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Management of End-of Life Vehicles (ELVs) in the US

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TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 OVERVIEW

This report seeks to provide a "snap-shot" detailing current management of end-of-life vehicles (ELVs) in the United States. The report is divided as follows:

- **Chapter 1 – Introduction:** Focused on estimating end-of-life vehicle (ELV) generation rates, identifying typical ELVs encountered and defining an "average" ("generic equivalent") ELV in terms of material composition.
- **Chapter 2 - ELV Management Process Description:** Providing a step-by-step description of ELV processing from initial dismantling to shredding of remaining "hulks" to subsequent recovery of metals, and finally, disposal of waste residues generated ("automotive shredder waste" – ASR).
- **Chapter 3 - Environmental and Energy Burdens of ELVs:** Detailing key environmental burdens in terms of ASR and scrap tires, along with elaboration of energy burdens associated with each stage of ELV processing.
- **Chapter 4 - Economic Assessment:** Estimating the value of "as is" ELVs, the business economics faced by key ELV processors and ASR landfill disposal costs.
- **Chapter 5 - Legislation/Policy Analysis:** Detailing pertinent ELV-related legislation and policy in Western Europe (where government plays a much more active role than in the US) as well as the US.
- **Chapter 6 - Key Players in ELV Management:** Identifying the general nature and composition of ELV processors (dismantlers, shredders and non-ferrous material processors), pertinent information regarding individual auto manufacturers, an outline of key technical and trade organizations and finally, discussion of the US Council for Automotive Research (USCAR) - the Big 3 automaker's collaborative research group which focuses on both technical and environmental issues.
- **Chapter 7 - Key Areas/Issues in ELV Management:** Identifying six key areas/issues at the current forefront of ELV management concerns/activities.
- **Chapter 8 - Conclusions**

1.2 BACKGROUND

The ultimate fate of vehicles in the US can vary, including being:

- <u>Recycled</u> via the existing end of life vehicle management infrastructure.
- <u>Abandoned</u>, typically in remote or hard-to-reach locations, thereby effectively preventing it from entering the existing end of life vehicle management infrastructure.
- <u>Stored indefinitely in inactive condition</u> by owners on private property (e.g., the classic case of a car stored on cinder blocks in the back yard or garage).
- <u>Stolen and processed for parts</u> through an illegal "chop shop" or smuggled out of the US for resale elsewhere.
- <u>Maintained indefinitely in working condition</u> by owners as collector items (i.e., classic/antique cars).

Using the above list, a distinction can be made between "retired" vehicles and "end-of-life" vehicles (ELVs). From a "retirement" perspective, each above-listed vehicle fate can be considered effectively a form of vehicle "retirement," as the original vehicle is no longer in normal, active use (at least within the confines of the US). However, from an end-of-life perspective, only the first two cases – recycled or abandoned – are vehicles permanently retired and, as such, are considered "end of life vehicles" (ELVs). Although perhaps somewhat of a semantic distinction, this distinction is made as, for purposes of this report, the focus is on management of permanently retired vehicles - ELVs.

Automobile owners permanently retire their vehicles for a variety of reasons such as:

- Loss of structural/mechanical integrity from corrosion or an accident
- Poor reliability of parts and components
- Degraded performance

The decision to permanently retire a vehicle poses a challenging resource optimization problem from both an environmental and economic perspective. Investment of additional resources in the form of parts and components can potentially extend the life of the vehicle, but the environmental performance of an older vehicle in terms of fuel economy and emissions is worse than a newer vehicle. The depreciated value of the vehicle and the owner's opportunity cost for making repairs are economic factors influencing this decision. It is difficult to develop guidelines to assist users in calculating precise environmental tradeoffs. The Center for Sustainable Systems is currently investigating optimal vehicle service life from environmental and economic perspectives. The first product of this effort is a life cycle optimization model for minimizing the total energy consumed over a specified time horizon (Kim et al., 2000).

The material flow from ELVs is affected by:

- ELV generation rate
- Fate of generated ELVs (i.e., recycled or abandoned)
- Material composition of ELVs generated.
- Technology and infrastructure in place to manage ELVs.

ELV generation rates are discussed in Section 1.3, their fates in Section 1.4, and their material composition in Section 1.5; the technology and infrastructure presently in place is taken up in Chapter 2.

1.3 ELV GENERATION RATES

The number of ELVs generated in a given year depends a multitude of potential factors including:

- General economic conditions (e.g., expect lower generation rates during economic downturns, higher generation during economic boom periods).
- Overall vehicle accident rates.
- General reliability of prevalent older-model vehicles.

Traditionally, ELV generation rates have been conservatively estimated on an annual basis based on vehicle retirement data, which, in turn, is based on state-reported vehicle registration data. Calculation of vehicle retirement data is relatively straightforward:

Estimated Number of Vehicles Retired From Use Per Year =
(Number of Vehicles Registered at the Beginning of the Year) +
(Number of Brand New Vehicles Registered During the Year) –
(Number of Vehicles Registered at the End of the Year)

Table 1.1 shows such estimates for 1990 to 1996 as cited by the American Automobile Manufacturers Association (AAMA, 1997).

Table 1.1 Estimated Motor Vehicles Retired From Use As Cited by the American Automobile Manufacturers Association

Year Ending 6/30:	Retirement Rate [million vehicles/yr]		
	Passenger Cars	Trucks & Buses[1]	Total
1990	8.9	2.2	11.1
1991	8.6	2.3	10.9
1992	11.2	1.6	12.8
1993	7.4	1.0	8.4
1994	7.8	4.6	12.4
1995	7.4	2.9	10.3
1996	7.5	3.3	10.8
Avg. (90-96)	**8.4**	**2.6**	**11.0**

Adopted from: [AAMA, 1997]. Based on vehicle registration & sales data.
[1] – As there are only about 0.7 million buses on the road [TEDB, 2000 – Table 8.13], bus retirement rates would be expected to be on the order of 30,000 per year or 1% of that of trucks.

As the AAMA effectively ceased operations in 1998, more current retirement data is not available. To attempt to fill in the gap, vehicle registration and sales data were obtained [TEDB[1], 2000] and used to estimate current retirement rates. The data and results are shown in Table 1.2.

[1] The Transportations Energy data Book (TEDB) is an annual publication prepared by the Oak Ridge National Laboratory for the US Department of Energy.

The calculated data in Table 1.2 show good agreement with AAMA-cited figures. One important item clearly borne out in Table 1.2 is that while new car sales and the number of cars in use has remained relatively constant, both new truck sales and the number of trucks in use have climbed steadily[2].

Thus, in estimating current vehicle retirement figures, for cars, use of the overall average (8.2 million per year, as cited in Table 1.2) seems most appropriate, while for trucks, use of most recent figure – 5.1 million seen in 1998, as cited in Table 1.2 – seems most appropriate, yielding an overall estimated current annual vehicle retirement figure of 13.3 million vehicles.

Table 1.2 Estimated Motor Vehicles Retired From Use As Calculated Using Available Vehicle Registration & Sales Data

	All figures cited are in [thousands]								
Year	New Auto Sales	Autos In Use	Retired Autos[1]	New Truck Sales[2]	Trucks In Use[2]	Retired Trucks[1,2]	New Vehicle Sales	Vehicles In Use	Vehicles Retired[1]
1989		122,758			53,202			175,960	
1990	9,301	123,276	8,783	4,845	56,023	2,024	13,849	179,299	10,807
1991	8,175	123,268	8,183	4,365	58,179	2,209	12,298	181,447	10,392
1992	8,213	120,347	11,134	4,905	61,172	1,912	12,842	181,519	13,046
1993	8,518	121,055	7,810	5,681	65,260	1,593	13,869	186,315	9,403
1994	8,990	121,997	8,048	6,420	66,717	4,963	15,023	188,714	13,011
1995	8,635	123,242	7,390	6,480	70,199	2,998	14,688	193,441	10,388
1996	8,527	124,613	7,156	6,930	73,681	3,448	15,046	198,294	10,604
1997	8,272	124,673	8,212	7,226	76,398	4,509	15,069	201,071	12,721
1998	8,139	125,966	6,846	7,826	79,077	5,147	15,438	205,043	11,993
Average	8,530	123,160	8,174	6,075	67,412	3,200	14,236	190,571	11,374

"Sales" and "In Use" Data Source: [TEDB, 2000 – Tables 6.3, 6.4, 7.3, 7.4, 8.2, 8.3, and 8.8]

[1] Calculated as: (In Use During Previous Year) + (New Sales During Indicated Year) – (In Use During Indicated Year)

[2] Truck figures include "light' (0-10,000 lb GVW), "medium" (10,001-26,000 lb GVW) and "heavy" (26,0001 lbs and over GVW). The vast majority (93%) of trucks currently on the road are "light," with most of those (67%) being 6,000 lb and less GVW. Furthermore, the majority (75%) of light trucks are used for personal use.

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[2] This surge in trucks is due specifically to a surge in "light duty" trucks (trucks with gross vehicle weight not exceeding 10,000 pounds), which dominate the truck category (94% of all trucks "in use" in 1998 were light-duty [TEDB, 2000 – Table 6.4]). In fact, data show that from 1970 to 1998, light truck sales and "in use" figures have grown approximately 6% per year on average (TEDB, 2000 – Tables 7.2 & 7.4). Such a steady increase can be explained when considering that pickup trucks, minivans and sport utility vehicles (SUVs) – all of which have enjoyed successive boons in popularity during the time period - all fall under the category of "light truck."

The figures cited in Table 1.2 for truck retirements includes both light and medium/heavy duty trucks. Based on current (1998) "in use" data, light trucks account for 93% of all trucks on the road [TEDB, 2000 – Tables 6.4 and 8.3]. Thus, assuming a somewhat lower retirement rate for medium/heavy-duty trucks (due to their inherent value) and using 5.1 million as the estimated current overall retirement figure for trucks, the truck retirement estimate can be broken down further into 4.9 light duty trucks and 0.2 million medium/heavy-duty trucks per year.

As noted in the previous section, however, not all "retired" vehicles are permanently retired (i.e., ELVs) – for instance, some may be in storage indefinitely, with the owner choosing to let the vehicle registration lapse. Furthermore, lack of vehicle registration is not a definitive indication of retirement - vehicles may be operated without proper registration (e.g., vehicles used exclusively on private farms). Thus, "retired from use" figures can be expected to over-estimate actual ELV generation, although the difference is likely not significant.

