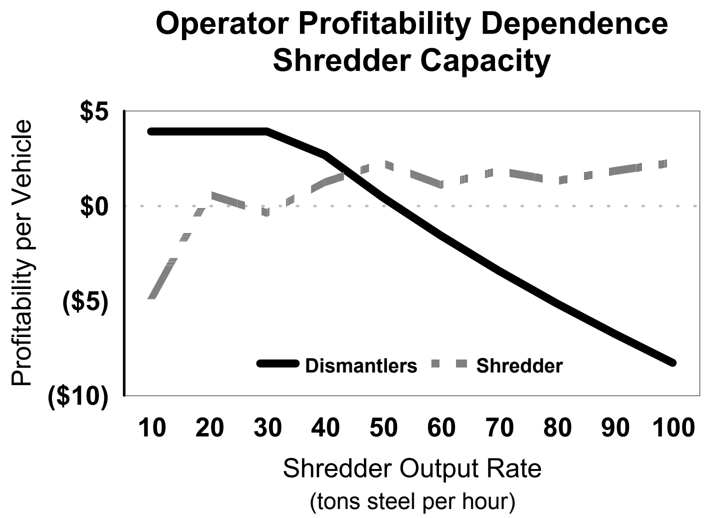

Figure 10: Operator Profitability Dependence on Shredder Capacity

Lastly, we have mentioned that potential scenarios include different degrees of vertical integration. In this way, transfer costs and transport costs are eliminated and thus reduce the overall cost. It is important to keep in mind that when looking at cost of a system, the cost for one operator is actually the revenue for the downstream operator and therefore costs may appear inflated. On the other hand, an examination of the transfer prices in terms of profitability can shed some light on which systems are actually functioning well.

In Figure 11, there are four cases of integration. The first two cases are based on the existing infrastructure which includes transaction costs between shredder and nonferrous separator. These two differ in that #2 includes some degree of presorting of nonferrous metals while the #1 does not. The next two cases involve facilities that co-locate both operators. Case #3 is designed for process integration. In this context, process integration means that the nonferrous separation operation is scaled to accept only the output of the co-located shredder (dedicated facility). Therefore, the nonferrous separation operation is not optimally sized from the perspective of scale economy, but its capital is fully utilized. Alternatively, consolidation in case #4 means the two co-located operators are sized for optimal processing economics, meaning that the nonferrous separation will accept material from outside shredders (nondedicated facility).

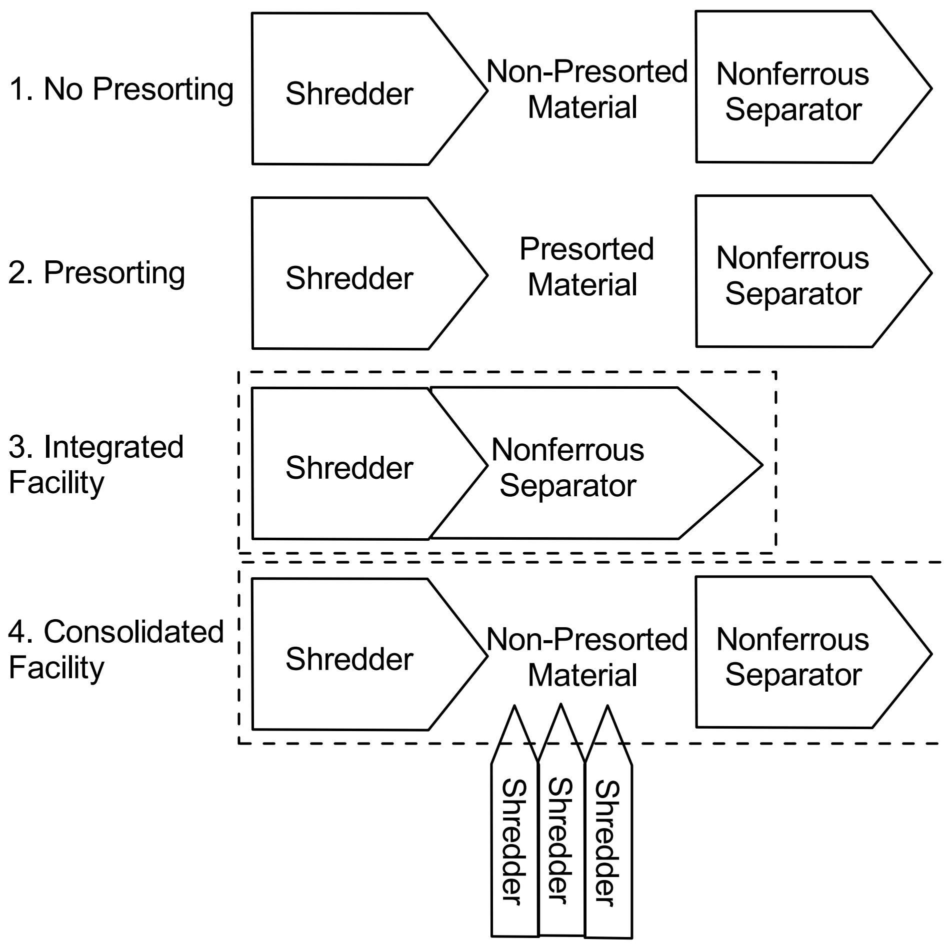

Figure 11: Shredder and Nonferrous Separator Configurations

From the graphs below (Figure 12), consolidation cases #3 and #4 create lower costs and higher profitability mainly due to the elimination of transport costs. Additionally, the consolidation case (#4) proves to be more profitable because each segment is operating at its optimal efficiency. This type of vertical integration reflects what is occurring at larger, profitable recycling sites, such as Huron Valley Steel where there are shredding facilities on-site but the company also processes outside sources of nonferrous material. However, when the system is organized in this way, some shredders may not be able to add on nonferrous separation facilities and will need to ship material to mega-facilities, such as HVS, for processing. These results suggest that shredders would be wise to opt for limited presorting before shipping their nonferrous materials for processing.

Though the profit margins are lower per vehicle for NF separation, the operator makes it up by aggregating feedstock from several shredders. In Europe's case, an average of five shredders is required to provide feedstock for one nonferrous separator, given that there are 220 shredders and 44 nonferrous (heavy media) separators in Europe. While not all shredders have the capability to provide a presorted nonferrous stream, the 5:1 ratio still indicates that it is unlikely that all shredders can afford to have on-site nonferrous separation. Instead, it may be reasonable to assume that many shredders would not bother with presorting of nonferrous material before delivery to nonferrous separators since the economics demonstrate that presorting creates a less profitable system.

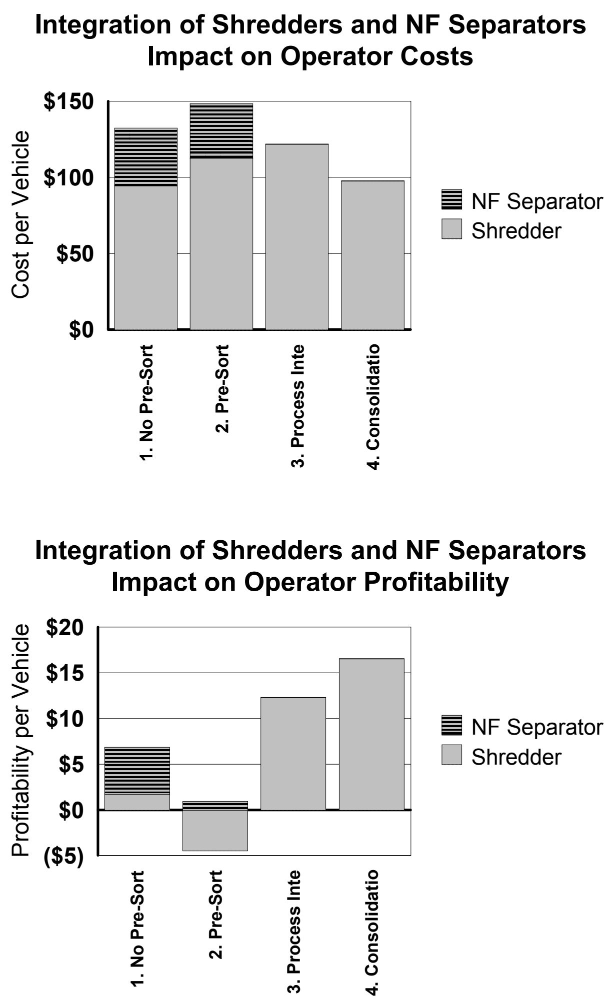

Figure 12: Integration of Shredders and NF Separators Impact on Operator Costs and Profitability

The results of sensitivity and consolidation testing demonstrate that 1) precise transfer prices are critical to the profitability of both upstream and downstream operators; 2) landfill fees impact profitability of existing operators and potential ASR separators; 3) large shredding facilities can cause dismantlers to be highly unprofitable due to higher transport costs; and 4) consolidation of nonferrous separators and shredders results in a more profitable business. These points will be important when considering outcomes of scenarios later.

9.2 Scenarios

9.2.1 Basic cost comparison

Having tested various sensitivities of the model, a base case was formulated for consistency later in scenario testing. In the base case, the model was set up to treat conditions resembling pre-Directive times when the infrastructure consists of dismantler, shredder, and nonferrous separators and transactions were mainly market driven except for required components removal. This baseline scenario was conducted for three different vehicles (Vehicles 1, 2, and 3) to examine the sensitivity of results due to material content of different vehicles. Material summaries for the three different vehicles is shown in Table 3. It is important to note that the summaries are highly aggregated descriptions of data actually used in the models. Vehicle 1 is an aluminum intensive vehicle while Vehicle 2 is a midsize sedan with an aluminum engine block. Vehicle 3 is a compact vehicle with a steel/aluminum engine block which accounts for its lower aluminum content. The analysis will focus mainly on Vehicle 3 because it best represents more of the existing vehicles on the road in Europe and its size more closely resembles that of average vehicles in Europe.

Table 3: Test Vehicles' Composition by Weight

	Vehicle 1		Vehicle 2		Vehicle 3	
	(kg)		(kg)		(kg)	
Steel/Fe	382	36.3%	814.2	63%	879.2	70.1%
Al	385.9	36.7%	191.6	14.8%	77.5	6.2%
Cu	5.7	0.5%	5.7	0.4%	20.5	1.6%
Pb	20.1	1.9%	20.1	1.6%	14.9	1.2%
Zn	0	0%	2.54	0.2%	3.05	0.2%
Glass	20	1.9%	20	1.5%	35.74	2.8%
Plastic	97.3	9.2%	97.3	7.5%	118.22	9.4%
Foam	12.6	1.2%	12.6	1%	15.67	1.2%
Rubber/Elastomer	50.9	4.8%	50.9	3.9%	54.11	4.3%
Fluff	29.6	2.8%	29.6	2.3%	15.42	1.2%
Misc	48.7	4.6%	48.7	3.8%	20.68	1.6%
Total*	1,052.8		1,293.3		1,255	

*May not add up exactly due to rounding

In researching the base case inputs, it became apparent that a fairly large gap exists between US and European prices for materials and other transactions between operators. This disparity is attributed primarily to an overall depressed metals market, but is exacerbated by less attractive market conditions for secondary materials in Europe. The lower metals prices also impact the hulk and ELV purchase prices. In conducting the first series of tests using European data, results showed that a profitable system could not exist at present transfer prices. However, with US metals prices, the system could be profitable, thus it was assumed that metal prices in Europe may reach parity with US prices when they recover from their current slump.

Table 4 contrasts the two regions' differences. Since landfill tipping fees are critical in developing European specific scenarios, the pricing of ASR disposal as that of hazardous landfill has to remain an European condition. Furthermore, since many nonmetallic secondary materials have no reported values, one of three assumptions were made: 1) they were valued at half of their virgin material value, 2) they were priced similarly as plastics from other post-consumer streams (i.e. plastic bottles, etc.), or 3) they were assumed to have a very low intrinsic material value. With these assumptions of materials prices, the total materials value of Vehicle 3 totals about $250. The assumptions for creating a baseline case are summarized below in Table 5. Additional inputs and assumptions are included in Appendix VII.

Table 4: Price Comparison Between Europe and US.

	Europe	United States
ELV Purchase Price (per vehicle)	$0-$50	50
Hulk Price (per ton)	15	$30-$80
Steel Scrap (per ton)	45	$90-$150
Mixed Aluminum Scrap (per ton)	780	~$1000
Nonhazardous Landfill (per ton)	$10-160	$10-$100
Hazardous Landfill (per ton)	$175-$715	?