1.4 FATE OF ELVS

As was discussed earlier, for purposes of this report, ELVs are defined as those vehicles permanently retired, with one of two associated fates:

- Recycled via the existing end of life vehicle management infrastructure.
- Abandoned, typically in remote or hard-to-reach locations, thereby effectively preventing it from entering the existing end of life vehicle management infrastructure.

The recycling rate for automobiles is frequently cited as 94% with the remaining 6% thought to be currently abandoned [AAMA, 1997]. Data cited on the Steel Recycling Institute's website (www.recycle-steel.org/cars/main.html) confirms that figure - based on auto-derived scrap steel figures, the auto recycling rate seen from 1993 to 1999 averaged 95%.

Therefore using the vehicle retirement rates cited in Section 1.3 as a conservative estimate of ELV generation and a 94% recycling figure, it is estimated that 12.5 million ELVs (7.7 million cars, 4.6 light trucks, and 0.2 million medium/heavy trucks) are recycled each year, while 0.8 million ELVs (0.5 million cars and 0.3 million light trucks) are abandoned each year.

This estimate of recycled ELVs is in good agreement (within 10%) of the 13.5 million figure cited by the Steel Recycling Institute (SRI) for 1999 based on the amount of ELV-derived scrap steel processed that year (SRI, 2001). The fact that the SRI estimate is above the estimate put forth here is potentially explained by the fact that SRI used the weight of an average passenger car (3200 pounds) in calculating the number of equivalent "vehicles" recycled, therefore not accounting for the presence of higher-weight vehicles (i.e., trucks) in the scrap material stream.

As discussed below, for modeling purposes, the use of (and reference to) a standard generic (i.e., "average") vehicle is desirable. Thus, in this report, the SRI-cited 13.5 million figure for recycled ELVs will be used with the understanding that it represents the number of "equivalent average vehicles" (specifically passenger cars) as specified in the next section.

1.5 TYPICAL ELVs AND A GENERIC EQUIVALENT ELV

In the real world, ELVs can range from motorcycles through busses, from virtually brand new to over 50 years old. For modeling purposes, however, it is important to identify the prevailing types and characteristics of typical ELVs and, as best as possible, establish a single "generic equivalent" ELV that can serve as a convenient reference point. Such identification is provided in the following sub-sections.

It should be kept in mind, however, that both the typical range and generic equivalent of ELVs change with time, similar to the changing face that one would see tracking the typical range and generic equivalent of new vehicles produced over time. Indeed, as detailed below, in essence the "face" of current ELVs largely reflects the prevailing mix of new vehicles produced 10 to 20 years ago. This observation has obvious implications for the future of ELV management as well, being that the vehicles produced today will be prevailing ELVs 10 to 20 years down the road.

1.5.1 TYPICAL ELVs

One way to identify typical ELVs is by estimating the median life expectancy of vehicles, which, in turn, can be used to identify model years one would expect most ELVs to be from.

Such data is presented in Table 1.3 - using vehicle registration data and a vehicle scrappage model, the Oak Ridge National Laboratory (ORNL) calculated the median lifetimes of 1970, 1980, and 1990 model year vehicles as shown in the table.

Table 1.3 Estimated Vehicle Median Lifetimes

	Estimated Median Lifetime (years)	
Model Year	Autos	Light Trucks
1970	11.3	16.8
1980	12.2	15.7
1990	14.0	15.2

Source: (TEDB, 2000 - Tables 6.9 & 6.10)

As seen from the table, calculated median lifetimes for older model year autos were somewhat lower than for the later model years, while just the opposite was seen in the case of light trucks.

Based on the above data, one might reasonable expect that mid-to-late 1980s model vehicles are being currently being permanently retired in the greatest numbers, with the bulk of recently retired vehicles being 1982-92 year models. Field observations (Orr, 2000) appear to confirm such expectations:

- Table 1.4 is a compilation of the top 30 vehicles not being re-registered (and thus, assumed to have become ELVs) in 1999 (Orr, 2000).
- Table 1.5 is a set of specific Big 3 (Chrysler, Ford, and GM) "target vehicles" that a team of experts compiled to assess potential opportunities for plastics recycling from ELVs (Orr, 2000). While not chosen strictly based on availability in the current overall ELV stream, such a consideration was a key criteria for selection. Thus, it is felt to be another good "take" on key vehicles present in the current overall ELV mix.

Table 1.4 Compilation of Top 30 Vehicles Not Re-Registered in 1999

Vehicle Make/Model	Model Year(s)
GM	
Buick Century/Regal	80-81
Chevrolet Impala/Caprice	78-79
Chevrolet Celebrity	84-86
Chevrolet Cavalier	84-86
Oldsmobile Cutlass	78-86
Ford	
Escort	84-87
F-150 Pickup	78-79
Tempo	84-85
Honda	
Accord	83
Nissan	
Sentra	87

Data Source: [Orr, 2000]

Table 1.5 Chrysler, Ford and GM Vehicles Targeted to Evaluate Potential Recycling of Recovered Plastics from ELVs

Vehicle Make/Model	Model Years
Chrysler	
Dodge Caravan	84-90
Plymouth Voyager	84-90
Ford	
Ford Taurus*	86-91
Mercury Sable*	86-91
Ford Tempo	88-94
Mercury Topaz	88-94
Ford Escort	81-90
GM	
Chevrolet Celebrity*	82-90
Buick Century	82-95
Oldsmobile Cutlass Ciera	82-95
Pontiac 6000	82-91
Chevrolet Cavalier*	88-94

Data Source: [Orr, 2000]
* - Includes both sedan and station wagon body styles

1.5.2 A Generic Equivalent ELV

A key modeling concept is the use of a single "generic equivalent" ("average") vehicle to represent all ELVs, with the focus being on the material composition of that "average" vehicle. The traditional approach has been to use average material consumption data for domestic automobiles for a selected year and use that mix to represent all ELVs. Such data is provided in Table 1.6 for 1985 and 1990, along with the average considering those two years.

As noted in the previous section, mid-to-late 1980s model vehicles are being currently being permanently retired in the greatest numbers. Thus, the "average of 1985 and 1990" entry in Table 1.6 will be used for modeling purposes in this report. It is important to note that there is little change in the values between 1985 and 1990, save for a slight increase in aluminum and plastics consumption, with a slight decrease in steel and iron usage rates. These are part of definite trends that are further discussed in Chapter 2.

It should also be noted that in the literature, the following "rules-of-thumb" are typically employed (sometimes implicitly): the average vehicle weighs 3200 pounds (3120 pounds minus the tires) and is comprised of 75% metals, 25% non-metals.

While the above can serve as a solid foundation for defining an ELV, more detailed information about the material construction of "typical" vehicles may be needed at times. To fill that need, Table 1.7 can be used. This table provides the material breakdown of a 1995 model year generic US family sedan. The generic vehicle defined in the table is a synthesis of 3 comparable 1995 vehicles: Dodge Intrepid, Chevrolet Lumina, and Ford Taurus. This analysis was performed in an effort to define the Life Cycle Inventory (LCI) to benchmark the environmental performance of new and future vehicles produced [Sullivan et. al., 1998]. While not strictly applicable to defining the average composition of current ELVs – the bulk of current ELVs being 1982-92 model vehicles – it nonetheless can serve as a general guide to typical vehicle composition, as well as an indication of the typical composition of ELVs expected 5 to 10 years in the future.

Table 1.6 Average Material Consumption for a Domestic Auto and Estimated Average ELV Composition

Material	1985		1990		Average of 1985 and 1990 (Estimated Avg. ELV Composition)	
	Weight [lbs]	% of Total	Weight [lbs]	% of Total	Weight [lbs]	% of Total
Ferrous Metals						
Conventional Steel[1]	1482	46%	1405	45%	1444	45%
Iron	468	15%	454	14%	461	14%
High-Strength Steel	218	7%	238	8%	228	8%
Other Steels (Except Stainless)	55	2%	40	1%	47	1%
Subtotal	***2223***	***70%***	***2137***	***68%***	***2180***	***68%***
Nonferrous Metals						
Aluminum	138	4%	159	5%	148	5%
Stainless Steel	29	1%	34	1%	32	1%
Copper and Brass	44	1%	49	1%	46	1%
Powder Metal Parts	19	1%	24	1%	22	1%
Zinc Die Castings	18	1%	19	1%	19	1%
Magnesium Castings	3	<1%	3	<1%	3	<1%
Subtotal	***251***	***8%***	***288***	***9%***	***270***	***9%***
Nonmetals						
Plastics/ Composites	212	6%	229	7%	220	7%
Fluids, Lubricants	184	6%	182	6%	183	6%
Rubber	136	4%	137	4%	137	4%
Glass	85	3%	87	3%	86	3%
Other Materials	99	3%	84	3%	91	3%
Subtotal	***716***	***22%***	***719***	***23%***	***717***	***23%***
Total Vehicle	**3188**		**3141**		**3165**	

[1] Includes cold-rolled and pre-coated steel.

Source: [TEDB, 2000 - Table 7.13] and [AAMA, 1997].

Table 1.7 Material Breakdown of a 1995 Model Year Generic US Family Sedan

Material Category/ Material	Mass (kg)	% of Category	% of Vehicle	Material Category/ Material	Mass (kg)	% of Category	% of Vehicle
Plastics				**Ferrous Metals**			
ABS	9.7	7%	0.6%	Iron (Ferrite)	1.5	<1%	0.1%
ABS-PC blend	2.8	2%	0.2%	Iron (Cast)	132	13%	8.6%
Acetal	4.7	3%	0.3%	Iron (Pig)	23	2%	1.5%
Acrylic Resin	2.5	2%	0.2%	Steel (cold rolled)	114	12%	7.4%
ASA	0.18	<1%	<0.1%	Steel (EAF)	214	22%	14.0%
Epoxy Resin	0.77	1%	0.1%	Steel (galvanized)	357	36%	23.3%
PA 6	1.7	1%	0.1%	Steel (hot rolled)	126	13%	8.2%
PA 66	10	7%	0.7%	Steel (stainless)	19	2%	1.2%
PA 6-PC blend	0.45	<1%	<0.1%	**Subtotal**	**985**	**100%**	**64.3%**
PBT	0.37	<1%	<0.1%	**Fluids**			
PC	3.8	3%	0.2%	Auto Trans. Fluid	6.7	9%	0.4%
PE	6.2	4%	0.4%	Engine Oil	3.5	5%	0.2%
PET	2.2	2%	0.1%	Ethylene Glycol	4.3	6%	0.3%
Phenolic Resin	1.1	1%	0.1%	Gasoline	48	65%	3.1%
Polyester Resin	11	8%	0.7%	Glycol Ether	1.1	1%	0.1%
PP	25	17%	1.6%	Refrigerant	0.91	1%	0.1%
PP Foam	1.7	1%	0.1%	Water	9.0	12%	0.6%
PP-EPDM blend	0.10	<1%	<0.1%	Windshield Cleaning Additives	0.48	1%	<0.1%
PPO-PC blend	0.025	<1%	<0.1%	**Subtotal**	**74**	**100%**	**4.8%**
PPO-PC blend	2.2	2%	0.1%	**Other Materials**			
PS	0.007	<1%	<0.1%	Adhesive	0.17	<1%	<0.1%
PUR	35	24%	2.3%	Asbestos	0.4	<1%	<0.1%
PVC	20	14%	1.3%	Bromine	0.23	<1%	<0.1%
TEO	0.31	<1%	<0.1%	Carpeting	11	6%	0.7%
Subtotal	**143**	**100%**	**9.3%**	Ceramic	0.25	<1%	<0.1%
Non-Ferrous Metals				Charcoal	0.22	<1%	<0.1%
Aluminum Oxide	0.27	<1%	<0.1	Corderite	1.2	1%	0.1%
Aluminum (cast)	71	51%	4.6%	Desiccant	0.023	<1%	<0.1%
Aluminum(extruded)	22	16%	1.4%	Fiberglass	3.8	2%	0.2%
Aluminum (rolled)	3.3	2%	0.2%	Glass	42	22%	2.7%
Brass	8.5	6%	0.6%	Graphite	0.092	<1%	<0.1%
Chromium	0.91	1%	0.1	Paper	0.20	<1%	<0.1%
Copper	18	13%	1.2%	Rubber (EPDM)	10	5%	0.7%
Lead	13	9%	0.8%	Rubber (extruded)	37	19%	2.4%
Platinum	0.002	<1%	<0.1%	Rubber (tires)	45	23%	2.9%
Rhodium	0.0003	<1%	<0.1%	Rubber (other)	23	12%	1.5%
Silver	0.003	<1%	<0.1%	Sulfuric Acid- in battery	2.2	1%	0.1%
Tin	0.067	<1%	<0.1%	Textile Fibers	12	6%	0.8%
Tungsten	0.011	<1%	<0.1%	Wood	2.3	1%	0.2%
Zinc	0.32	<1%	<0.1%	**Subtotal**	**192**	**100%**	**12.5%**
Subtotal	**138**	**100%**	**9.0%**	**GRAND TOTAL**	**1532**		**100.0%**

* Adopted from Sullivan et al, 1998 (USCAR AMP Project overview).

2. ELV MANAGEMENT PROCESS DESCRIPTION

Except for lead-acid batteries, the automobile is the most frequently recycled product in the US. Figures obtained from the Battery Council International's website (www.batterycouncil.org/recycling.html) indicate over 96% of lead-acid batteries are recycled, while newspapers, aluminum cans and glass bottles have recycling rates of 68%, 64% and 38%, respectively. The recycling frequency for automobiles, on the other hand, is, as previously noted in Section 1.4, cited as 94% with the remaining 6% thought to be abandoned [AAMA, 1997]. It was estimated in Section 1.4 that 12.5 million ELVs (7.7 million cars, 4.6 light trucks, and 0.2 million medium/heavy trucks) are recycled in the US each year, while, for modeling purposes, a figure of 13.5 million generic ELVs (weighing approximately 3200 pounds (1450 kg) each and with the material composition provided in Table 1.6) was selected for use.

In this chapter, a detailed description of the ELV management process and infrastructure currently in place in the US is provided.

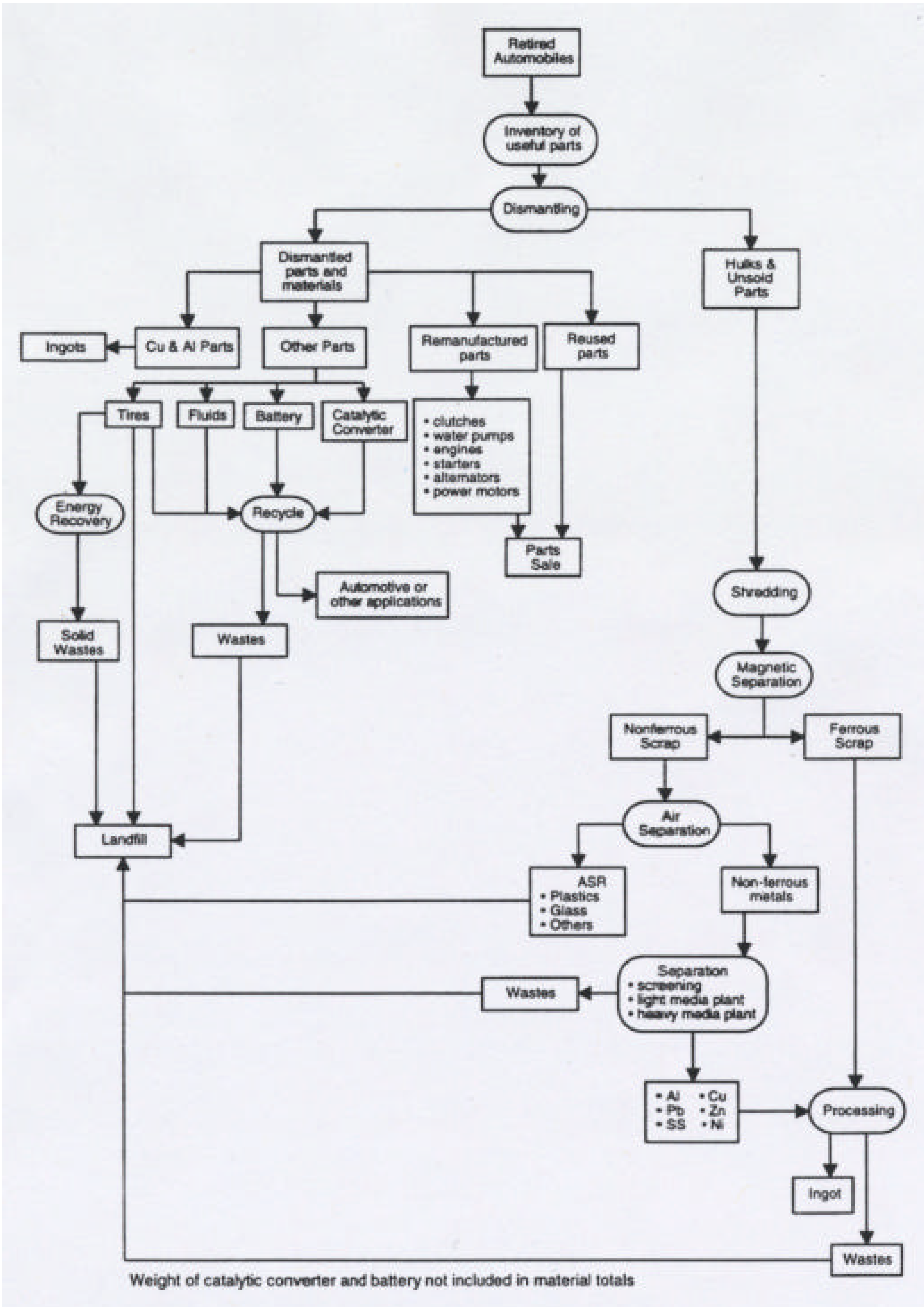
2.1 OVERVIEW

A generalized flow diagram indicating the overall ELV processing structure and associated materials streams is provided in Figure 2.1. As this figure shows, the four main activities are as follows:

1. Dismantling: Occurring at either a dismantler facility or a salvage/scrap yard, a variety of parts and all vehicle fluids and tires are removed for either:
    - Direct reuse (e.g., body panels used to repair collision-damaged vehicles)
    - Remanufacture (e.g., clutches, starters, engines)
    - Recycle (e.g., fluids, batteries, catalytic converters, steel fuel tanks)
    - Energy Recovery (e.g., tires)
    - Disposal (e.g., plastic fuel tanks)

   After removal, the remaining gutted vehicle ("hulk") is typically flattened prior to shipment to the shredding facility.
2. Shredding: Occurring at a shredding facility, the vehicle hulks are placed in a shredder, which tears the hulks into fist-sized pieces.
3. Post-shredder material separation and processing: Initially, the post-shredder material stream is separated at the shredding facility into two basic streams, using magnetic separation technology:
    - Ferrous metal (all iron and steel, except stainless steel)
    - Non-ferrous materials (both metals and non-metals)

   Following initial separation, the ferrous metal fraction is sent for recycling to steel smelters, almost exclusively electric arc furnaces (EAFs), which specialize in processing steel scrap. The non-ferrous material fraction is then typically separated out into the following streams.



Source: [Keoleian, et al., 1997]

Figure 2.1 The ELV Management Process

- Individual nonferrous metal streams (aluminum, brass, bronze, copper, lead, magnesium, nickel, stainless steel, and zinc).
- Auto Shredder Residue (ASR or "fluff", consisting of remaining non-metallic materials – plastics, glass, rubber, foam, carpeting, textiles, etc. – along with dirt and metallic fines). This is currently considered non-recoverable waste material and is sent to landfills for disposal.

Separation of the non-ferrous material fraction can occur at either the shredder or at a separate, dedicated facility (a "nonferrous processing facility"). Shredders often use eddy-current techniques or flotation systems to recover aluminum and zinc alloys or to increase the concentration of metals prior to shipping to a nonferrous processor. Nonferrous processors use a series of techniques – ranging from highly complex, automated systems to simple manual sorting - to recover individual nonferrous metal streams (brass, bronze, copper, lead, magnesium, nickel, and stainless steel).

Waste ASR generated at the shredder is referred to as the "light fraction," while waste ASR generated at the non-ferrous processor is referred to as the "heavy fraction."

4. Landfill disposal of ASR: As noted above, ASR is currently considered non-recoverable waste material and is sent to landfills for disposal. Reduction of this waste stream via recovery and recycling of plastics currently contained in ASR is the focus of several research efforts, as noted in Chapter 7.

From the above, key facilities engaged in ELV management activities include:

1. Dismantlers, consisting of two distinct types:
   - High-value parts dismantlers (high volume, quick turnover operations targeting late-model vehicles).
   - Salvage/scrap yards (low volume, slow turnover operations accepting most vehicles).
2. Shredding facilities
3. Non-ferrous separation facilities
4. Steel mills (specifically, Electric Arc Furnaces - EAFs)
5. Landfills

Table 2.1 provides an overall summary of ELV-related estimated mass flows in the US based on the following:

- 13.5 million generic equivalent ELVs recycled.
- ELV composition as given in Table 1.6 (using the "average of 1985 and 1990" figures)
- Complete (100%) removal of fluids.
- Complete (100%) separation and recovery of metals (either via dismantling of parts or reclaimed via shredding, separation, and recovery).
- Scrap tires weighing 20 lb per tire (average weight for scrap passenger cars times per the Rubber Manufacturers Association [RMA, 2001a]).
- ASR consists of all non-metals listed in 1.6 except for fluids and scrap tires.