Refer to Appendix V for detailed sources

Table 5: Assumptions for Base Case

Variable	Value	Comments
Part Value	Included	Part values are not resale values; some components, such as batteries, have material market value as a whole unit
Forced Part Removal	Included Level 1	Required removal of parts through regulation or shredder requirements (but not IDIS)
Hulk Price	$60/metric ton	Estimate based on price from AMM (see Appendix V)
Nonferrous Reduction	25%	Price for nonferrous stream material from shredders are priced at 25% off of estimated nonferrous metal content.
Deregistration/ ELV Delivery Cost	$50/vehicle	This covers costs for either towing abandoned vehicles or paying last owner for vehicle.
Direct Wages	$20/hr	This includes benefits.
Utilization	Nondedicated	Nondedicated lines imply facilities process other inputs, i.e. shredders process appliances (white goods) in addition to hulk
Shifts	1 per day	Due to low average throughput per facility
Transportation	$10+$1.75/km (min of $225/truck)	Transport varies based on distance. Assumed maximum weight per truck is 25 tons/truck except for transporting hulks 12 tons/truck.
Landfilling Cost	$160/ton	Estimate based on doubling of average nonhazardous landfill fees in Europe. ASR is currently considered hazardous waste
ASR Separation	Not Included	Since ASR separation does not currently exist

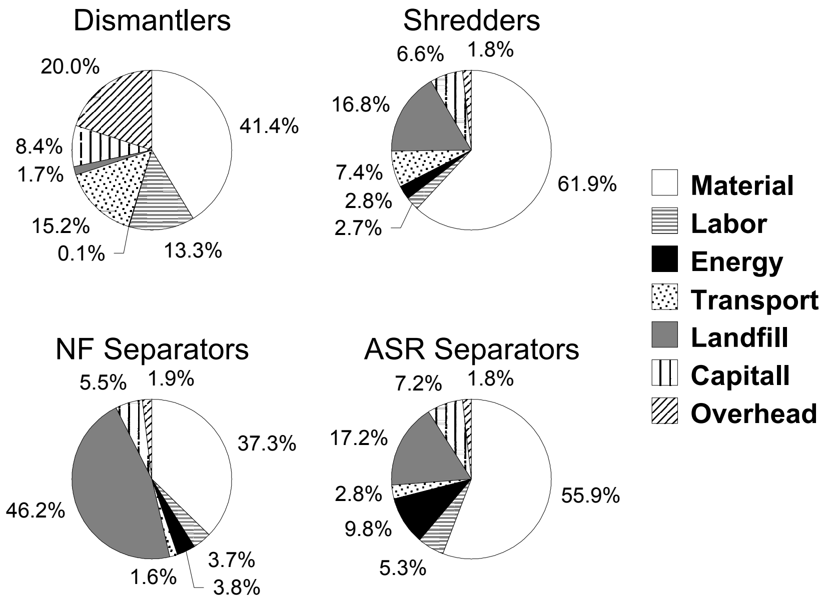

Figure 13: Cost Breakdown of Operators Using Vehicle 3 as the Base Case

A cost breakdown shows that a major cost component of each operator is material purchases. Therefore, estimates of material transfer prices will greatly influence profitability. However, since each operator is aware of his own costs, in practice he is only willing to pay prices for his input material reflected by the limitations imposed by his other costs and what his expected revenue will be (i.e. output materials' index prices). In this way, transfer prices along the chain are closely linked to one another. Once one operator is unprofitable due to depressed materials prices, others will also feel significant economic consequences.

As for labor and overhead costs, these costs are only an issue for dismantlers since only this step is particularly labor intensive. For the other operators, labor and overhead account for only around 5%-7% of their total cost compared to an estimated 33% at a dismantler's facility (if not more, since dismantler's capital costs can actually be quite low).

For dismantlers, it was difficult to gauge the cost of recycling or disposing of fluids since some may be recycled while other fluids are burned. Therefore, the cost was assumed to be negligible. In contrast, waste disposal in the form of landfilling accounted for the second major expense for all operators except dismantlers.

Transport costs are also significant for both dismantlers and shredders. This is normally the case when moving low-valued commodities in bulk volumes. From earlier sensitivity tests and the above cost breakdown, transport, along with material transfer prices and landfilling costs will play significant roles in operators' profitability and future survival.

Costs and factor prices will also affect recovery of materials, especially at the dismantlers' stage where dismantlers have more control over the exact amount of recovery. In the base case (Figure 14), approximately the same material is recovered at each stage of the recycling process for Vehicles 2 and 3--which is 80-82% of total vehicle weight. This figure does not include fluids but it does include the parts that may not have inherent part value yet must be removed to meet existing regulatory requirements[17]. While more aluminum is being recovered in the dismantling phase for Vehicle 1, there is still not enough of an economic incentive to recover all aluminum in this phase and some material is lost during shredder and post-shredder operations, yielding a lower overall recovery fraction.

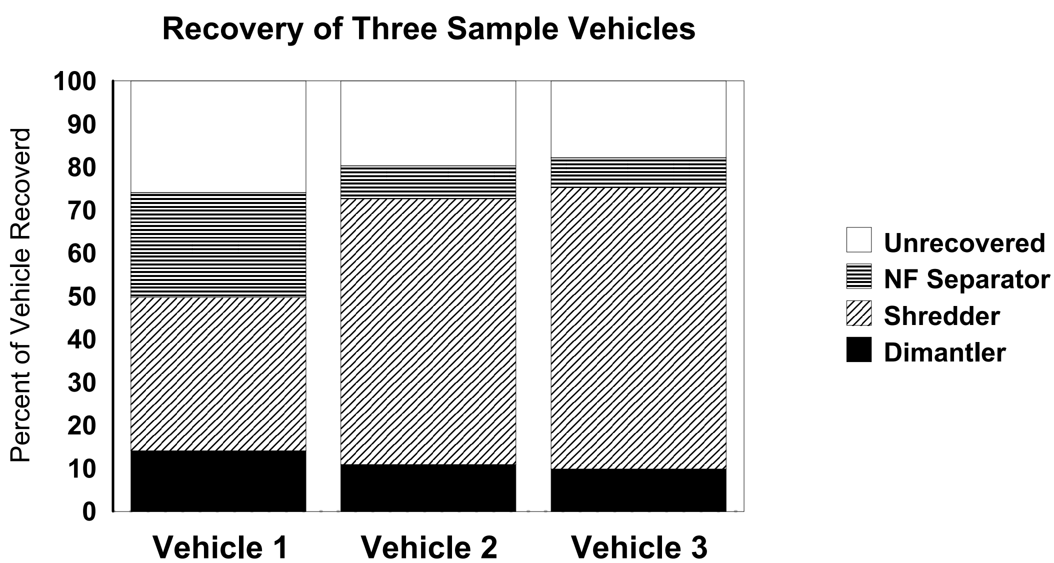

Figure 14: Recovery of Three Sample Vehicles

[17] Parts required for removal include: batteries, liquefied gas tanks, air bags, tires, catalyst, and various fluids containers.

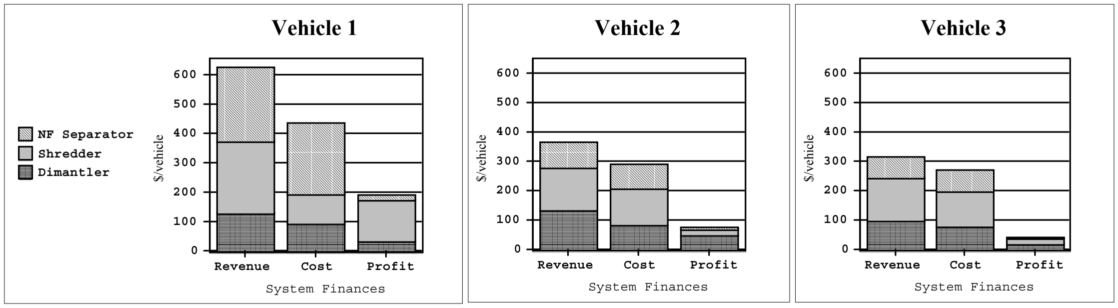

Figure 15: Recovery Economics of Three Sample Vehicles

On the economics side of this comparison, either total profitability of the system or individual operator's profitability from a vehicle can be examined. In the base case, all three vehicles result in profitable operations for the system on a whole and for each individual operators. However, it may seem a bit counterintuitive that the most profitable vehicle (1) with its high aluminum content stimulates the smallest percentage of material recovery. This can be explained by two main factors. First of all, the total percentage of nonmetal materials in vehicle 1 is higher than the other two vehicles. However, the mass of nonmetals are approximately the same as the other vehicles: only the total mass for vehicle 1 is less. Therefore, the percentage of metal materials is lower and thus a lower fraction of metal is recoverable. Nevertheless, revenue for vehicle 1 is boosted by the much higher value of secondary aluminum, which has a premium over steel scrap of approximately 8X. This result shows an interesting distortion, which could bias against extensive use of aluminum since its lower weight translates to lower mass percentage of recyclable material content in vehicles. In particular, the lower recycling performance of the vehicle conflicts directly with vehicle lightweighting goals to reduce fuel consumption and carbon dioxide.

9.2.2 Marginal cost comparison

An analysis of marginal cost can be used to assess costs for incremental improvements in recovery. In this case, the EU has a preferential position on recovery which is through dismantling rather than dealing with post-shredder residue (see Appendix I). Using our base case and Vehicle 3, we first assess how costs might accumulate in the system with the addition of ASR recovery. Then, this scenario is compared with high pre-shredder recovery through dismantling (which is material price and cost driven) and an additional scenario where IDIS recommended components are also removed.

Table 6: Incremental Scenarios

Scenario #	Scenario Name	Description
1	Incremental-ASR Recovery	Existing infrastructure (BAT) with ASR recovery added
2	Incremental-Dismantling	High level of dismantling in the existing infrastructure with ASR recovery added
3	Incremental-Dismantling w/ IDIS	High level of dismantling with IDIS recommendations in the existing infrastructure with ASR recovery added

A few key points to note in comparing a post-shredder recovery technique versus pre-shredder recovery techniques are:

1. Amount of material recoverable with and without ASR recovery
2. Cost effectiveness of scheme for individual operators and total system
3. Where might subsidies need to be injected?
4. Recovery does not necessarily mean recycling--especially in the case for mandatory parts and fluids removal.
5. Revenue, cost, and profitability are not absolute numbers but should be used in comparison. Cumulative amounts include transaction prices between operators and, thus, reflect higher costs and revenues than a system without such transactions. For a better assessment, profitability of the system as a whole may better reflect the system's efficiency.

As described earlier, cost for ASR recovery is related to the number of different types of materials an operator desires to recover. In the base case, where only acrylonitrile butadiene styrene (ABS), nylon, and polypropylene (PP) are recovered, ASR recovery operations are unprofitable because the inherent value of the materials are not enough to compensate for costs. However, with the addition of a washing/separation tanks, there are dual benefits in terms of added material recovery (landfill avoidance) and added revenue from the new material streams. The main revenue boost comes from the addition of a polyurethane (PUR) recovery system, a nonferrous recovery system, and a polycarbonate (PC) recovery system. However, when pushed to separate out rubber/elastomers, the profits drop slightly due to the zero economic value of these materials in the model. Overall, recovery percentage does increase from 83.3% in the base case to 90.6% without exorbitant costs, since recovering a larger assortment of materials will provide some profitability for ASR separators (see Table 7). In fact, if some or all materials mentioned above are recovered and there exists a secondary market, the profitability per base case vehicle is about $1-$3. This is not an absolute number, of course, since it is dependent on assumptions of recovery efficiencies and market prices of materials.

Table 7: Summary of ASR Separation

	Cum Recovery	Additional Cost	Additional Revenue	Additional Cum Profit
NF Separator	83.3%	0	0	0
PP, Nylon, ABS	87.7%	$58.18	$57.92	$-0.26
+PUR	88.7%	$61.57	$64.62	$3.05
+NF	89.2%	$63.48	$65.1	$1.62
+PC	89.6%	$65.32	$68.18	$2.86
+Rubber/Elastomer	90.6%	$67.55	$68.18	$0.63

In considering the impact of material prices, especially for plastics, results can be beneficial for one operator while damaging for others. On one hand, if material values are high enough, more valuable plastics are recovered by dismantlers, while the least valuable materials will flow to ASR separators. On the other hand, if material values are too low, although the separator will receive more material and thus more revenue from landfilling avoidance, they will also receive less revenue from the recovered materials. Ultimately, there is a fine balance that the market must maintain to ensure viable ASR recovery.

Like nonferrous separators, the technology of ASR recovery requires operators to take on the role of an aggregator of materials. Even if profitability is apparently low at $1 per vehicle, ASR separators still can create $8 million per year (assuming 8 million ELVs per year) in industry profits and recover capital expenses without subsidies. With ASR separation, recovery can be increased by up to 8% in the base case.

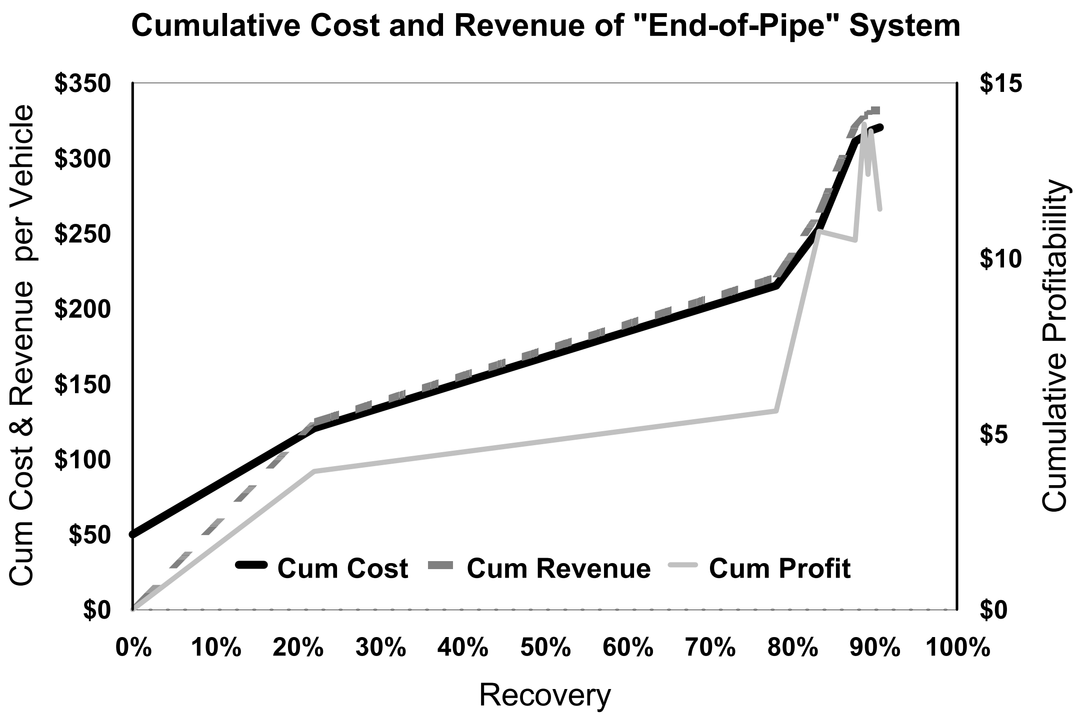

Figure 16: Cumulative Cost, Revenue, Profitability of "End-of-Pipe" System. (Scenario 1: Adding ASR separation to the end of existing infrastructure.)

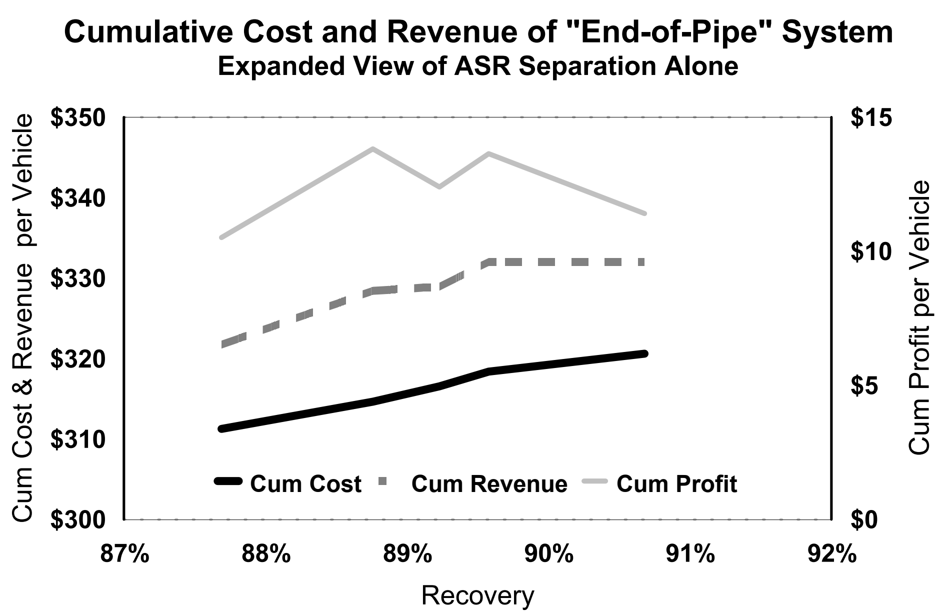

Figure 17: ASR Recovery System Alone (Cost, Revenue, and Profit)

In general (Figure 16), the entire recycling system manages to stay profitable: increased costs associated with ASR recovery range from $50-$70 per vehicle, which is supplemented by landfill avoidance and potential material value. Referring to Figure 16, the system, before adding ASR recovery, has a profitability of ~$11 per vehicle (recovering up to 83%) with cumulative costs around $260 per vehicle. With ASR recovery, the profitability of the system totals ~$12 per vehicle (recovering up to 90%) with cumulative costs of ~$320 per vehicle (see Figure 17). This implies that there should be no added expenses to producers/automakers as long as a market is created for the recovered nonmetallic materials, which is not a simple feat in itself. Since ASR recovery is still not a proven technology for large scale processes, the potential for the technology and its products are still uncertain.

Instead of ASR recovery, pre-shredder dismantling is the preferred option for regulators. To understand the costs associated with this strategy, two incremental scenarios (scenarios #2 and #3) were developed and tested with the model. The first pre-shredder recovery scenario (scenario #2) permits material value and extraction costs to drive recovery up to around 35.5% during dismantling (see Figure 18). It should be noted that without industry or government subsidies, this level of recovery will not be profitably achieved at the dismantler stage unless material prices increase or parts are recovered for resale. Since the high value of materials is purely a market effect, a great increase in demand will be necessary to get significant increases. In fact, with an increase of secondary nonmetallic materials entering the market due to the ELV Directive, prices may be driven down without a corresponding expansion of market demand.

In the absence of an increase in material values, subsidies to cover negative revenues and compensate operators would need to be as high as $60 per vehicle with incremental dismantling scenarios recovering up to 86% of vehicle weight without ASR recovery. This subsidy ($60) is the sum of the normal system profitability at regular recovery levels plus the losses incurred for higher dismantling. To achieve higher levels of recovery, ASR recovery techniques are still needed. Employing this technique brings the recovery percentage to 91%. Since it is a break-even business venture, there should not be any added subsidies required for this sector. Since a minimum of 95% recovery will be needed by 2015, the remaining fluff and mixed polymers can be recovered using energy recovery methods. This scenario seems to be significantly lower than ACEA's estimate of euro 150 per vehicle for recovery. One benefit of pre-shredder recovery is a higher level of recovery achieved without changing or adding to the existing recycling system. An estimated 86% of the base vehicle is recovered even before ASR separation and 91% is recovered with ASR separation.

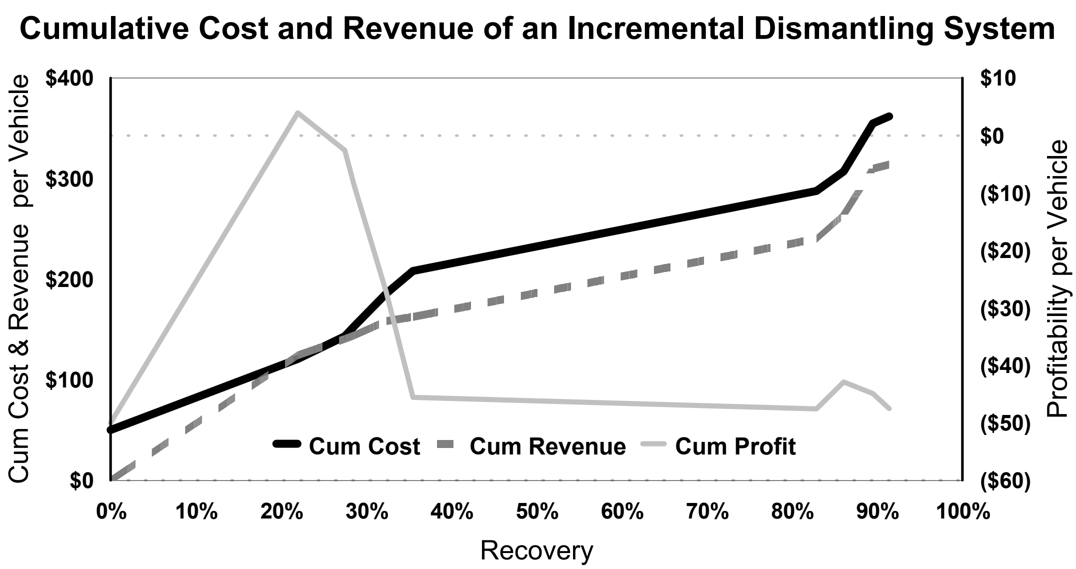

Figure 18: Cumulative Cost and Revenue of an Incremental Dismantling System

In scenario #3, both material-value driven dismantling with IDIS recommended recovery of specific parts are incorporated. This scenario also corresponds with the spirit of the ELV Directive in which dismantlers are to remove as many components and fluids as possible. In fact, this scenario recovers the most parts during dismantling, totaling 37.3% recovery (see Figure 19). However, IDIS requirements, which include the removal of glass components, are unprofitable above 20% level of recovery. In describing this analysis, it is important to point out that auto glass does not have intrinsic material value. This is clearly evidence by a negative price in US markets[78]. Additionally, since the suggested recovery method for glass by IDIS is to break the glass into a bag, the windows lose any resale value as windows[79]. Furthermore, certain materials, especially engineering plastics, may be undervalued since no transparent market (published prices) exists for these materials. Since most valuable materials are dismantled, recovery downstream at shredders is also unprofitable. The formulation to compensate operators through subsidies may equal the difference of the profitability of the existing infrastructure with the losses of a high dismantling infrastructure ($80+$10)=$90 per vehicle. Nevertheless, despite the higher costs, recovery is highest for this scenario with 90% recovery within the existing system and 94.5% with ASR separation.

By examining marginal costs using these three scenarios, it becomes clear that while a high-level of pre-shredder dismantling can lead to 3-6% increase in recovery, the alternative post-shredder processing is not only a more economical solution but it also results in up to 91% recovery by mass. This is sufficient to meet Directive requirements if most or all of the material "recovered" can be recycled.

However, since there are some technical challenges regarding the cleanliness and purity of ASR recovered materials, pre-shredder assembly may provide cleaner material streams through labor intensive sorting of materials. Nonetheless, dismantled components will inevitably require additional cleaning and processing, as well, incurring still higher costs.

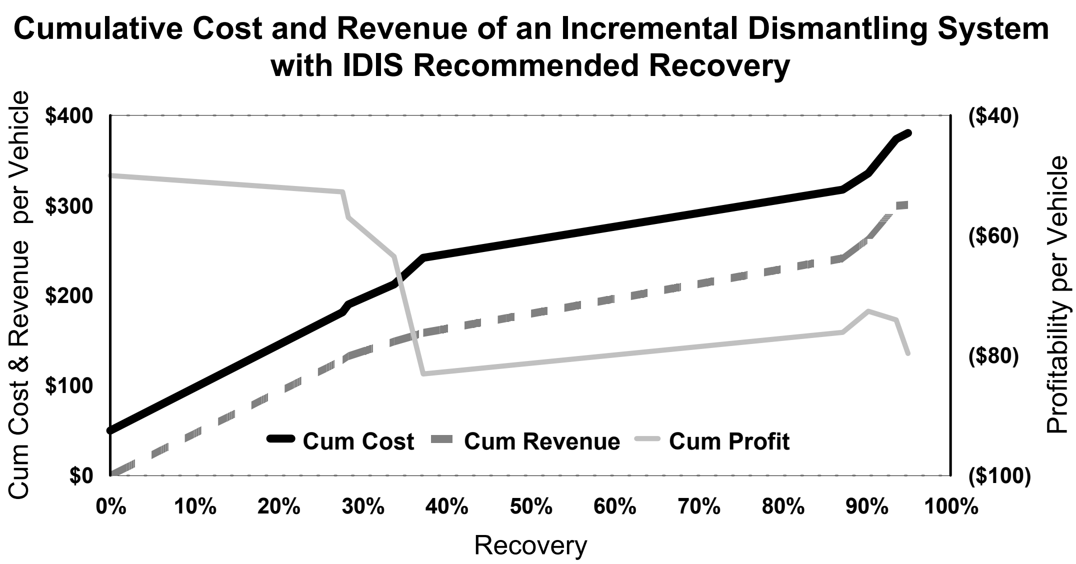

Figure 19: Cumulative Cost and Revenue of an Incremental Dismantling System with IDIS Recommended Recovery

9.2.3 Radical vs. Incremental Scenarios

In the previous section, cumulative costs of implementing incremental improvements using the existing infrastructure was examined. In order to assess more "radical" approaches, the following scenarios assume a complete shift in the existing infrastructure and departure of many inefficient operators. First of all, the costs for the three previous scenarios of ASR recovery (#1), high dismantling (#2), and high dismantling with IDIS (#3) recommendations are combined in the following graph (see Figure 20). We see that cumulative costs for the system actually converge at ~85% but no crossover occurs for dismantling to be a lower cost option.