- Ignores presence of moisture, dirt and metal fines found in "real-world" ASR, which, as discussed in Section 3.1.1, can be 30-50% of the total by weight.

Table 2.1 ELV Management Process Mass Flow Summary

Fraction	Total Quantity (per 13.5 million ELVs*) [million metric tons]	[million short tons]	% of Total	Quantity per ELV [kg/ELV]	[lb/ELV]
Recovered Ferrous Metals	13.4	14.7	68%	989	2180
Recovered Non-Ferrous Metals	1.7	1.8	9%	122	270
ASR**	2.8	3.1	14%	206	454
Fluids	1.1	1.2	6%	83	183
Scrap Tires	0.5	0.5	2.5%	36	80
Total ELV	19.4	21.4	100%	1420	3165

* Represents estimated current annual recycling rate for ELVs.

** Ignores presence of moisture, dirt and metallic fines found in "real-world" ASR (see Section 3.1.1 for details).

More details regarding ELV management processes and associated facilities are presented below. Exact environmental and energy burdens associated with the process are discussed in Chapter 3, while economic issues are discussed in Chapter 4.

2.2 Dismantling

Once the decision is made to permanently (and properly) retire a vehicle (without just abandoning it), the vehicle owner, or more frequently, a towing service delivers the new ELV to a "dismantler." There are two distinct types of dismantlers:

- <u>High-value parts dismantlers</u>: Retail/wholesale businesses that remove and inventory useful, high-value parts (e.g., starters, alternators) for resale. Parts inventories are maintained in nationwide computer databases, permitting interested parties (repair shops, etc.) located across the country to quickly and efficiently locate and purchase recovered parts. These operations target late-model ELVs (which, because of their age, tend to have both more high value and more highly valued parts) and operate on a relatively high volume, quick turnover basis – processing rates of 400-500 cars per day have been reported [Bigness, 1995]. As such, these businesses serve as a reliable source of used parts and tend to have good business economics. After processing, the ELVs may be either sent directly to a shredder, or first sold to a salvage/scrap yard.

- Salvage/scrap yards: Typified by traditional "U-Pull-It"- and/or "mom and pop"-type businesses, these are low-tech operations that essentially store ELVs while parts are gradually removed and sold (ELVs can remain an average of 2 to 5 years in scrap yards [Ecology Center et al., 2001]). They do not maintain detailed parts inventories and sell parts mainly to local repair shops and "do-it-yourselfers." These operations tend to collect older, less desirable vehicles (i.e., those not valued by high-value parts dismantlers) and operate on a relatively low volume, slow turnover basis. As such, these operations are not a particularly reliable source of used parts (i.e., "hit and miss") and tend to operate on marginal business economics. Reflective of that fact, salvage/scrap yards are usually located on the fringes of towns and cities, often on farmland (i.e., low-cost locations)[3].

A frequently cited estimate for the number of dismantlers in North America is over 12,000 [Curlee et al., 1994; Steel Recycling Institute website, etc.]. However, more grounded estimates indicate that figure is closer to 10,000, with the bulk (8000) being traditional salvage/scrap yards (Ecology Center et al., 2001).

For the US, the US Census Bureau's 1997 Economic Census counted 7105 establishments reporting NAICS code 42114 (Used Motor Vehicle Parts Wholesalers – "establishments primarily engaged in wholesaling used motor vehicle parts (except used tires and tubes) and establishments primarily engaged in dismantling motor vehicles for the purpose of selling the parts") as their primary code [US Census website at www.census.gov/epcd/ec97/us/US000_42.HTM)]. This represents a 17% increase from the 6075 establishments that similarly reported such operations in the 1987 Economic Census. The national trade association representing dismantlers – the American Recyclers Association (ARA) – cites 6000 businesses in the US [ARA, 2001]. The ARA also notes the prevailing "small business" nature of dismantlers in citing that 86% of US dismantlers employee 10 or fewer people [ARA 2001].

In terms of removal practices, dismantlers remove specific parts and materials from ELVs primarily because of economic reasons (i.e., value and demand for individual parts and materials), but also, in certain cases (vehicle fluids, air conditioning refrigerant gases, batteries), at least in part due to environmentally based legal requirements. Other factors also impact removal practices – safety considerations dictate removal of residual gasoline and the actual fuel tank, while shredders refuse to accept tires, dictating their removal by dismantlers. Finally, available space in salvage/scrap yards can be a factor potentially limiting which parts are removed and sold.

Theoretically, the entire contents of an ELV could be removed for reuse in one form or another in another vehicle. Realistically, however, logistical and economic reasons limit removal operations. Listed below are typical parts/materials removed and their typical ultimate disposition.

[3] Scrap yards first came into existence in the 1940s and 1950s when cars (and other metal scrap) were disposed of in open fields. At that time, shredding technology was not available and inoperative cars were stored strictly for their parts [Ecology Center et al., 2001].

- Electro-mechanical parts (clutches, water pumps, engines, starters, alternators, transmissions, and motors for power windows): Typically remanufactured and sold for reuse.
- Structural body parts (body panels, wheels, etc): Removal for use in repairing accident-damaged vehicles.
- Aluminum and copper parts: Removal for sale directly to nonferrous processors. Alternatively, dismantlers can make ingots from the parts and sell them to the nonferrous scrap market.
- Gasoline: Recovered for use.
- Vehicle fluids (engine oil, transmission fluid, ethylene glycol, windshield cleaning fluid): Recycled.
- Batteries: Sent to a lead-acid battery recycler for recycling.
- Tires: Sent to a scrap tire dealer for disposition (typically burned for energy recovery, landfilled or stockpiled)
- Catalytic converters: Sent to a recycler for precious metal (platinum) recovery
- Air conditioning refrigerant gases: Recovered for reuse or destruction.
- Air bags: Recovered for reuse or deployed and disposed of.
- Fuel tanks: Steel tanks are flattened and recycled; plastic tanks are disposed of in landfills.

If parts removed for potential sale are not sold during a reasonable period of time, they are transported to the shredder along with subsequent hulks. The time period for storing a part is a function of various factors such as:

- Size of the dismantler.
- Model year of the vehicle to which the part belongs.
- Manufacturers' warranties.

What remains of the vehicle after dismantlers remove all useful parts and materials is commonly referred to as the "hulk." Typically, hulks consist of steel structural materials, plastic dashboards, foam seats, and other components. Although stripped of many parts and items, hulks typically retain at least 70% of the original weight of the ELV.

The hulk is typically flattened for ease of transport to the shredder. During flattening, a shattered glass waste stream is generated, which the dismantler typically disposes of in a landfill (see Chapter 7 for further discussion of vehicle glass management issues).

2.3 SHREDDING

Following the dismantling process, gutted ELVs are sent (typically flattened) to a shredder for shredding, followed by separation of shredded material into two basic streams (ferrous metal and nonferrous materials). In addition to ELVs, shredders typically also process “white goods” (appliances – refrigerators, washers, etc.) and other discarded objects containing sheet and light structural steel. There are approximately 200 shredding facilities in North America, 182 in the US and 22 in Canada [AISI, 1992]. In the US, shredders are located primarily in heavily populated states, largely east of Mississippi River.

At shredder facilities, hulks are inspected prior to shredding to ensure that potentially hazardous components such as batteries, gas tanks, and fluids have been removed. Hulks (and other collected materials) are then shredded into fist-sized pieces using large hammer mills. A typical processing rate for shredders is one ELV per 45 to 60 seconds [SRI, 2001b].

2.4 POST-SHREDDER MATERIAL SEPARATION AND PROCESSING

Following shredding, two basic separations are made:

- An initial separation of the combined material stream into ferrous and nonferrous fractions using a magnetic separation process.
- Separation of the nonferrous material stream into metal and non-metal fractions using a variety of techniques (typically air separation if performed at the shredder).

The three basic streams thus generated are:

- Ferrous metal (iron and steel) – 65 to 70% by weight.
- Non-ferrous metal (aluminum, stainless steel, copper, brass, lead, magnesium, zinc, and nickel) – 5 to 10% by weight.
- Auto Shredder Residue (ASR or “fluff”, consisting of “other materials – plastics, glass, rubber, foam, carpeting, textiles, etc.) – 20 to 25% by weight.

As neither of the separations are 100% efficient, a certain level of contamination exists in each material steam generated. The ferrous metal fraction, however, is relatively pure, typically containing only 0.5 to 1% of impurities (consisting of fines, rust and non-ferrous metals – principally copper). ASR, on the other hand, typically contains an appreciate amount of metallic fines, along with significant quantities of dirt and moisture entering during normal processing activities.

Further processing of the post-shredder material streams are detailed separately below.

2.4.1 Ferrous Metal Fraction

The separated ferrous metal fraction (containing iron and steel) is sent for recycling to steel smelters. ELV scrap is almost exclusively handled by electric arc furnaces (EAFs)[4], which utilize electric energy to melt and refine scrap in a batch process to make steel products. In 1999, there were a reported 120 EAP mini-mills operating in the US, with total production being approximately 45 million metric tons (50 million short tons) or roughly 80% of capacity (Ecology Center et al., 2001). Based on the current estimated recovery figure of 13.4 million metric tons (15 million short tons) per year cited in Table 2.1, ELV scrap accounts for 30% of the total scrap processed by US EAFs in 1999 and over 20% of the 64 million tons of scrap steel reported recycled in the US in 1999 (SRI, 2001a).

2.4.2 Nonferrous Metal Fraction

The separated non-ferrous metal fraction (containing aluminum, brass, bronze, copper, lead, magnesium, nickel, stainless steel, and zinc) is typically sent to another, specialized facility to separate the stream into its individual metals by a variety of means. Aluminum and stainless steel are separated by both "light-media" and "heavy-media" plants. Copper and brass require additional separation, which is accomplished mainly by image processing. Separated nonferrous scrap is typically further processed into ingots, for ultimate sale to the nonferrous scrap market.

In performing these separations, a significant amount of contaminants (non-metals) are removed. This waste, referred to as "heavy ASR," is sent for landfill disposal.