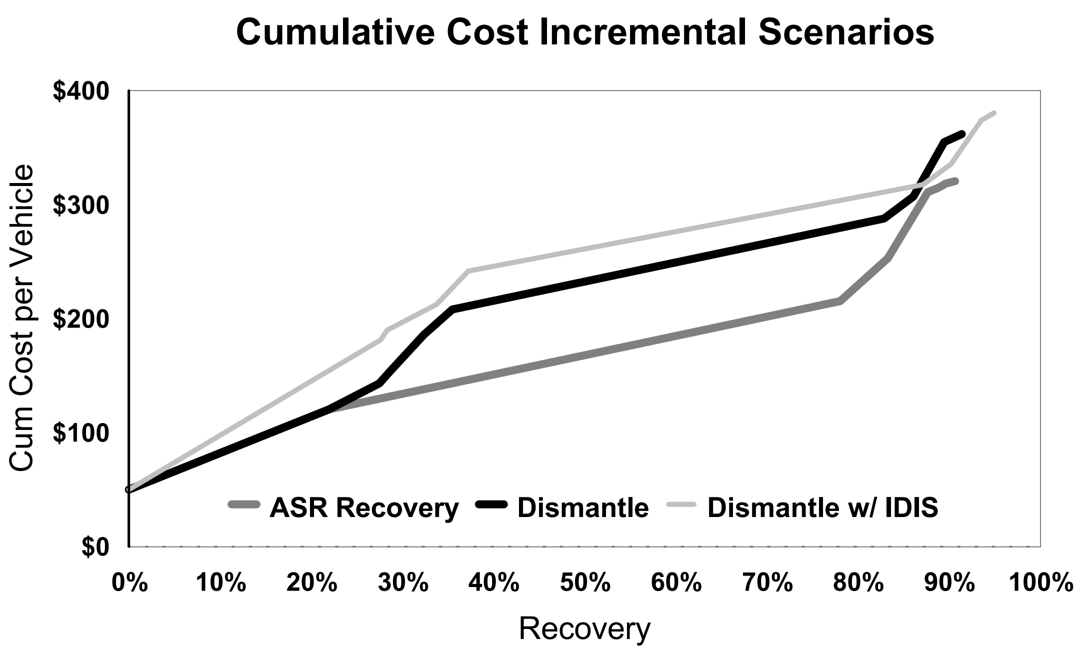

Figure 20: Cumulative Cost of Incremental Scenarios

Table 8 shows the addition of two radical scenarios. Both involve the consolidation of facilities so that dismantling, shredding, and nonferrous separation occur at the same site. However, one scenario encourages much higher dismantling levels and, thus, incurs higher costs early on in recovery. This scenario is called #5- Radical (high dismantle).

Table 8: Incremental and Radical Scenario Descriptions

Scenario #	Scenario Name	Description
1	Incremental-ASR Recovery	Existing infrastructure (BAT) with ASR recovery added
2	Incremental-Dismantling	High level of dismantling in the existing infrastructure with ASR recovery added
3	Incremental-Dismantling w/ IDIS	High level of dismantling with IDIS recommendations in the existing infrastructure with ASR recovery added
4	Radical-Consolidation	Moderate level of dismantling in a consolidated facility of dismantling, shredding (no presorting), and nonferrous separation
5	Radical-High Dismantling	Taking advantage of larger facility, initiate high level of dismantling

As with the incremental scenarios, cumulative costs for radical scenarios converge around 85% recovery (see Figure 21). At first glance, this may lead one to conclude that these two systems are functionally equivalent. However, looking at the profitability of the system as a whole is very different (see Figure 22). Since the facilities increase in size and, therefore, their service radius, transportation costs to bring ELVs to the facilities increase significantly. Additionally, transfer prices between operators once allowed each operator to capture some profitability (recall that cost for a downstream operator is actually revenue for an upstream operator) but a consolidated system eliminates transfer pricing. Also, recovery is higher at consolidated facilities with more capabilities, which pushes costs up but the extra expenses cannot be recovered through material revenue alone. Therefore, profitability of a large integrated facility can range between (-$30) to (-$140) per vehicle depending on the level of recovery desired (see Figure 22).

A rough comparison between total costs for a consolidated system (~$300-$400 per vehicle) and the total maximum material value of a vehicle ($250) reflects the same range of expected losses (-$50 to -$150). These values indicate that $40 to $150 in subsidies may be needed to contribute to the economic survival of large facilities, if material recovery is the major goal and prices remain depressed. This amount is reflected in the Dutch "green fee" discussed previously where all new vehicles are charged $100 in order to support new dismantling facilities in the Netherlands. An alternative solution to meet increased processing costs is for these facilities to recover and remanufacture parts for resale. In this way, if they can recoup profits of greater than $100 per vehicle, then consolidated facilities can become profitable and sustainable. It is more ideal for these larger facilities to remanufacture parts because they can keep a much larger inventory than SMEs. Larger facilities can also partner with automakers to recover their parts and become certified parts distributors for these automakers, as in the case for Volvo[80].

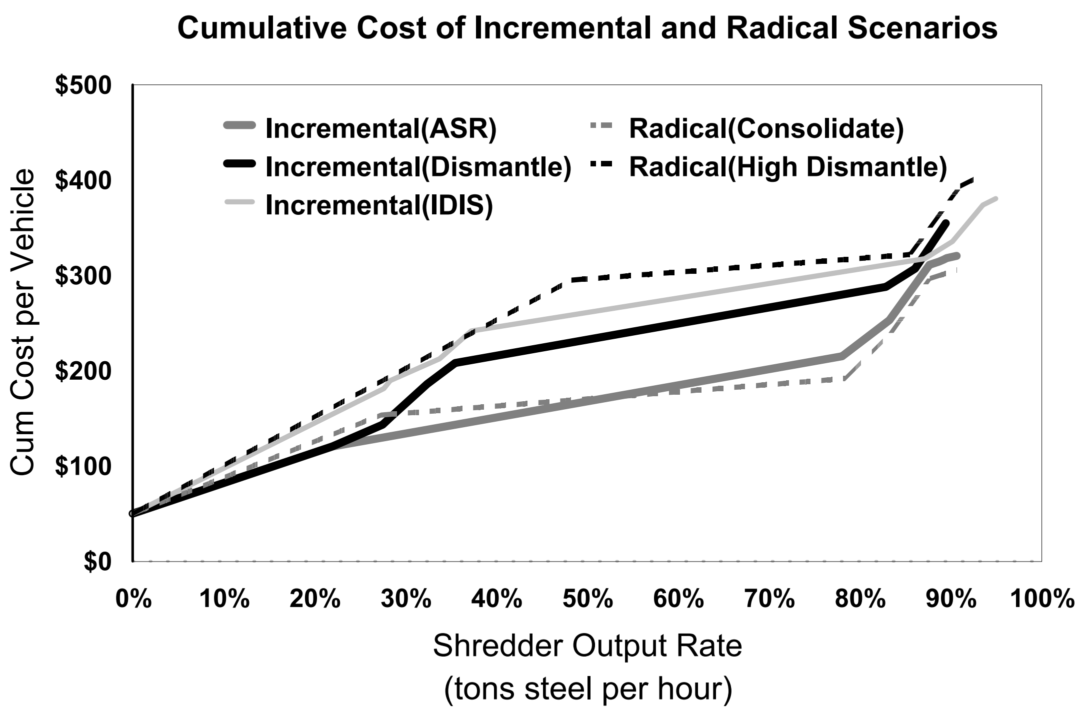

Figure 21: Cumulative Cost of Incremental and Radical Scenarios

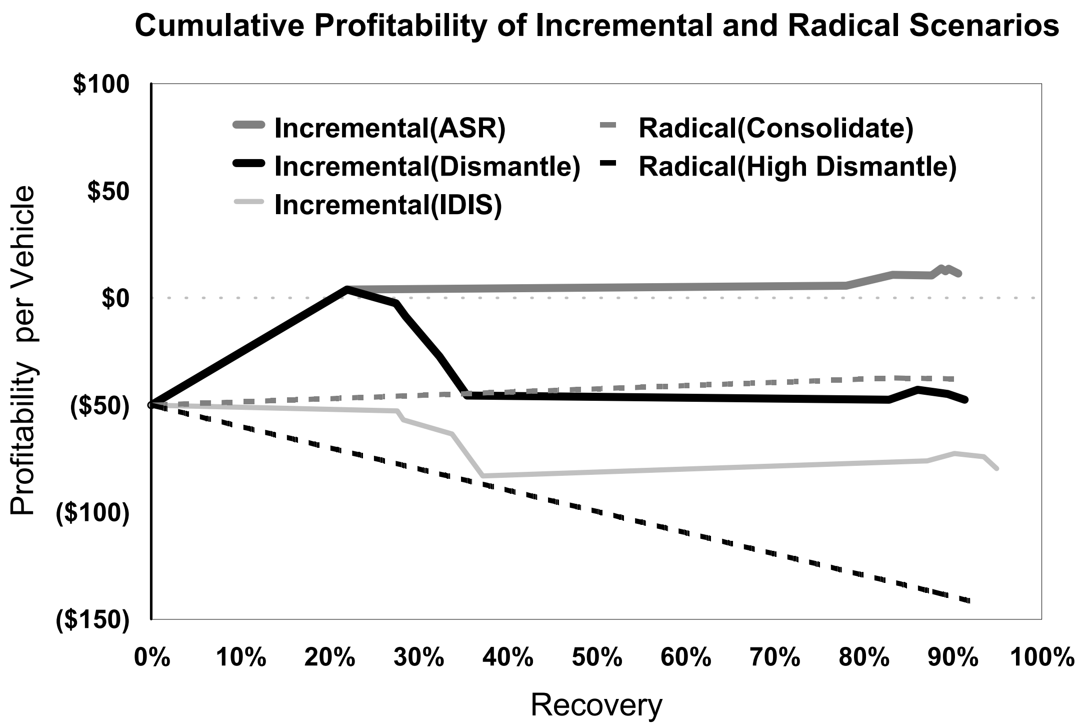

Figure 22: Cumulative Profitability of Incremental and Radical Scenarios

Along with additional operating costs for greater dismantling, new investments into facilities will also be necessary. The results depicted below, in Figure 23, show that, as expected, greater potential levels of recovery correspond to higher investment needs. The first bar labeled Incremental ASR (scenario #1), excluding "Additional ASR Investment", represents today's infrastructure if all facilities were operating with the best alternative technologies (BAT). As such, the vertically striped portion of this bar reflects investments already made in existing facilities. For all incremental scenarios, the total amount of investment includes the previous investments in the infrastructure. Any investments above this amount will constitute additional required investments. This reflects any additional tools or expansions required at existing sites to implement increased dismantling. Therefore, additional investments may range from $900 million in the high dismantling scenario to $1.2 billion in the high dismantling scenario using IDIS recommendations.

In the radical scenarios, most investment costs would be new since they need to replace the existing infrastructure including dismantlers. It is possible that the role of vehicle collector may fall to local car dealers or specially created collection centers that do not perform any dismantling. In these cases, new investments might be $1.1 to $2.4 billion for the entire system. However, for a $1.1 billion investment, recovery potential at the dismantlers' phase is limited by the new facilities and actually does not function much better than the existing system. The most important development for the radical systems would be better managed parts recovery on a large scale which can produce more components for resale rather than for recycling.