Most nonferrous shredder wastes generated east of Colorado are shipped to Huron Valley Steel Corporation (HVSC), located in Belleville, Michigan [Ecology Center et al., 2001]. HVSC processes about 1 million pounds of mixed metals daily or about 65% of all the nonferrous shredder material from the eastern US. The process is completely mechanized and sorts the incoming mix to a high degree of purity based on density, color and reflectivity. The separated metals include aluminum, brass, bronze, copper, lead, magnesium, nickel, stainless steel, and zinc. A large amount of water is needed to perform the separations; this water is treated and recycled in a closed-lop system.

Apart from the separation process, HVSC also smelts zinc into ingots. Any nonmetallic material – estimated at 50% by weight – is transferred to local landfills.

[4] Basic Oxygen Furnaces (BOFs), the other major steel-making process, also uses scrap steel, but they rely on non-ELV sources for their scrap.

2.4.3 Automotive Shredder Residue (ASR) Fraction

Generated ASR contains the bulk of non-metallic materials present in shredder hulks (plastics, glass, rubber, foam, carpeting, textiles, etc), entrained metallic fines, dirt and moisture (see Chapter 3 for typical composition details). Two types of ASR streams can be generated from overall ELV processing:

- <u>"Light" ASR ("fluff")</u>: Generated at the shredder facility when the nonferrous fraction is separated into metal and nonmetallic streams using air classification processes (the non-metallic fraction being "fluff").
- <u>"Heavy" ASR</u>: Generated at the non-ferrous metal processing facility during separation of the various metal steams (the heavy ASR representing rejected contaminants extracted during processing).

Currently, due to a variety of reasons (principally low disposal costs – see Chapter 4), both light and heavy ASR are landfilled "as is" in municipal/industrial landfills (except in California, where ASR is considered a "hazardous waste," and must be handled as such). Both types of ASR contain similar materials (plastics, glass, rubber, foam, carpeting, textiles, metallic fines, dirt, moisture, etc.), just in different proportions (light ASR containing a larger proportion of lighter materials like plastic and rubber; heavy ASR containing a larger proportion of heavier materials like glass and metal fines).

3. ENVIRONMENTAL AND ENERGY BURDENS OF ELVs

The environmental and energy burdens associated with ELV management are strongly dependent on the material composition of vehicles processed and the infrastructure in place to process those vehicles. These factors also influence the potential for material and energy recovery, which reduces burdens experienced both at end-of-life and upstream in the life cycle such as during materials production and vehicle manufacturing/assembly activities.

3.1 ENVIRONMENTAL BURDENS

Overall, there are a number of environmental burdens associated with ELV management, including:

1. Wastes produced as an immediate and direct end result of normal ELV processing, principally:
    - ASR
    - Scrap tires
2. Waste/emissions produced in ancillary activities associated with ELV processing. Such ancillary activities include:
    - Recycling of removed vehicle fluids, batteries, catalytic converters, and, when used for energy recovery, tires.
    - Remanufacturing of removed electro-mechanical parts (engines, alternators, etc.)
    - Smelting of recovered scrap iron and steel.
    - Production of ingots from recovered non-ferrous metals.
3. Burdens associated with abandoned ELVs (approximately 6% all ELVs), principally leaking of vehicle fluids and air conditioning refrigerant into the environment.
4. Burdens associated with traditional scrap/salvage yards, due to the historic low-tech nature of operations that often operate with little regard for environmental protection – the principal concern being releases of ELV fluids and air conditioning refrigerant into the environment.
5. The potential release to the environment of mercury (a toxic chemical) from mercury-containing switches potentially present in ELVs during hulk shredding and subsequent ferrous metal recovery activities (i.e., at EAF plants) (see Chapter 7).

For purposes of this report, the focus will be on the first category - wastes produced as an immediate and direct end result of normal ELV processing, principally ASR and scrap tires.

Characterization of the ASR and scrap tire waste streams is presented below, with discussion of management issues associated with each provided in Chapter 7.

3.1.1 Automotive Shredder Residue (ASR)

Automotive Shredder Residue (ASR) is considered to be essentially comprised of all non-metallic materials present in ELVs, except for vehicle fluids and scrap tires removed during dismantling (this ignores removal by dismantlers of parts containing non-metallic components, which is believed insignificant). Therefore, based on the estimated average ELV composition given previously in Table 1.6, a theoretical composition of ASR is presented in Table 3.1

Table 3.1 Theoretical Composition of ASR

Material	Amount [lbs/ELV]	% of Total
Plastics	220	48%
Rubber	57	13%
Glass	86	19%
Other Materials*	91	20%
Total	***454***	***100%***

* - Mostly carpeting and textiles – See Table 1.7 for a complete listing.

Source: Table 1.6 (cited rubber quantity of 137 pounds reduced by 80 pounds to account for scrap tires which are separately managed and thus, not part of ASR).

As seen from Table 3.1, theoretically, nearly ½ of ASR is comprised of plastics, with another 1/3 being rubber and glass and the remainder mostly carpeting and textiles.

In reality, however, two factors significantly affect the actual composition of ASR:

- Presence of moisture and dirt, entering from normal exposure to the elements during ELV/hulk processing.
- Presence of metal fines, the result of incomplete separation of metals.

Orr reports the following composition of actual ASR, based on data from the AAMA combined with ASR data from a Canadian shredder [Orr, 2000]:

- Plastic: 20-35%
- Elastomers (rubber): 10-20%
- Glass: 5-10%
- Wood/Paper/Other: 5-10%
- Dirt and Metal Fines: 15-25%
- Moisture: 15-25%

A second source [Environmental Defense, 1999] reports a lower moisture content range of 1 to 20%, averaging 8%, while giving a density range of 300 to 400 kg/m^3 (506 to 674 lb/yd^3).

Assuming that 35% by weight of “real-world” ASR consists of dirt, metal fines and moisture (20% dirt and metal fines; 15% moisture), a projected “real-world” composition for ASR is given in Table 3.2.

Table 3.2 Projected "Real-World" Composition of ASR

Material	Amount [lbs/ELV]	% of Total
Plastics	220	31%
Rubber	57	8%
Glass	86	12%
Other Materials*	91	13%
Dirt and Metal Fines	140	20%
Moisture	105	15%
Total	***700***	***100%***

* - Mostly carpeting and textiles – See Table 1.7 for a complete listing.

Assuming 13.5 million generic equivalent ELVs are recycled each year, with 700 lbs (318 kg) of ASR generated per ELV, it is estimated that 4.7 million tons (4.3 million metric tons) of ASR is generated per year, representing 3.9% of the 121 million tons of municipal solid waste landfilled in the US in 1998[5] (USEPA, 2000). At an assumed average density of 350 kg/m^3 (590 lb/yd^3), that equates to a volume of 12.3 million m^3 (16.0 million yd^3) disposed on annually in landfills.

Reduction of ASR is an issue that has received much attention and research over the past decade. Most effort has focused on plastics recycling, which makes sense given that it dominates the waste stream. Such efforts are discussed in Chapter 7.

Finally, certain toxic contaminants have been detected in ASR. Table 3.3 provides a summary of results from four studies as reported in [Ecology Center et al., 2001].

[5] While 220 million tons of municipal solid waste was generated in the US in 1998, only 121 million was actually landfilled, with 62 million tons being recycled and 37 million tons being combusted.

Table 3.3 Toxic Contaminants Measured in ASR

	Concentration (mg/kg)			
Contaminant	USEPA Study of US ASR (1991)	Study of California ASR	Study of a Minnesota Shredder's ASR (2001)	Study of German ASR (1996)
Mercury	NM	0.7	0.33 to 3.2 (Mean: 1.15)	6 to 15
Lead	570 to 12,000 (mean: 2700)	2330 to 4616	NM	3500 to 7050
Cadmium	14 to 200 (mean: 47)	46 to 54	NM	60 to 100
Chromium	NM	247 to 415	NM	370 to 770
Arsenic	NM	NM	NM	57 to 63
PCBs	1.7 to 210 (mean: 32)	NM	NM	NM

NM: Not Measured.
As reported in [Ecology Center et al., 2001]

3.1.2 Scrap Tires

The issue of scrap tires naturally extends beyond just ELVs, given that the bulk (80%, as calculated below) of scrap tires generated are due to normal wear and tear rather the vehicle itself being permanently retired. Nonetheless, given the relative prominence of the issue in the US – particularly in the context of existing scrap tire stockpiles that grab the general public's attention when one catches on fire– it is important to understand the overall context of the problem, as well as the relative contribution of ELVs.

In that regard, a few pertinent scrap tire facts and figures [RMA, 2001a; RMA, 2001b]:

- 270 million scrap tires were estimated to have been generated in 1998 based on industry replacement sales and tires on scrapped vehicles.
- 84% of scrap tires come from passenger cars; 15% from light and heavy trucks; 1% from heavy equipment, aircraft and off-road tires.
- The average weight of a passenger car tire is 25 pounds new, 20 pounds when scrapped, while truck tires average 120 pounds new, 100 pounds when scrapped.
- 2.5 pounds of steel are present on average in a steel-belted radial passenger car tire (tires being essentially composed of rubber and steel).

It can be estimated that the relative contribution of ELVs to scrap tire generation is 20% - assuming an ELV generation rate of 13.5 million, with four tires per vehicle, ELVs contribute 54 million scrap tires a year, exactly 1/5 of the estimated 270 million total generation rate cited above.

Management issues associated with scrap tires are identified in Chapter 7, while pertinent policy and regulatory issues are discussed in Chapter 5.

3.2 ENERGY BURDENS

For purposes of this report, evaluation of energy burdens will focus on those burdens associated with immediate and direct management of ELVs, namely:

1. Traditional ELV management processes (dismantling, shredding and material separation)
2. Three key transportation-derived burdens associated with ELV management processes, namely:
   - Transportation of dismantled hulks to shredders.
   - Transportation of recovered metals to metal processors.
   - Transportation of ASR to landfills for disposal.

Other sources of energy burdens (not considered here) include:

1. Initial transportation of permanently retired vehicles to dismantlers (typically accomplished by a tow truck service).
2. Ancillary activities associated with ELV processing. Such ancillary activities include:
   - Recycling of removed vehicle fluids, batteries, catalytic converters, and, when used for energy recovery, tires.
   - Disposal or other use of used tires (besides recycling for energy recovery).
   - Remanufacturing of removed electro-mechanical parts (engines, alternators, etc.)
   - Smelting of recovered scrap iron and steel.
   - Production of ingots from recovered non-ferrous metals.
3. Transportation to/from ancillary activities

Table 3.4 is a summary of results obtained in evaluating the energy burden involved in direct ELV management activities for the US, along with an estimated obtained from the literature evaluating conditions in Germany [Eyerer et al., 1992]. The results show the overall ELV management energy requirement to be on the order of 1 MJ/kg, with transportation constituting the major energy burden. Applied to the typical 1450 kg (3200 lb) passenger vehicle, this translates into 1450 MJ/vehicle (1.45 GJ/vehicle), less than 1% of reported overall life cycle energy burden of vehicles, which appears to be on the order of 500 to 1000 GJ/vehicle (Keoleian et al., 1997). Thus, the amount of energy consumed in ELV management processes is insignificant in comparison to other vehicle life cycle stages.

Table 3.4 Energy Requirements for ELV Management

ELV Management Process	Estimated Energy Use (kJ / kg)	
	US	Germany*
Dismantling	4	-
Shredding	100	185
Separation	236	64
Transportation	665	360
Total	1005	609

* Source for German condition: [Eyerer et al., 1992]

Discussion of individual ELV energy burdens and associated construction of Table 3.4 is provided below.

3.2.1 Dismantling

By its very nature, dismantling is relatively manual-labor intensive. Dismantlers use a variety of tools such as air driven tools, impact notches, hand tools, abrasive blades and oxyacetylene torches to remove targeted parts (oxyacetylene torches are only used when parts cannot otherwise be removed). Most of the dismantling performed requires human energy. The only potentially significant mechanical energy expended involves flattening of dismantled hulks prior to transport to the shredder. Manufacturers specifications for a typical daily-use type scrap yard car crusher indicate an average cycle time of 45 seconds employing a 150-hp (112 kJ/sec) engine [R.M. Johnson Company, E-Z Crusher. Model B Specifications]. Thus, a total of 5040 kJ would be expended on average to flatten a vehicle. Assuming an average ELV weight of 3200 lb (1450 kg), this translates into a 3.5 kJ/kg energy burden, as shown in Table 3.4.

3.2.2 Shredding

The shredding of intact vehicle hulks into fist-size chucks using a hammermill entails a significant expenditure of electrical energy. Shredding energy varies as a function of load (tons / hr) and the horsepower requirements of the shredder motor (from 2000 hp to 7000 hp). Three estimates for shredder energy burdens were obtained:

- **51 Btu/lb (118 kJ/kg):**[Sullivan and Hu, 1995].
- **42 Btu/lb (97 kJ/kg):** [McGlothlin, 1995], based on the following reported for an operating shredder in Texas: shredder energy = 2827 Btu/s with an operating load = 67.4 lb/s. Thus the shredder energy = 2827/67.4 = 42 Btu/lb.
- **32 Btu/lb (74 kJ/kg):** Per US Department of Energy estimates (as quoted in [Sullivan and Hu, 1995]).

Thus, shredding energy requirements appear to fall on the order of 75-125 kJ/kg. Correspondingly, an average value of 100 kJ/kg is cited in Table 3.4. This is significantly lower, however, than the value reported in the German-based study (185 kJ/kg) also cited in Table 3.4.

Shredding energy includes shredding and magnetic separation of ferrous materials; the latter is considered an insignificant energy burden.

3.2.3 Nonferrous Separation

Nonferrous separation energy varies depending on the type of materials separated and the extent of separation performed. According to Huron Valley Steel, typical energy requirements for a light-media plant are 66 kJ/kg, while separation in a heavy media plant usually requires 170 kJ/kg. Assuming both are necessary for adequate separation, a total of 236 kJ/kg is obtained, as cited in Table 3.4.

The Germany estimate for separation is significantly lower at only 64 kJ/kg; it appears likely that that estimate assumes only a light-media plant, ignoring heavy-media separation.

3.2.4 Transportation

Three key transportation-derived burdens associated with ELV management processes were evaluated, namely:

- Transportation of dismantled hulks to shredders.
- Transportation of recovered metals to metal processors.
- Transportation of ASR to landfills for disposal.

The typical transportation energy for a diesel-operated tractor-trailer is taken from [Franklin, 1992a] as 1945 Btu / ton-mile (1.026 kJ / lb-mile). Average transportation distances were assumed as follows [APC, 1994]:

- Dismantlers to shredders: 100 miles
- Shredder to metal processors: 200 miles
- ASR transport to landfill: 200 miles

Assuming a 3200 lb (1450 kg) average vehicle, comprised of 75% recoverable metals (2400 lb – 1088 kg) and about 700 lbs (320 kg) ASR per vehicle (see Section 3.1.1), this results in a transportation energy requirement of:

$$(3200)(1.026)(100) + (2400)(1.026)(200) + (700)(1.026)(200) = 965{,}000 \text{ kJ/ELV}$$

This yields 665 kJ/kg for the assumed 1450 kg vehicle, as cited in Table 3.4. The German-based study quotes a significantly lower transportation burden (360 kJ/kg), likely due to shorter transportation distances in Germany compared to the US.

4. ECONOMIC ASSESSMENT

The economics of the ELV management process depend principally on the following factors:

- Value of ELVs ("as is" value)
- Processing costs incurred by ELV processors
- Recovered scrap metal value
- ASR disposal costs (i.e., landfill disposal costs)
- Regional/local conditions/factors (potentially affecting all of the above)

Specific economic data or analyses on ELV activities are relatively unavailable and/or difficult to obtain. While the overall economics are obviously favorable – the industry has continued to survive over the years without a major collapse – it is thought to be a low-profit margin venture, subject to the up and down cycles characteristic of most other recycling industries. This is reflected in the fact that the key stakeholders involved – dismantlers, shredders and non-ferrous separators – are mainly comprised of small, independent businesses.

4.1 VALUE OF ELVs

In the US, the "as is" value of ELVs is reflected in the price dismantlers are willing to pay to obtain them. Dismantler procurement costs for ELVs typically include:

- Payment to final owners (or third parties who handle disposition for owners, such as repair shops or, more recently, organizations soliciting "clunker car" donations for charities).
- Cost of towing non-functional vehicles to the dismantler's facility.

A survey within the Ann Arbor, MI area in 1996 indicated a typical towing charge of $30. The dismantler usually tows the vehicle. This survey also indicated that payment to the last user could vary from $25 to $50 depending on the type of vehicle. If the vehicle owner delivers the vehicle directly to the dismantling yard, payment may vary from $50 to $80.

Elsewhere – specifically Germany – "as is" ELVs have a negative value, reflected in the fact that consumers pay between $25 and $150 to permanently retire their vehicles [King, 1995]. The reason for this negative valuation is that ASR is designated as a hazardous waste in Germany, resulting in much higher disposal costs compared to the US. As a result, ASR disposal costs exceeds the salvage value of "as is" ELVs – thus, the need to essentially charge consumers for vehicle recycling

4.2 BUSINESS ECONOMICS OF ELV PROCESSORS

Key ELV processors include dismantlers, shredders, and nonferrous processors, each separately considered below

4.2.1 Dismantlers

As was noted in Chapter 2, there are two distinct types of dismantlers:

- Traditional salvage/scrap yards: Low volume, slow turnover operations accepting most vehicles.
- High-value parts dismantlers: High volume, quick turnover operations targeting late-model vehicles and high-value parts.

It was estimated in Chapter 2 that most (80%) of dismantlers fall under the traditional salvage/scrap yard classification.

The economics underpinning these two types of operations are fundamentally different:

- Traditional salvage/scrap yards rely on low capital and operating costs. This is especially true in the case of "U-Pull-It" operations that seek to minimize expenses by having customers perform actual dismantling.
- High-value parts dismantlers rely on quick turnover of selected high-value items that entail relatively high margins upon sale. In return, however, such operations make significant expenditures in terms both performing actual dismantling (a labor-intensive activity) as well as technology (listing specific parts available in computer databases to reach a wide range of potential customers) and shipping (getting parts to customers).

No matter which type of operation employed, basic costs to dismantlers consist of ELV processing (including removal and disposition of fluids, batteries, tires and typically flattening remaining hulks prior to transportation) and transportation of remaining hulks to shredders. On the other hand, basic income to dismantlers results from sales of removed parts and materials, along with sale of the remaining hulk to the shredder.

For traditional salvage/scrap yards, an estimate of overall economics obtained from an American Plastics Council (APC) case study based on 1992 dollars is as follows [APC, 1994]:

- Total fixed and variable costs: $146 / hulk
- Total credits: $216 / hulk.
- Gross profit margin: $ 70 / hulk (simple payback achieved in 2.9 years).

The APC study made the following key assumptions:

- Acquisition costs to the dismantler for an ELV is $30, while the stripped hulk sales value to the shredder is also $30.
- Dismantler income from recovery of catalytic converters, batteries, tires, and fluids is $170.

Hulk values appear to have increased significantly since the APC study; as reported in a recent study [Ecology Center, 2001, hulks are typically sold to shredders for about 3 cents a pounds. Assuming an average hulk weight of 2600 lb (or 1180 kg) (based on the average passenger vehicle weight of 3200 lbs, minus a 10% allowance for removal of resalable parts and materials at the dismantler and removal of vehicle fluids and tires – approximately 260 pound per Table 2.1), this yields a hulk value of $78. At the same time, hulk acquisition costs appear to have corresponding increased to around $50 to $80 (see previous section). Thus, ELV acquisition costs and hulk sales income appear to continue to approximately equal one another.

One important consideration in terms of costs is the cost to transport hulks to the shredder. Based on the following, an average hulk transportation cost of $19/hulk was calculated (1992 dollars):

- Transportation costs for flattened and unflattened hulks are $0.12 and $0.18 / ton-mile respectively [APC, 1994].
- Assuming a 50% split between flattened and unflattened hulks (a conservative assumption – most hulks are flattened prior to transport to keep such costs down), total transportation cost is $0.15 / ton-mile.
- Assuming an average transportation distance of 100 miles between the dismantler and shredder facility
- Assuming an average hulk weight of 2600 lb (or 1180 kg) (based on the average passenger vehicle weight of 3200 lbs, minus a 10% allowance for removal of resalable parts and materials at the dismantler and removal of vehicle fluids and tires – approximately 260 pound per Table 2.1).

No economic analysis regarding high-value parts dismantlers was found in a check of the literature.

4.2.2 Shredders

Basic costs to shredders consist of hulk processing, transportation of recovered metals to metal processors and transportation and disposal of ASR. Income to shredders consists of payment for both ferrous and nonferrous scrap metals produced.

An estimate of overall economics for shredders based on the American Plastics Council case study previously cited (1992 dollars) is as follows [APC, 1994]:

- Total fixed and variable costs: $117 / hulk
- Total credits: $125 / hulk.
- Gross profit margin: $ 8.60 / hulk (simple payback achieved in 17.5 years).