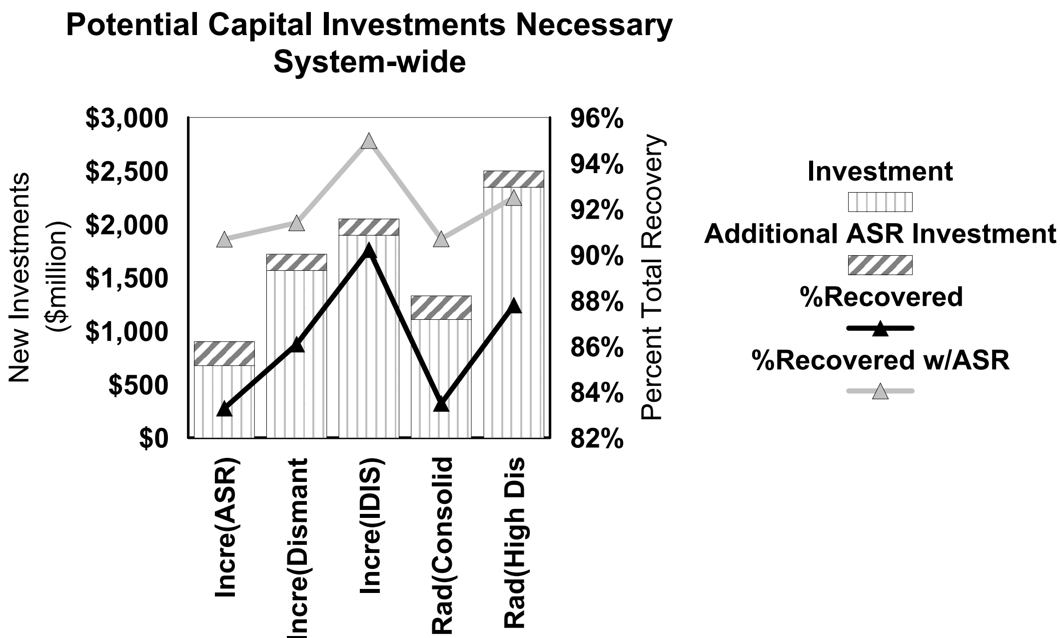

Figure 23: Potential Capital Investments Necessary System-wide

In closing, these scenarios have offered insight into two important points:

- Incremental solutions may be a more cost-effective and feasible solution in the short to medium term, assuming materials prices become more favorable.
- However, large consolidated facilities may be a good long term solution if economics of dismantling become more agreeable, especially with the growth of a remanufactured parts industry.

Overall, however, the costs for implementation can be seen in stages, using marginal cost of technology as a determinant. The first stage is to add nonferrous separation capabilities to more facilities so high-value nonferrous metals are captured in post-shredder processes. Secondly, ASR recovery systems, currently in pilot testing stages, can supplement any inefficiencies in the existing infrastructure, as long as a secondary market is created for recovered polymers. Third, in conjunction with implementing the creation of consolidated facilities, automakers will need to help develop a profitable secondary parts market. In reality, all of the above conditions will occur concurrently because the existing infrastructure and consolidated facilities may diverge and deal with different segments of ELVs. The existing infrastructure will deal with very old, low-value vehicles whose only value is in the materials themselves. This segmentation, along with stricter regulations, will force many inefficient operators to exit the market. Any excess business will be captured by consolidated facilities. The consolidated facilities will deal with newer, higher-value vehicles whose parts can be remanufactured and introduced into a secondary parts market. In some cases, these facilities may be willing to pay last users a premium for delivery of their vehicles. However, it is interesting to note that it may not be necessary to proceed down this system development path in order to meet at least the 2005 and possibly even the 2015 directive targets.

9.3 Model's Potential as a Tool

In the previous examples of sensitivity and scenario analysis, we have demonstrated that several key ideas can be deduced from using technical cost modeling. The model has several important elements that assist in the analysis process. First, we were able to assess the impact of critical factors and their effects on system profitability. This is important when stakeholders make assumptions in forecasting future costs. Additionally, by adjusting these factors, stakeholders can also help to maintain a profitable system when necessary with perhaps less cost. Second, examining system alternatives provides insight into their real potentials and costs. Finally, these capabilities when combined can help to bound the fears concerning excessive costs initiated by regulation forced targets.

10 Stakeholders' Roles and Responsibilities

Upon examining stakeholders' motives, both conflicting and complementary goals arise amongst stakeholders. The closing chapter attempts to match some of the consistent goals to develop joint acceptance of the Directive either as it exists or with further amendments. At this point, since the Directive has been approved pending additional amendments, it may be more helpful to consider what the parties involved can do to assist each other in creating a more profitable system. In light of the scenarios tested above, several proposed courses of action can be developed. In Table 9, a list of proposed actions are supported by their benefits and risks. The risks may be mitigated given the referenced stakeholder performs appropriately.

Table 9: Recommendations to Stakeholders

Stakeholder	Activities
Automakers	Focus on developing an efficient remanufactured parts market + Higher prices for reused/remanufactured parts + Greater profitability for recycling industry without a need for artificial subsidies + Economics based incentives to increase recovery rates − Potential reduction of OEM share of aftermarket parts business (strategy dependent) Strive to make use of materials derived from vehicle recycling + Increased demand for materials derived from vehicle recycling + Greater profitability for recycling industry + Creates incentives to increase recovery/recycling rates − Risk that content targets get high enough that secondary materials become scarce and cost more than primary (see recyclers role)
Recyclers	Consolidate facilities at a local level or work out partnerships with downstream operators + Economies of scale/scope, more efficient operations + Potentially better environmental management + Maintains participation of more SMEs − Loss of autonomy/independence

Stakeholder	Activities
Recyclers (cont'd)	– Potential closing of some local firms (see government role) Allow new entrants to recover ASR + Potential reduction in costs for ASR disposal relative to landfilling + Less need for labor intensive dismantling + Maintain profitability for all operators along the system – Risk of not having a secondary materials market (see automakers role)
Government	Maintain landfilling costs at a fairly high level + Economic incentive to reduce costs through recycling/recovery, especially ASR separation – Risk of disproportionately high number of operators out of business (see recyclers) Assist in creating transparency of secondary materials market through information dissemination, certification, and quality standards. + Increased participation in recycled materials markets + Increased demand for recycled materials with standardized quality and transparent commodity pricing – Risk that government is not equipped to create such transparency Monitor health of recycling industry and be prepared to offer short-term funding or assistance to ease transitions + Maintain industry/investor confidence + Foster technological development – Danger of over-subsidizing inefficient firms (government must be prepared to shut down and compensate marginal operators)

11 Conclusions

The pending ELV Directive in the EU has stakeholders concerned, especially automakers, that costs will dramatically increase in order to meet the EU's recycling targets. These costs have the potential to distort existing market dynamics, translating into higher new vehicle sticker prices or tightened suppliers' margins. These concerns have been examined through stakeholder analysis and technical cost modeling. The results show that solutions can be created without exorbitant marginal costs when several market conditions are satisfied. However, since the Directive employs both dynamic and static steering tools, the resulting operations may be sub-optimal in terms of market efficiency.

First of all, the cost analysis shows that, in order to meet the Directive's recycling targets of 80% by 2006 and 85% by 2015, an incremental approach of maintaining the existing infrastructure and adding on ASR separation treatment is adequate to achieve these "dynamic" targets. This conclusion assumes that 1) the remaining recovery targets of 85% by 2006 and 95% by 2015 can be achieved through incineration, 2) a secondary nonmetallic materials market exists, and 3) landfill tipping fees are sufficiently high for ASR separators to be self-sustaining. Since the incremental scenario also assumes facilities to be the best alternative technologies (BAT), some inefficient SMEs will need to exit the current infrastructure or refurbish existing facilities to match the capabilities of more efficient facilities. Additionally, the development of ASR recovery will help stakeholders achieve the final incremental recycling percentages needed, as long as material prices are favorable enough and only moderate dismantling is conducted upstream. Unfortunately, these two conditions may be difficult to achieve due to additional "static" requirements in the Directive, such as mandatory dismantling of specified parts (Annex I).

These static requirements may trigger a move to the more radical scenarios of industry consolidation and high dismantling. While integrated facilities can offer better parts and materials recovery within controlled environments, their emergence will create dislocation implications, inefficient markets, and recurring deadweight loss per vehicle. Dislocation refers to the case where creation of large dismantling facilities will force local SMEs out of business, impacting local employment and economy. Though new facilities create new jobs, it is unclear whether the increase greatly offsets the loss of jobs in local areas. Secondly, since the radical scenario is likely to incur added costs which automakers may need to supplement, market price distortions can arise. In addition, such subsidies may support some inefficient operators, increasing deadweight loss.

Instead of supplementing dismantling for materials recovery, it is important that these integrated facilities develop remanufacturing of parts as a core business to create additional value. This is evidenced by the intrinsically lower value of materials in our base vehicle ($250) relative to the cost for operating large dismantling facilities ($300-$400) per vehicle. This estimate cost for dismantling is likely to increase further if even more dismantling is required.

Given that material value alone is insufficient to drive dismantling, the ELV Directive's static steering tools will create undesirable, unprofitable sectors. As a technology forcing regulation, the ELV Directive demonstrated some progressive solutions for motivating innovation through dynamic goals and producer pays principle, but ultimately falls short by placing boundaries on those innovations.

What then do these costs mean to industry? The automakers will need to create a solid secondary parts market by promoting the use of remanufactured parts through warranty coverage. In the very least, they will need to close the loop for recycling materials by both creating a market for the recovered materials and maintaining relatively high prices, comparable to virgin materials, to ensure a profitable recycling industry. In this way, they are promoting profitability throughout the life cycle chain without having to be burdened with added costs directly.

When the regulations come into force, some existing recyclers may not meet the requirements for certification and will inevitably leave the market. Their departure signals that the remaining facilities are more efficient, but new or expanded facilities and distribution centers will be needed to pick up their service areas.

Governments' role may be to have a reduced role in market intervention but a greater one in facilitating market transparency. For example, the Directive specifies that member states should "ensure that in implementing the provisions...competition is preserved, in particular as regards the access of small and medium-sized enterprises (SMEs) to the collection, dismantling, treatment, and recycling market." [81] Whether this provision is necessary in developing a more efficient market is questionable. In fact, if this is interpreted by some governments as subsidies or tax incentive programs for SMEs, then inefficient operators may be allowed to remain in the market.

Furthermore, while radical solutions may sometimes present more cost effective solutions in the long run, an incremental approach seems to be more practical in this case. The cost model shows that the level of dismantling should not be forced to exceed what is economically viable. An incremental approach of adding on ASR recovery into the system will help achieve recycling targets. The concern in the past had been that hazardous chemicals were entering the recycling stream but under the new regulation, most or all of these chemicals should not be introduced into shredder and post-shredder streams and thus permitting cleaner recovery.

Overall, the pending regulations should not translate to excessive costs for the system as long as favorable market conditions are created. The benefits of these regulations, in terms of less hazardous materials and better resource use, will help promote these favorable conditions. However, government should focus on creating more transparency in the materials market and proper incentives for use of secondary materials without deadweight loss instead of dictating methods for recycling and recovery.

12 Future Work

This technical cost model was built on the efforts of several previous theses. To continue to refine the approach and extend its applications, future work should include testing of additional vehicles to recognize variations in cost due to material content, incorporating modular designs with faster disassembly potential, and more precise dismantling times (preferably provided by automakers). Additionally, a better understanding of Europe's most current recycling system is necessary, since gaps of knowledge exist between the best available technologies (BAT) and the more typical operations. A deeper exploration and comparison of a greater variety of recycling innovations may present insight into alternative solutions, especially energy recovery solutions and parts remanufacturing solutions. Furthermore, a comparison of energy recovery versus plastics recycling may be helpful to assess whether more energy recovery can help with waste abatement targets.

From a policy perspective, it would be interesting to compare and contrast the ELV Directive with other similar policies. The goal would be to understand which policy tools can be successful and which may hinder innovation and development.

On the economics side, transfer prices between operators may require further refining and testing. A more careful assessment of any waterfall effects that material prices may have along the value-chain will be helpful in determining which operators are most vulnerable to changing systems.

13 Appendices

Appendix I: Annex I from Proposal for a Directive on the End of Life Vehicles[82]

Minimum technical requirements for treatment in accordance with Article 6(1) and (3)

1. Sites for storage (including temporary storage) of end-of-life vehicles prior to their treatment:
   - Impermeable surfaces for appropriate areas with the provision of spillage collection facilities, decanters and cleanser-degreasers,
   - Equipment for the treatment of water, including rainwater, in compliance with health and environmental regulations.
2. Sites for treatment:
   - Impermeable surfaces for appropriate areas with the provision of spillage collection facilities, decanters and cleanser-degreasers,
   - Appropriate storage for dismantled spare parts, including impermeable storage for oil-contaminated spare parts,
   - Appropriate containers for storage of batteries (with electrolyte neutralization on site or elsewhere), filters and PCB/PCT-containing condensers,
   - Appropriate storage tanks for the segregated storage of end-of-life vehicle fluids: fuel, motor oil, gear box oil, transmission oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, battery acids, air conditioning system fluids and any other fluid contained in the end-of-life vehicle,
   - Equipment for the treatment of water, including rainwater, in compliance with health and environmental regulations,
   - Appropriate storage for used tires, including the prevention of fire hazards and excessive stockpiling.
3. Treatment operations for depollution of end-of-life vehicles:
   - removal of batteries and liquefied gas tanks,
   - removal or neutralization of potential explosive components (e.g. air bags),
   - removal and separate collection and storage of fuel, motor oil, transmission oil, gear box oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, air conditioning system fluids and any other fluid contained in the end-of-life vehicle, unless they are necessary for the reuse of the parts concerned.
4. Treatment operations in order to promote recycling:
   - removal of catalysts,
   - removal of metal components containing copper, aluminium and magnesium if these metals are not segregated in the shredding process, – removal of tires and large plastic components (bumpers, dash board, fluid containers, etc.),
   - removal of glass.
5. Storage operations are to be carried out avoiding damage to components containing fluids or to recoverable components and spare parts.