Thus, per the APC study, shredders have a much lower profit margin than traditional dismantlers. That is an expected result, since traditional dismantlers are low-volume based operations while shredders are concentrated, high-volume operations.

One important consideration in terms of costs is the cost to transport recovered metal scrap to the metal processors. Based on the following, an average hulk transportation cost of $29 was calculated (1992 dollars):

- Transportation costs are \$0.12 / ton-mile respectively (same as for flattened hulks) [APC, 1994].
- Assuming an average transportation distance of 200 miles between the shredder and metal processing facility.
- Assuming an average scrap weight of 2400 lb (or 1090 kg) (based on 75% metallic content of the average 3200 lb passenger vehicle)

ASR disposal costs are considered in section 4.3.

Shredder income is wholly dependent on the sale of recovered metal scrap to metal processors – particularly iron and steel scrap to steel mills. Thus, key factors influencing shredder income include:

- Prices for scrap metals, particularly scrap steel.
- Metal content and mixtures in ELVs.
- Production of clean ferrous and nonferrous scrap from hulks.
- Proximity of shredders to scrap metal industries.

From an income standpoint, a rough estimate can be made as to the current potential income to shredders from iron and steel scrap recovery based on:

1. The US composite average price for No. 1 Heavy Melting Steel scrap in 1999 - \$94/metric ton (\$85.50 per ton) [Fenton, 2000] and
2. The amount of ferrous scrap present in the average passenger vehicle - 990 kg (2180 lb) – taken from Table 2.1.

Using the above, it is calculated that the iron and steel scrap present in a typical hulk is worth approximately \$93 (1999 dollars).

4.2.3 Nonferrous Processors

Information on the economics of nonferrous processors was not found. The main cost to nonferrous processors involve materials processing and disposal of heavy ASR produced, while income is derived from sale of recovered non-ferrous scrap metal.

The scrap value of recovered metals dictates processor credits. Copper (\$0.90/lb), brass (\$0.60/lb), aluminum (\$0.40/lb), and stainless steel (\$0.35/lb) usually have the highest scrap value. Based upon current scrap values and the amount of corresponding metals in the average ELV (see Table 1.6), an estimated income figure (assuming 100% recovery) of \$108 per ELV was arrived at, as detailed in Table 4.1.

Table 4.1 Estimated Potential Income to Non-Ferrous Processor from the Sale of Recovered Non-Ferrous Scrap Metal

Metal	Weight in	Scrap value	Value per

	ELV [lb]*	[$/lb]	ELV
Aluminum	148	$0.40	$59.20
Stainless steel	32	$0.35	$11.20
Copper	32	$0.90	$28.80
Brass	15	$0.60	$ 9.00
TOTAL	227		$108.20

*Based on material compositions given in Table 1.6, with copper and brass split according the percentage distribution indicated per Table 1.7. Assumes 100% recovery of materials present in original ELV.

ASR disposal costs are considered in Section 4.3.

4.3 ASR LANDFILL DISPOSAL COSTS

Except in California, ASR (both light and heavy fractions) is considered a non-hazardous solid waste and thus, can (and is) disposed of in regular municipal or industrial solid waste landfills. (In California, ASR is considered a hazardous waste and thus, must be disposed of in accordance with applicable California hazardous waste regulations.) In addition, some states require treatment of ASR to fix and immobilize heavy metals present prior to landfill disposal or have imposed other regulations on ASR disposal.

Based on state-provided data (Biocycle, 1999), the average landfill “tipping” (disposal) fee in the US in 1998 was $33.60 per ton. There was considerable variation seen between states, ranging from $10/ton (Wyoming) to $65/ton (Vermont). Most states had fees between $18 and $51 per ton. Fees varied by region as follows:

- New England: $52.50/ton
- Mid-Atlantic: $52/ton
- West: $37/ton
- South: $32/ton
- Great Lakes: $30.25/ton
- Rocky Mountain: $26/ton
- Midwest: $25.50/ton

State-specific pretreatment or other special requirements for ASR management and disposal add costs on top of the tipping fee. In California, due to its handling as a hazardous waste, ASR disposal is significantly more expensive than elsewhere.

Applying the 1998 national average tipping fee of approximately $34 per ton for landfill disposal cost, the total cost for disposing of ASR (estimated as 700 lb or 320 kg – see Section 3.1.1) is estimated at $12 per vehicle. This is a key figure, as it represents the economics necessary for free market-driven recycle/recovery of ASR.

4.4 SUMMARY

Table 4.2 indicates the costs and credits associated with ELV management for key stakeholders. Based on current figures, the scrap value of hulks (assuming complete recovery) is approximately $200 ($150 of which is due to steel and aluminum recovery). Further, assuming dismantler credits have not changed substantially from 1992 to the present, an ELV as generated (i.e., prior to processing) appears to be worth on the order of $400-500.

Table 4.2 Summary of Credits and (Costs) for Key ELV Management Stakeholders

Stakeholder	$ / vehicle [1992 $]
Dismantler	
Fixed + variable cost	(146)
Credit	216
Shredder	
Fixed + variable cost	(117)
Credit	125
Steel Scrap value	93
	[1999 $]
Nonferrous Processor	
Scrap value	108
	[1999 $]
Landfill Disposal of ASR	(12)
	[1998 $]

5. LEGISLATION/POLICY ANALYSIS

In the US, relatively little in the way of laws and regulations apple to ELV management activities, save for waste management regulations dealing with vehicle fluids and, to a lesser extent, disposal of scrap tires and ASR. Instead, market forces have for the most part dictated operations and outcomes.

In contrast, Western European nations (and now the European Union) have taken a much more aggressive stance in attempting to regulate management operations and outcomes. Thus, within this chapter, both situations are examined.

5.1 WESTERN EUROPE

Within Western European governments, laws have been passed which set minimum targets for ELV recycling and establish dismantler certification policies. Several nations have also mandated a recycling "deposit" with new vehicle purchases in order to help defray ELV disposal costs.

The European Commission has sought to harmonize the various national efforts within the framework of a single ELV directive. The resulting ELV Directive (2000/53/EC) was adopted by the European Union (EU) in September 2000. The directive [Ecology Center et al., 2001]:

- Establishes Extended Producer Responsibility (EPR) for ELV management, requiring manufacturers and importers of autos to pay for the costs of end-of-life management. Specifically, producers will be responsible for the costs of recycling vehicles put on the market after 1 July 2002. They will not be responsible for recycling vehicles put on the market before July 1, 2002 until January 1, 2007 – at that time, they will be responsible for recycling all vehicles, without regard to age. The last owner of the vehicle will be induced to turn the car over for proper management by mandating that they pay vehicle registration fees until the owner provides a certificate from the dismantler indicating that the car has been turned over for recycling.
- Sets increased recycling requirements. Specifically:
    - By January 1, 2006:
        - Reuse and recovery: Minimum 85% by weight on average
        - Reuse and recycling: Minimum 80% by weight on average

        Where reuse means used for the same purpose for which they were conceived; recycling means reprocessing for original or other use (except for energy recovery) and recovery includes recycling plus energy recovery (i.e., combustion)
    - By January 1, 2015:
        - Reuse and recovery: Minimum 95% by weight on average
        - Reuse and recycling: Minimum 85% by weight on average
    - To aid in meeting these recycling goals, all vehicles put on the market after December 31, 2004 must:
        - Be reusable and/or recyclable at a minimum of 85% by weight

    - Be reusable and/or recoverable at a minimum of 95% by weight

- Established phase-outs in use of certain heavy metals. Requiring EU member states to adopt legislation to ensure that vehicle put on the market after July 1, 2003 do not contain lead, mercury, cadmium, and hexavalent chromium, except in certain excluded components (e.g., lead in lead-acid batteries, hexavalent chromium as a corrosion preventative coating, lead-containing alloys of steel, aluminum and copper, lead as a coating inside fuel tanks, and mercury in headlamps). The directive requires labeling of some components that are exempt from the phase-outs so that they can be stripped before shredding.
- Other provisions:
    - Member state must encourage Design for the Environment (DFE) practices.
    - Vehicle manufacturers and their suppliers must increase the quantity of recycled materials in their products.
    - Vehicle manufacturers and their suppliers must code components and materials to facilitate product identification for material reuse and recovery.
    - Producers must provide dismantling information for every vehicle they build.
    - Producers and member states must report on ELV management and product design measures that enhance reuse and recycling.
    - ELV management systems must be upgraded in accordance with more stringent environmental standards that call for:
        - Registration of collection and treatment facilities
        - Improvements in treatment facility design
        - Removal of fluids, hazardous materials and recyclable materials from ELVs before shredding.

Thus, under the ELV Directive, manufacturers are responsible for designing new vehicles that meet minimum recyclability requirements and for informing dismantlers of proper disassembly procedures (for both new and existing models), while dismantlers are responsible for obtaining certification and for recovering materials in an environmentally sound manner. Vehicle manufacturers (as opposed to consumers) are held responsible for ensuring the cost-free disposal of ELVs.

In addition to the above ELV Directive, it should be noted that, unlike in the US, ASR is usually considered a hazardous waste in Europe [Ecology Center et al., 2001].

5.2 THE US

Scrap vehicle recycling has received much less regulatory interest in the US than in Europe. Only one piece of legislation has ever been introduced on a national level specifically targeting ELV management: the Automobile Recycling Study Act of 1991 (HR 3369). The proposed legislation would have required the US Environmental Protection Agency (USEPA), in consultation with the Secretaries of Transportation and Commerce, to study the potential for increased automobile recycling; at a minimum the study would [Ecology Center et al., 2001]:

- Identify major obstacles to increased recycling of auto components and develop new ways to overcome those obstacles.
- Define methods for incorporating recyclablity into the planning, design and manufacturing of new autos.
- Identify the toxic and non-recyclable material used in autos and possible substitutes for those materials.
- Study the feasibility of establishing design standards for autos that would results in a gradual phase out of hazardous and non-recyclable materials used in autos.
- Examine methods for creating more recyclable plastics for use in autos.

The bill was refereed to the House Committee on Energy and Commerce, but does not appear to have ever been referred out of that committee [Ecology Center et al., 2001].

Instead, ELV management activities have been impacted mainly from national legislation addressing solid and hazardous waste disposal practices, namely:

- Banning the disposal of free liquids in landfills, leading to the practice of collection of all vehicle fluids for subsequent recycling.
- Banning the disposal of lead-acid batteries in landfills, leading to the practice of collection for subsequent recycling.
- Applicable recycling regulations that govern management of vehicle fluids and batteries.