Appendix II: Summary of Stakeholders' Roles under ELV Mandate

Stakeholders	Vehicle Design	Infrastructure
Member States	• Periodic inspection on new vehicles to ensure that vehicles do not contain hazardous chemicals from Annex 1 • Update and change Annex II, the allowable applications for hazardous materials list	• Ensure economic operators set up appropriate, environmentally safe systems for collection of ELV with adequate availability • Ensure SME's are economically preserved in infrastructure • Set up a certificate of destruction as a condition of deregistration
Producers (automakers, material & equipment manufacturers)	• Limit or eliminate use of hazard materials from Annex 1 • Design for dismantling and 3 R's, with main focus on recycling • Integrate recycled material into design	• Become authorized to issue certificates of destruction to last owner through (dealers, collection points) • Be responsible for all or a significant part of cost of implementation and/or take back programs without cost for last holder and/or owner
Economic Recycling Operators (dismantlers, shredders, etc.)	•	• Become authorized to issue certificates of destruction to last owner
Consumers (drivers, last users, buyers)	•	• Turn in vehicle to receive certificate of destruction for deregistration • Be compensated for delivery costs if vehicle has no or negative market value

Appendix II: Summary of Stakeholders' Roles under ELV Mandate (cont'd)

Stakeholders	Recovery/Recycle	Enforcement/ Information Dissemination
Member States	• Take necessary measures to encourage reuse of components, recovery of components which cannot be reused, and giving preference to recycling • Ensure reuse, recovery, and recycling targets are met	• Work out agreements with economic operators to set objectives and define ways of enforcement
Producers (automakers, material & equipment manufacturers)	• Provide detailed dismantling procedures for dismantlers • Use common component and material coding standards	• Information made available by economic operators to prospective buyers • Publish design info with view to recoverability/recyclability
Economic Recycling Operators (dismantlers, shredders, etc.)	• Strip vehicles to at least the extent specified in Annex I	• Information made available by economic operators to consumers • Report on environmentally sound treatment of ELV
Consumers (drivers, last users, buyers)	•	•

Appendix III: Summary of Stakeholders Issues

	Producers	Dismantlers
Economics	• Potential cost burden of euro 23 billion • Retroactive responsibility will be potentially expensive since older vehicles were not designed for disassembly or recycling • Disassembly may force producers to enter disassembly market and push out SME's • Any added costs would still transfer to vehicle owners through higher new vehicle prices	• Not all of the 20,000 highly fragmented SME's will have the capital or revenue to improve facilities up to certification standards • No market incentive (material prices/market) exists for economical removal of nonmetal components • Uncertainty in how this effects core used parts business
Technology	• Plastics sorting and recycling are complex due to technological and infrastructure limitations • Design for disassembly and recycling are potentially competing with other design objectives • Incineration (energy recovery) should be permitted as part of landfill avoidance plan	• No infrastructure for collection or storage of plastic components exists • Disassembly information is available but dissemination and use of the information is up to the dismantler
Benefits	• Recyclers will be brought up to the same level of environmental standards • A certificate of destruction is required for deregistration by last owner of vehicles to prevent abandonment	• Producers may help offset costs for acquiring ELV's since economics are not always favorable

Appendix III: Summary of Stakeholders Issues (cont'd)

	Shredders/NonFerrous Separators	ASR Separators
Economics	• Potential profit loss due to decreasing metal content as dismantlers remove more valuable components to offset any added expenses due to negative value of some components	• Uncertainty of having a profitable secondary market for plastics • No market infrastructure or transparency exists now for proper commodity trading mechanisms • If dismantlers remove most of the valuable plastics components, value of ASR decreases
Technology	• No significant technology changes except for adding refined sorting methods to capture more nonferrous metals from going into the landfill	• Current recovery technologies are in their pilot stages and have not tested full scale feed stocks and economics • Directive favors dismantling for material recovery rather than post-shredder processing
Benefits	• Recyclers will be brought up to the same level of environmental standards • A certificate of destruction is required for deregistration by last owner of vehicles to prevent abandonment	• Producers may help offset costs for acquiring ELV's since economics are not always favorable

Appendix IV: Description of CARS [83]

One Baltimore based company, Comprehensive Automotive Reclamation Services (CARS) of Maryland, has introduced the total dismantling concept to the United States. CARS is using Dutch technology to operate a labor intensive, economically profitable, and environmentally sound disassembly and recycling system. The CARS system is potentially able to reduce the amount of landfilled material to less than five percent of total car weight, as well as eliminate the need for metal shredders. CARS provides a model of what auto recycling may look like in the future.

CARS is a visionary project. The first dismantling operation in the United States, CARS was created through a partnership of William Hyman, an environmentally conscious entrepreneur, and Jay Cullen, an insider in the auto industry who provided necessary startup funds and crucial contacts with General Motors. The plant is located in the low income neighborhood of Orangeville, on Baltimore's East Side. This area has been designated an enterprise zone, which allows CARS access to six acres of city land tax-free, in exchange for employing a certain number of local people (Worden). CARS is a for-profit business: like other auto recyclers, it exists to make money. But it was also founded to bring state-of-the-art green technology to this country, and demonstrate that cars can be profitably recycled without harming ecosystems or human communities. This attitude of environmental stewardship seems to be pervasive throughout the entire company.

At the moment, CARS is the only operative disassembly plant in the United States. The company has been in operation since 1996, and expects to be operating in the black by June of 1997. Currently, 80 people are employed, although 200 employees working between three shifts is ultimately expected. The full production capacity of CARS is 30-40 thousand cars per year. According to the Automotive Recyclers Association, 11 million cars are scrapped annually in the US, so while this number is significant it is not exhaustive (ARA "Automotive"). The company envisions that 100-150 such plants will be operating in this country within their first ten years of existence--a quantity which could account for approximately 50% of this country's end-of-life vehicles. Because CARS owns the US patent rights to the technology, it is evident that they plan on dominating the market.

CARS operates similarly to the De Mosselaar disassembly line described above using equipment purchased from another Dutch company, Car Recycling Systems B.V. Several state-of-the-art dismantling systems hail from the Netherlands because the National Environmental Policy Plan of that country finances environmentally sound automobile recycling (Johnson). Each step of the dismantling process has been designed to insure maximum environmental protection and maximum recyclability.

A quick overview of how the plant operates:

End-of-life vehicles are brought to the facility, mainly by local towing companies and salvage auctions. Like other salvage lots, many of the cars which come in have been "totaled" in accidents, and are ready to be scrapped. For example, Nationwide Insurance brings all of their destroyed vehicles from the region to CARS. Immediately, the cars are drained of all fluids. (CARS maintains this process 24 hours a day). The fluids are kept separated, and are sent to various reprocessors who have the specialized equipment necessary to deal with such substances. Gasoline and oil are burned on site to heat the 200,000 square foot facility. The immediate fluid draining works to prevent the type of ground contamination which is present at most scrapyards (Swamikannu 66). As a safeguard, the premises are also monitored for ground contamination.

The actual dismantling process takes place indoors in a refurbished warehouse. All parts are removed and sold in large quantities to be rebuilt or sold "as-is". The sale of used parts is the greatest profit maker for CARS and what allows them to afford more elaborate and time consuming dismantling. All metallic materials are stripped from the car, to be sold for remanufacturing. This is one area in which the advantage of a large dismantling plant over a small salvage facility is evident. Many nonferrous metals in automobiles occur in small quantities and are difficult to remove from the vehicle. They also do not attract the high resale price which would make extraction profitable. Instead the nonferrous elements are sent with the car hulks to the shredder, where they are broken into small pieces and mechanically separated again. This process causes small bits of the metals to get mixed up with other types as "tramp" elements, which reduces the metal's potential to be remanufactured into a high quality product. In addition, some of the shredded metal becomes fugitive dust which settles out of the air to become ground contamination. CARS however, has the scale and the machinery to make dismantling possible. GM (who supplied original funding for CARS) has an agreement to buy all commodity items, which benefits CARS by creating an automatic market for their scrap and GM by giving them a discount on the materials. This commodity sale includes steel, catalytic converters (which contain platinum), aluminum, copper, and batteries.

Tires are sold for recycling through a three-tiered system: the best ones are destined to be resold as used tires, medium grade ones are retreaded for sale, and the unusable ones are processed for heat recovery through pyrolysis. Plastic remanufacturing is similarly outsourced. Because the complex mix of plastics used in every modern automobile makes complete plastic separation extremely difficult, the plastic is removed from the car frame en masse. CARS is working with an outside entrepreneurial venture to develop a mixed plastic product derived from the various plastics removed from cars. As the recyclability of automobiles increases, removing and reusing or recycling plastic components individually may be possible. Other materials in the car, such as glass and foam, are either sold for remanufacture or landfilled appropriately.

As new remanufacturing technologies emerge and vehicles are designed to be more recyclable, the percentage of landfilled material will decrease. The ultimate goal of CARS is to make sure that less than 5% of the car mass ends up in a landfill; they are continually working with scrapped based manufacturers to develop new ways of reusing car parts. After the entire dismantling process is completed, the car body--stripped of all nonferrous components--is baled and shipped to a steel mill, where it can be remanufactured without prior shredding.

CARS is unique in the international scene (though this may change as processes become more sophisticated) in that the car hulks it produces can be used--unshredded--by an electric arc furnace. It remains economically successful for the same reason that most scrapyards can turn a profit--because of the inherent value of the parts and materials in automobiles. Although CARS does have expenses beyond the typical salvage facility because of the extensive dismantling they do, they also are able generate a larger income. The large volume of vehicles traveling through the facility, coupled with the comprehensive dismantling done there, creates a reliable supply of used parts that are continuously sold to other businesses. Typical scrapyards tend to send a large number of these vehicle parts to the shredder with the car hulk, thereby wasting a valuable source of income. Also, by selling directly to the steel mill, CARS is paid for the full worth of the steel scrap. The implicit cost of shredder maintenance and ASR disposal present in the scrap price paid to the salvage yard from the shredder are absent. In the words of John Resslar, a product engineer at Saturn, "[recycling by shredding] is the industry standard. It's considered the state of the art. But the process results in major contamination of the components. Any components that can't be removed are destroyed. Plus, the shredding process is extremely energy inefficient (Varacchi 34)."

Automobile dismantling was pioneered in the Netherlands as a means of reducing waste, and was thought to be unprofitable. In fact, the process was financed through a $100 green fee that was tacked onto the cost of every new vehicle to pay for appropriate dismantling, recycling, and disposal (Green Plans). CARS of Maryland has demonstrated that vehicle recycling can be profitable in the United States, and is seeking to change the way end-of-life vehicles are disposed of in this country.

Insurance companies are particularly interested in supporting vehicle dismantling efforts, because they save money every time a car is fixed with a used car part instead of a new part, and they benefit from having an ample, consistent supply available from a dismantling company. American Reinsurance, which provides insurance for insurance companies, is taking an extremely active role in CARS: they recently made a $2.5 million investment in the company, and are pushing CARS to open a second facility as soon as possible. Although CARS and American Reinsurance are thinking of sites near the original Maryland facility, they plan to open dismantling plants across the country in the near future.

Appendix V: Table of Market Prices from Various Sources

		Value	Units	Value	Units
	Source				
Hulk Value	1	66.52	/gross ton	0.07	/kg
Auto Shredder Scrap	1	121.28	/gross ton	0.12	/kg
Nonferrous Scrap	2	0.45	/lb	0.99	/kg
US Landfill	2	100	/short ton	110	/metric ton
Gross Ton	3	2,240	lbs	1,018	/kg
ABS(Virgin)	4	$1700-$2000	/metric ton		
PVC (Virgin)	4	$400-$570	/metric ton		
PP Homopolymer	4	$400-600	/metric ton		
PP CoPolymer	4	$430-$620	/metric ton		
Steel Scrap	5	35	/short ton	0.04	/kg
Copper Scrap	5	0.49	/lb	1.08	/kg
Brass Scrap	5	0.28	/lb	0.62	/kg
Aluminum Scrap	5	0.24	/lb	0.53	/kg
Zinc Scrap	5	0.48	/lb	1.06	/kg
Lead Scrap	5	0.19	/lb	0.42	/kg
Copper(Virgin)	5	0.79	/lb	1.74	/kg
Aluminum(Virgin)	5	0.56	/lb	1.23	/kg
Zinc(Virgin)	5	0.48	/lb	1.06	/kg
Lead(Virgin)	5	0.19	/lb	0.42	/kg
Transmission	5	0.02	/lb	0.04	/kg
Motor Block	5	65	/short ton	0.07	/kg
Mixed Aluminium	6	410	/metric ton	0.65	/kg
Batteries	6	15	/metric ton	0.02	/kg
Complete car/lorry engines	6	32	/metric ton	0.05	/kg
Car shells	6	9	/metric ton	0.01	/kg
Brass&Copper Radiators	6	400	/metric ton	0.64	/kg
Mixed brass	6	500	/metric ton	0.8	/kg
Landfilling (Nonhazardous)	7	euro 10-160	/metric ton	80	/metric ton
Landfilling (Hazardous)	7	175,715	/metric ton	300	/metric ton
Heavy Copper	8	750	/metric ton	1.19	/kg
Heavy Brass	8	540	/metric ton	0.86	/kg
Mixed Aluminum Alloy	8	490	/metric ton	0.78	/kg
Clean HE9	8	700	/metric ton	1.11	/kg
Lead Scrap	8	315	/metric ton	0.5	/kg

		Value	Units	Value	Units
No. 1 Old Steel Scrap	9	50	/metric ton	0.08	/kg
PET Colorless Bottles	6	90	/metric ton	0.14	/kg
PVC Bottles	6	35	/metric ton	0.06	/kg

Sources:

1. American Metals Market (1998 Average for Philadelphia)
2. AISI estimates (through correspondents)
3. NIST Handbook
4. S&P Platt's (Free On-Board Northwest Europe) 1999 Range <http://www.plasticsplatform.com>
5. Recycle Net Composite Index. March 2000 <www.recycle.net/price/auto.html>
6. Recycling World Material Prices Page. March 2000. <tecweb.com/recycle/rwprice.htm>
7. European Toxic Centre on Waste (ETC/W) 1998 Nonhazardous Landfill Charges
8. Eller, Robert. "Regulatory Concerns and New Technology...The View from Europe." WARD's Auto World. January, 1996.
9. British Metal Federation. March 1999
10. Metals Bulletin March 1998 (noted to be exceptionally low)

Appendix VI: Materials and Related Prices Used in Model

Material ID	Material Name	Secondary Material Value
		($/kg)
10001	AL	0.78
10101	Mixed	0
10103	CU/Copper	0.86
10104	Steel/Ferrous	0.13
10105	Lead	0.5
10107	ABS	0.85
10108	Carpet	0.04
10109	Elastomer	0.04
10110	PC	0.7
10111	ABS/PC	0.75
10112	Polyester	0.26
10113	PET	0.14
10114	PP	0.3
10115	PUR	0.5
10116	TPO	0.04
10117	Xenoy	0.04
10118	ZN/Zinc	0.48
10119	Glass	0.04
10120	Vinyl Ester	0.09
10121	PVC	0.06
10122	Miscellaneous Plastic	0
10123	Miscellaneous Scrap	0
10130	PA-6/PA-66	0.42
10132	PBT	0.04
10133	EPDM	0.04
10134	NonFerrous	0.08
10135	Nylon	0.42
10136	FIBERBOARD	0
10137	PPO	0.04
10138	PAPER	0
10139	SHODDY	0
10140	FABRIC	0
10141	PMMA	0.04
10142	PE	0.4
10143	PHENOLIC RESIN	0
10144	TEO	0.04
10145	PP/EPDM	0.04
10146	PC/PBT	0.04
10147	SMC	0.04

Appendix VII: Series of Inputs for Scenarios (Incremental-Base Case)

Base Case				
Total Retired Vehicles Per Year	**8,000,000**			
Average Vehicle Weight	1,255 kg			
Additional Subsidies	$0			
Add'l Recycling Investment (max) - $ million	506	120	64	148
Operating Parameters	**Dismantler**	**Shredder**	**NF Separation**	**ASR Separation**
Total European Operators	**4000** (EU TOTAL 20000)	135	34	**35** needed
Annual Industry Volume	8,000,000 vehicles/year	6,238,009 tons/year	1,028,557 tons/year	1,272,084 tons ASR /year
Annual Processing Volume	**2,000** vehicles/year	**46,367** hulk tons /year	**30,000** tons input /year	**10,000** "Max"tons /year
Throughput Rate per Facility	2.49 veh/hr	**25** tons Steel Produced/hr	**15** tons input /hr	4 tons/hr
Annual Output	1,560 hulk tons /year	33,333 tons Steel /year 7,645 tons NF/year	18,629 tons ASR /year	937,751 landfill tons/year 9.3%
Base Case=(No ASR Recovery)	1 (1=yes,0=no)	4,708 tons ASR /year		
		0 Include Nonferrous Equipment (0=no,1=yes)		
		0 Include NF Separation		
		35% NF Content to NF Separator		
Hulk/Material Transaction Price	**$0.06** /kg Hulk	$0.13 /kg Fe	$0.78 /kg Al	Refer to List
Secondary Materials Prices		$0.12 /kg NF	$0.86 /kg Red Metals	
Subsidy/Delivery Cost Ratio	**0.00**			
Deregistration/ELV Delivery Cost	**$50** /vehicle			
Producers Price Support	$0 /vehicle			
Landfilling (Hazardous?)	**1** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Actual Landfill Cost	$160.00 /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Non-hazardous landfill cost	**$80.00** /ton	$80.00 /ton	$80.00 /ton	$80.00 /ton
Hazardous landfill cost	**$160.00** /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Capital				
Capital Investment Override (optional)	**$115,000** $/line	**$0** $/line	**$0** $/line	**$0** $/line
Capital Investment	N/A /facility	$892,573 /facility	$1,868,333 /facility	$3,417,000 /facility
Capital Recovery Rate	**10.0%**	10.0%	10.0%	10.0%
Capital Recovery Period	**10** years	10 years	Look In Model years	10 years
Price of Building Space	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter
Building Recovery Rate	**20** years	**20** years	**20** years	**20** years
Building Space Requirement	**1000** sq. meter/line	**0** sq. meter	1,667 sq. meter/line	**4,000** sq. meter/line
Dedicated Line?	**0** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Working Capital Period	**2** months	2 months	2 months	2 months

Operating Parameters	Dismantler	Shredder	NF Separation	ASR Separation
Materials/Utilities				
Energy Cost	**0.1** $/kWh	0.1 $/kWh	0.1 $/kWh	$0.10 $/kWh
Natural Gas				$0.25
Direct Labor				
Working Days/Year	**250**	**250**	**250**	**250**
Number of Workers	**2** persons/line	3 persons/line	**0** persons/line	**6** persons/line
Number of Workers (override)			6	
Hours per Shift	**8** hours	**8** hours	**8** hours	**8** hours
Number of Shifts	**1** shifts/day	**1** shifts/day	**1** shifts/day	**1** shifts/day
Direct Wages (w/benefits)	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Indirect Labor/Overhead Staff				
Maintenance Crew	**1** persons/line	**1** persons/line	**1** persons/line	**1** persons/line
Overhead Wage	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Staff	**2** person	**2** person	**2** person	**2** person
Staff Salary	**$40,000** /year	**$40,000** /year	**$40,000** /year	**$40,000** /year
Transportation				
Hulks (tons/truck)	**12** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck
Price per km per truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck
Average Distance	47 Km (b/w dism)	104 Km (b/w dism &shredder)	124 Km (b/w dism &shredder)	202 Km (b/w shredd / nf&ASR)
Price per ton for Receiving	$18.75 /ton	$18.75 /ton	$9.11 /ton	$14.53 /ton
Price per ton for Sending	$18.75 /ton	$9.11 /ton	$9.11 /ton	

Appendix VII (Cont'd): Series (Incremental-High Dismantling)

Incremental-High DIsmantling				
Total Retired Vehicles Per Year	**8,000,000**			
Average Vehicle Weight	1,255 kg			
Additional Subsidies	$0			
Add'l Recycling Investment (max) - $ million	1424.5	99	47	105
Operating Parameters	**Dismantler**	**Shredder**	**NF Separation**	**ASR Separation**
Total European Operators	**4000** (EU TOTAL 20000)	114	25	**25** needed
Annual Industry Volume	8,000,000 vehicles/year	5,159,666 tons/year	750,400 tons/year	1,057,000 tons ASR /year
Annual Processing Volume	**2,000** vehicles/year	**45,353** hulk tons /year	**30,000** tons input /year	**10,000** "Max"tons /year
Throughput Rate per Facility	0.88 veh/hr	**25** tons Steel Produced/hr	**15** tons input /hr	5 tons/hr
Annual Output	1,290 hulk tons /year	33,333 tons Steel /year	20,686 tons ASR /year	800,280 landfill tons/year
Number Parallel Lines	1.13	6,596 tons NF/year		8.0%
Base Case=(No ASR Recovery)	1 (1=yes,0=no)	4,743 tons ASR /year		
		0 Include Nonferrous Equipment (0=no,1=yes)		
		0 Include NF Separation		
		35% NF Content to NF Separator		
Hulk/Material Transaction Price	**$0.06** /kg Hulk	$0.13 /kg Fe	$0.78 /kg Al	Refer to List
Secondary Materials Prices		$0.00 /kg NF	$0.86 /kg Red Metals	
Subsidy/Delivery Cost Ratio	**0.00**			
Deregistration/ELV Delivery Cost	**$50** /vehicle			
Producers Price Support	$0 /vehicle			
Landfilling (Hazardous?)	**1** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Actual Landfill Cost	$160.00 /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Non-hazardous landfill cost	**$80.00** /ton	$80.00 /ton	$80.00 /ton	$80.00 /ton
Hazardous landfill cost	**$160.00** /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Capital				
Capital Investment Override (optional)	**$115,000** $/line	**$0** $/line	**$0** $/line	**$0** $/line
Capital Investment	N/A /facility	$874,000 /facility	$1,868,333 /facility	$3,417,000 /facility
Capital Recovery Rate	**10.0%**	10.0%	10.0%	10.0%
Capital Recovery Period	**10** years	10 years	Look In Model years	10 years
Price of Building Space	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter
Building Recovery Rate	**20** years	**20** years	**20** years	**20** years
Building Space Requirement	**1000** sq. meter/line	**0** sq. meter	1,667 sq. meter/line	**4,000** sq. meter/line
Dedicated Line?	**0** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Working Capital Period	**2** months	2 months	2 months	2 months

Operating Parameters	Dismantler	Shredder	NF Separation	ASR Separation
Materials/Utilities				
Energy Cost	**0.1** $/kWh	0.1 $/kWh	0.1 $/kWh	$0.10 $/kWh
Natural Gas				$0.25 $/MBTU
Direct Labor				
Working Days/Year	**250**	**250**	**250**	**250**
Number of Workers	**2** persons/line	3 persons/line	**0** persons/line	**6** persons/line
Number of Workers (override)			6	
Hours per Shift	**8** hours	**8** hours	**8** hours	**8** hours
Number of Shifts	**1** shifts/day	**1** shifts/day	**1** shifts/day	**1** shifts/day
Direct Wages (w/benefits)	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Indirect Labor/Overhead				
Staff				
Maintenance Crew	**1** persons/line	**1** persons/line	**1** persons/line	**1** persons/line
Overhead Wage	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Staff	**2** person	**2** person	**2** person	**2** person
Staff Salary	**$40,000** /year	**$40,000** /year	**$40,000** /year	**$40,000** /year
Transportation				
Hulks (tons/truck)	**12** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck
Price per km per truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck
Average Distance	47 Km (b/w dism)	113 Km (b/w dism &shredder)	146 Km (b/w dism &shredder)	245 Km (b/w shredd / nf&ASR)
Price per ton for Receiving	$18.75 /ton	$18.75 /ton	$10.60 /ton	$17.58 /ton
Price per ton for Sending	$18.75 /ton	$10.60 /ton	$10.60 /ton	

Appendix VII (Cont'd): Series (Incremental-High Dismantling&IDIS)

Incremental-High Dismantling w/IDIS				
Total Retired Vehicles Per Year	8,000,000			
Average Vehicle Weight	1,255 kg			
Additional Subsidies	$0			
Add'l Recycling Investment (max) - $ million	1,906	93	35	149
Operating Parameters	**Dismantler**	**Shredder**	**NF Separation**	**ASR Separation**
Total European Operators	4000 (EU TOTAL 20000)	114	19	25 needed
Annual Industry Volume	8,000,000 vehicles/year	4,816,000 tons/year	570,000 tons/year	729,000 tons ASR /year
Annual Processing Volume	2,000 vehicles/year	42,300 hulk tons /year	30,000 tons input /year	10,000 "Max"tons /year
Throughput Rate per Facility	0.66 veh/hr	25 tons Steel Produced/hr	15 tons input /hr	3 tons/hr
Annual Output	1,200 hulk tons /year	33,333 tons Steel /year 5,000 tons NF/year	18,700 tons ASR /year	374,500 landfill tons/year 3.7%
Base Case=(No ASR Recovery)	1 (1=yes,0=no)	3,300 tons ASR /year		
		0 Include Nonferrous Equipment (0=no,1=yes)		
		0 Include NF Separation		
		35% NF Content to NF Separator		
Hulk/Material Transaction Price	$0.06 /kg Hulk	$0.13 /kg Fe	$0.78 /kg Al	Refer to List
Secondary Materials Prices		$0.04 /kg NF	$0.86 /kg Red Metals	
Subsidy/Delivery Cost Ratio	0.00			
Deregistration/ELV Delivery Cost	$50 /vehicle			
Producers Price Support	$0 /vehicle			
Landfilling (Hazardous?)	1 (1=yes,0=no)	1 (1=y,0=n)	1 (1=y,0=n)	1 (1=y,0=n)
Actual Landfill Cost	$160.00 /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Non-hazardous landfill cost	$80.00 /ton	$80.00 /ton	$80.00 /ton	$80.00 /ton
Hazardous landfill cost	$160.00 /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Capital				
Capital Investment Override (optional)	$115,000 $/line	$0 $/line	$0 $/line	$0 $/line
Capital Investment	N/A /facility	$820,000 /facility	$1,868,333 /facility	$4,817,000 /facility
Capital Recovery Rate	10.0%	10.0%	10.0%	10.0%
Capital Recovery Period	10 years	10 years	Look In Model years	10 years
Price of Building Space	$200 /sq. meter	$200 /sq. meter	$200 /sq. meter	$200 /sq. meter
Building Recovery Rate	20 years	20 years	20 years	20 years
Building Space Requirement	1000 sq. meter/line	0 sq. meter	1,667 sq. meter/line	4,000 sq. meter/line
Dedicated Line?	0 (1=yes,0=no)	1 (1=y,0=n)	1 (1=y,0=n)	1 (1=y,0=n)
Working Capital Period	2 months	2 months	2 months	2 months

Operating Parameters	Dismantler	Shredder	NF Separation	ASR Separation
Materials/Utilities				
Energy Cost	**0.1** $/kWh	0.1 $/kWh	0.1 $/kWh	$0.10 $/kWh
Natural Gas				$0.25 $/MBTU
Direct Labor				
Working Days/Year	**250**	**250**	**250**	**250**
Number of Workers	**2** persons/line	3 persons/line	**0** persons/line	**6** persons/line
Number of Workers (override)			6	
Hours per Shift	**8** hours	**8** hours	**8** hours	**8** hours
Number of Shifts	**1** shifts/day	**1** shifts/day	**1** shifts/day	**1** shifts/day
Direct Wages (w/benefits)	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Indirect Labor/Overhead				
Staff				
Maintenance Crew	**1** persons/line	**1** persons/line	**1** persons/line	**1** persons/line
Overhead Wage	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Staff	**2** person	**2** person	**2** person	**2** person
Staff Salary	**$40,000** /year	**$40,000** /year	**$40,000** /year	**$40,000** /year
Transportation				
Hulks (tons/truck)	**12** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck
Price per km per truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck
Average Distance	47 Km (b/w dism)	113 Km (b/w dism &shredder)	167 Km (b/w dism &shredder)	260 Km (b/w shredd / nf&ASR)
Price per ton for Receiving	$18.75 /ton	$18.75 /ton	$12.10 /ton	$18.60 /ton
Price per ton for Sending	$18.75 /ton	$12.10 /ton	$12.10 /ton	

Appendix VII (Cont'd): Series (Radical-Dismantling)

Radical Dismantling				
Total Retired Vehicles Per Year	**8,000,000**			
Average Vehicle Weight	1,255 kg			
Additional Subsidies	$0			
Add'l Recycling Investment (max) - $ million	668	112	206	148
Operating Parameters	**Dismantler**	**Shredder**	**NF Separation**	**ASR Separation**
Total European Operators	**120** (EU TOTAL 20000)	123	127	**35** needed
Annual Industry Volume	8,000,000 vehicles/year	5,813,000 tons/year	1,016,000 tons/year	1,263,000 tons ASR /year
Annual Processing Volume	**66,700** vehicles/year	**47,400** hulk tons /year	**8,000** tons input /year	**10,000** "Max"tons /year
Throughput Rate per Facility	1.89 veh/hr	**25** tons Steel Produced/hr	4 tons input /hr	4 tons/hr
Annual Output	48,400 hulk tons /year	33,333 tons Steel /year	5,000 tons ASR /year	936,800 landfill tons/year
Number Parallel Lines	17.7	8,300 tons NF/year		9.3%
Base Case=(No ASR Recovery)	1 (1=yes,0=no)	5,100 tons ASR /year		
		0 Include Nonferrous Equipment (0=no,1=yes)		
		1 Include NF Separation		
	1 Consolidation	35% NF Content to NF Separator		
Hulk/Material Transaction Price	**$0.00** /kg Hulk	$0.13 /kg Fe	$0.78 /kg Al	Refer to List
Secondary Materials Prices		$0.00 /kg NF	$0.86 /kg Red Metals	
Subsidy/Delivery Cost Ratio	**0.00**			
Deregistration/ELV Delivery Cost	**$50** /vehicle			
Producers Price Support	$0 /vehicle			
Landfilling (Hazardous?)	**1** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Actual Landfill Cost	$160.00 /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Non-hazardous landfill cost	**$80.00** /ton	$80.00 /ton	$80.00 /ton	$80.00 /ton
Hazardous landfill cost	**$160.00** /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Capital				
Capital Investment Override (optional)	**$115,000** $/line	**$0** $/line	**$0** $/line	**$0** $/line
Capital Investment	N/A /facility	$912,000 /facility	$1,624,000 /facility	$3,417,000 /facility
Capital Recovery Rate	**10.0%**	10.0%	10.0%	10.0%
Capital Recovery Period	**10** years	10 years	Look In Model years	10 years
Price of Building Space	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter
Building Recovery Rate	**20** years	**20** years	**20** years	**20** years
Building Space Requirement	**1000** sq. meter/line	**0** sq. meter	1,667 sq. meter/line	**4,000** sq. meter/line
Dedicated Line?	**0** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Working Capital Period	**2** months	2 months	2 months	2 months

Operating Parameters	Dismantler	Shredder	NF Separation	ASR Separation
Materials/Utilities				
Energy Cost	**0.1** $/kWh	0.1 $/kWh	0.1 $/kWh	$0.10 $/kWh
Natural Gas				$0.25 $/MBTU
Direct Labor				
Working Days/Year	**250**	**250**	**250**	**250**
Number of Workers	**2** persons/line	3 persons/line	**0** persons/line	**6** persons/line
Number of Workers (override)			6	
Hours per Shift	**8** hours	**8** hours	**8** hours	**8** hours
Number of Shifts	**1** shifts/day	**1** shifts/day	**1** shifts/day	**1** shifts/day
Direct Wages (w/benefits)	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Indirect Labor/Overhead				
Staff				
Maintenance Crew	**1** persons/line	**1** persons/line	**1** persons/line	**1** persons/line
Overhead Wage	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Staff	**2** person	**2** person	**2** person	**2** person
Staff Salary	**$40,000** /year	**$40,000** /year	**$40,000** /year	**$40,000** /year
Transportation				
Hulks (tons/truck)	**8** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck
Price per km per truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck
Average Distance	274 Km (b/w dism)	109 Km (b/w dism &shredder)	65 Km (b/w dism &shredder)	187 Km (b/w shredd / nf&ASR)
Price per ton for Receiving	$30.58 /ton	$28.13 /ton	$9.00 /ton	$13.46 /ton
Price per ton for Sending	$28.13 /ton	$9.00 /ton	$9.00 /ton	

Appendix VII (Cont'd): Series (Radical-High Dismantling)

Radical-High Dismantling				
Total Retired Vehicles Per Year	**8,000,000**			
Average Vehicle Weight	1,255 kg			
Additional Subsidies	$0			
Add'l Recycling Investment (max) - $ million	2,101	80	166	149
Operating Parameters	**Dismantler**	**Shredder**	**NF Separation**	**ASR Separation**
Total European Operators	**100** (EU TOTAL 20000)	102	103	**25** needed
Annual Industry Volume	8,000,000 vehicles/year	4,135,000 tons/year	620,000 tons/year	993,000 tons ASR /year
Annual Processing Volume	**80,000** vehicles/year	**43,700** hulk tons /year	**6,000** tons input /year	**10,000** "Max"tons /year
Throughput Rate per Facility	0.60 veh/hr	**22** tons Steel Produced/hr	**3** tons input /hr	4 tons/hr
Annual Output	41,400 hulk tons /year	29,333 tons Steel /year	4,400 tons ASR /year	609,000 landfill tons/year
Number Parallel Lines	66.7	6,100 tons NF/year		6.1%
Base Case=(No ASR Recovery)	1 (1=yes,0=no)	5,300 tons ASR /year		
		0 Include Nonferrous Equipment (0=no,1=yes)		
		1 Include NF Separation		
	1 Consolidation	21% NF Content to NF Separator		
Hulk/Material Transaction Price	**$0.00** /kg Hulk	$0.13 /kg Fe	$0.78 /kg Al	Refer to List
Secondary Materials Prices		$0.00 /kg NF	$0.86 /kg Red Metals	
Subsidy/Delivery Cost Ratio	**0.00**			
Deregistration/ELV Delivery Cost	**$50** /vehicle			
Producers Price Support	$0 /vehicle			
Landfilling (Hazardous?)	**1** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Actual Landfill Cost	$160.00 /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Non-hazardous landfill cost	**$80.00** /ton	$80.00 /ton	$80.00 /ton	$80.00 /ton
Hazardous landfill cost	**$160.00** /ton	$160.00 /ton	$160.00 /ton	$160.00 /ton
Capital				
Capital Investment Override (optional)	**$115,000** $/line	**$0** $/line	**$0** $/line	**$0** $/line
Capital Investment	N/A /facility	$791,000 /facility	$1,600,000 /facility	$4,817,000 /facility
Capital Recovery Rate	**10.0%**	10.0%	10.0%	10.0%
Capital Recovery Period	**10** years	10 years	Look In Model years	10 years
Price of Building Space	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter	**$200** /sq. meter
Building Recovery Rate	**20** years	**20** years	**20** years	**20** years
Building Space Requirement	**1000** sq. meter/line	**0** sq. meter	333 sq. meter/line	**4,000** sq. meter/line
Dedicated Line?	**0** (1=yes,0=no)	**1** (1=y,0=n)	**1** (1=y,0=n)	**1** (1=y,0=n)
Working Capital Period	**2** months	2 months	2 months	2 months

Operating Parameters	Dismantler	Shredder	NF Separation	ASR Separation
Materials/Utilities				
Energy Cost	**0.1** $/kWh	0.1 $/kWh	0.1 $/kWh	$0.10 $/kWh
Natural Gas				$0.25 $/MBTU
Direct Labor				
Working Days/Year	**250**	**250**	**250**	**250**
Number of Workers	**2** persons/line	3 persons/line	**0** persons/line	**6** persons/line
Number of Workers (override)			6	
Hours per Shift	**8** hours	**8** hours	**8** hours	**8** hours
Number of Shifts	**1** shifts/day	**1** shifts/day	**1** shifts/day	**1** shifts/day
Direct Wages (w/benefits)	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Indirect Labor/Overhead				
Staff				
Maintenance Crew	**1** persons/line	**1** persons/line	**1** persons/line	**1** persons/line
Overhead Wage	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr	**$20.00** /hr
Staff	**2** person	**2** person	**2** person	**2** person
Staff Salary	**$40,000** /year	**$40,000** /year	**$40,000** /year	**$40,000** /year
Transportation				
Hulks (tons/truck)	8 Tons/Truck	**25** Tons/Truck	**25** Tons/Truck	**25** Tons/Truck
Price per km per truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck	**$1.75** /km/truck
Average Distance	300 Km (b/w dism)	120 Km (b/w dism &shredder)	72 Km (b/w dism &shredder)	221 Km (b/w shredd / nf&ASR)
Price per ton for Receiving	$33.44 /ton	$28.13 /ton	$9.00 /ton	$15.84 /ton
Price per ton for Sending	$28.13 /ton	$9.00 /ton	$9.00 /ton	

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