Other significant legislative/policy issues regarding ELV management in the US include:

- California's classification of ASR as a hazardous waste.
- Certain other states imposing pretreatment and/or special management requirements regarding ASR disposal in landfills.
- State-level landfill restrictions on mercury-containing devices (such as auto convenience lighting switches).
- State-level interest in scrap tire management, namely [RMA, 2001c]:
    - 48 states have scrap tire legislation/regulations

  - 33 states ban whole tires from landfills; 12 states ban all tires from landfills; 5 states have no landfill restrictions at all; 7 states allow monofills (dedicated landfills).
  - 40 states have a scrap tire disposal fee program, with such programs being currently active in 35 of those states; 10 states have no program at all. Most often, a fee – ranging from $0.25 to $2.00 per tire – is collected by the tire dealer at the time of sale of a new tire.

- National and state-level regulations and policy regarding burning of scrap tires for energy recovery purposes.
- Imposition of national storm water runoff management regulations on dismantling operations (implemented on a state-specific basis).

Looking to the future:

- On a short-term basis, the focus will likely be on management/disposal of mercury-containing devices, an issue being actively pursued by several public interest groups. This issue is oulined in Chapter 7.
- On a long-term basis, given the European initiatives, combined with the fact that vehicular waste streams are becoming a global concern, the stage may be set for North American regulations on ELV recycling. However, rather than following the European model, it is more likely that the US, through the US Environmental Protection Agency (USEPA) or individual state-led initiatives, would issue regulations restricting landfill disposal of ASR, thereby creating an immediate incentive to investigate and implement alternative means of dealing with ASR.

6. KEY PLAYERS IN ELV MANAGEMENT

In this chapter, a brief introduction is provided to identified specific "key players" involved in ELV management activities, including:

- Dismantlers, shredders, and nonferrous processors
- Auto manufacturers
- Technical and trade organizations
- The US Council for Automotive Research (USCAR)

6.1 DISMANTLERS, SHREDDERS, AND NONFERROUS PROCESSORS

6.1.1 Dismantlers

As discussed in Chapter 2, there appears to be approximately 6000 to 7000 dismantlers in the US, broken down as follows:

- 80% traditional salvage/scrap yards: Typified by traditional "U-Pull-It"- and/or "mom and pop"-type businesses, these are low-tech operations that essentially store ELVs while parts are gradually removed and sold. They operate on a low volume basis with slow turnover and accept most vehicles.
- 20% high-value parts dismantlers: Retail/wholesale businesses that remove and inventory useful, high-value parts (e.g., starters, alternators) for resale. They operate on a high volume, quick turnover basis, targeting late-model vehicles and high-value parts.

Dismantlers strongly tend to be small businesses - 86% of US dismantlers employee 10 or fewer people [ARA, 2001].

The national trade association representing dismantlers is the American Recyclers Association (ARA). The ARA claims nearly 2,000 direct and associate members as well as 3,500 other companies through 50 affiliated chapters worldwide. They offer a two-tier facility certification program:

- **Certified Automotive Recyclers (CAR) Program:** Initial certification based on general business standards, as well as adherence to current environmental and safety requirements.
- **CAR Gold Seal Program:** Advanced certification focused on customer service/ satisfaction and written product warranties.

The initial CAR certification process consists of the facility submitting: 1) a general application form, 2) a three part checklist certification form (covering general business, environmental issues, and safety issues), and 3) a VHS videotape, recorded according to a specified standard script, showing areas/items corresponding to items listed on the checklist certification form (i.e., for verification purposes).

Per the ARA's website listing, however, only 200 facilities are fully certified under the basic CAR program, with another 22 facilities being partially certified (of those 222 certified facilities, 209 are in the US, 9 in Canada, 3 are in Australia, and 1 is in the UK). The 209 CAR-certified companies in the US represents less than 4% of the 6000 to 7000 estimated dismantlers present, and is only a small fraction – approximately 10% - of ARA member companies.

Indeed, the true influence of the ARA seems suspect. From an op-ed published on the American Recycler Newspaper website [Wiesner, 2001], it was noted that:

- Auto dismantlers/ recyclers are small mom-and-pop shops, organized at best on a state level.
- The ARA is supposed to represent all, but is not well thought of by many.

6.1.2 Shredders

There are approximately 200 shredding facilities in North America, 182 in the US and 22 in Canada [AISI, 1992]. In the US, shredders are located primarily in heavily populated states, largely east of Mississippi River.

There is no known trade association representing them.

6.1.3 Nonferrous Processors

Data on this segment of the ELV management industry was not found. A major (if not the major) player is Huron Valley Steel Corporation (HVSC, located in Belleville, Michigan), which processes about 1 million pounds of mixed metals daily (about 65% of all the nonferrous shredder material generated in the eastern US). Reportedly, most nonferrous shredder wastes generated east of Colorado are shipped to HVSC [Ecology Center et al., 2001].

6.2 AUTO MANUFACTURERS

While auto manufacturers do not generally become involved directly in ELV management activities in the US (although Ford is beginning to – see below), they obviously have tremendous influence and impact on the industry through the design and construction of their products.

In terms of the "Big 3" US automakers, most of their efforts and interest in ELV management is focused through the US Council for Automotive Research (USCAR), as further detailed in the next section.

From a review of key automakers websites (Ford, Daimler-Chrysler, GM, Toyota, and Honda), the following pertinent information was noted:

Ford (at www.ford.com, under "Environmental Initiatives"):

- Has purchased more than 25 vehicle-recycling operations, with more purchases expected. As Ford acquires the facilities, it plans to bring them up to a common standard and work with

dealers and affiliated repair facilities to develop them as a source of recovered parts and materials.
- Has an Experimental Dismantling Center in Germany, with the information obtained ultimately provided to Ford-licensed dismantlers.
- Was reportedly the first to issue worldwide vehicle recycling guidelines (design for disassembly and use of recycled/ recyclable materials in design) to its suppliers and engineers.
- Maintains a Recycling Action Team ("RAT Patrol") that, since the early 1990s, has identified more than 24 component applications for post-consumer materials (including ELVs) that have been used on vehicles manufactured in North America.

Daimler-Chrysler (at www.daimlerchrysler.com under "Environmental Report 1999"):
- Has established the following pertinent Corporate goals:
    1. Increase the recyclability rate of all new passenger cars and commercial vehicle models to 95% by 2005; to 90% for carryover models, again by 2005.
    2. Reduce the number of different materials employed by 40% by 2015.
    3. Increase the recycled content in Chrysler, Plymouth, Dodge, and Jeep cars by 1/3 by 2002.

General Motors (at www.gm.com under "Environment"):
- Highlights of the 2000 model year full-size SUVs include:
    1. Up to 200,000 pounds of Saturn fender scrap are recycled into wheel cap assemblies.
    2. Over 2,750 tons of recycled fabrics from the textile industry are used for floor insulation per model year.
    3. Radiator side air baffles are made from 56,000 recycled tires per model year.

Toyota (at www.toyota.com under "Environmental Committment"):
- Produces vehicles that are now 85 percent recyclable.
- Entered into a cooperative agreement with Volkswagen in 1998 involving:
    1. Exchanging information pertaining to recycling-related technologies and trends regarding end-of-life vehicles
    2. Cooperating in areas including the study of recyclability evaluations and the development of technologies for recycling shredder residue and plastic components
    3. Cooperating in the treatment of end-of-life vehicles and recycling of plastic components in Europe
    4. Cooperating in the recycling of bumpers in Japan

No pertinent information was gleaned from a review of the Honda website.

6.3 TECHNICAL AND TRADE ORGANIZATIONS

Table 6.1 provides a summary of pertinent technical and trade organizations, including a few European-based organizations. The Automotive Recyclers Association was previously discussed in Section 6.1.1, while the US Council for Automotive Research is discussed in more detail in the next section.

Table 6.1 Pertinent Technical and Trade Organizations (page 1 of 2)

Organization	Description
US Council for Automotive Research (USCAR) (includes Vehicle Recycling Partnership and Auto Materials Partnership) (www.uscar.org)	Shared research center for the "Big 3" US automakers, working on technological and environmental issues. Also coordinates the automakers interaction with federal government researchers via the Partnership for a New Generation of Vehicles (PNGV), a program established to develop technologies for a new generation of vehicles. With respect to ELV management, two key research consortiums under USCAR are the Vehicle Recycling Partnership (VRP) and the Automotive Materials Partnership (AMP).
Society of Automotive Engineers (SAE) (www.sae.org)	Technical engineering society advancing self-propelled vehicle use on land, sea, air and space. Source for a multitude of technical papers on the full range of auto issues, including environmental and recycling issues. Conducts an annual conference (World Congress), along with an annual Environmental Sustainability Conference. Operates the Environmental Sustainability Standing Committee.
Automobile Recyclers Association (ARA) (www.autorecyc.org)	Trade association serving the auto recycling industry in 18 countries internationally. Services 2,000 member companies through direct membership and 3,000+ other companies through 52 affiliated chapters.
Steel Recycling Institute (SRI) (www.recycle-steel.org)	Trade association that promotes and sustains the recycling of all steel products. A unit of the American Iron and Steel Institute (AISI), SRI has 19 member companies.
Aluminum Association (www.aluminum.org)	Trade association for producers of primary and secondary aluminum and semi-fabricated products. Its 50+ member companies operate 200 plants in 27 states.
Auto Aluminum Alliance (www.autoaluminum.org)	Partnership focused on coordinated technical research between the Aluminum Association and USCAR-AMP
American Plastics Council (APC) (www.ameriplasticscouncil.org) see also APC's Auto Learning Center (www.plastics-car.org)	Trade association with 25 member companies, 18 of which are part of APC's Automotive Group (none are automakers). APC operates the Automotive Learning Center, a conference and information center in Troy, MI "committed to helping engineers explore new ways of thinking about plastics to enhance automotive performance." Frequent collaborator with USCAR.

Table 6.1 Pertinent Technical and Trade Organizations (page 2 of 2)

Organization	Description
International Tire & Rubber Association (ITRA) (www.itra.com) (operates Tire and Rubber Recycling Advisory Council)	Trade association representing the tire, rubber, transportation and recycling industries. Conducts an annual World Expo. Operates the Tire and Rubber Recycling Advisory Council whose mission is to "ensure the long-term viability of tire and rubber recycling worldwide."
Rubber Manufacturers Association (RMA) (www.rma.org) (operates Scrap Tire Management Council - STMC)	National trade association for the finished rubber products industry, representing 120+ member companies. Comprised of two divisions – Tires and General Products. Operates the Scrap Tire Management Council, which promotes scrap tires as a valuable commodity.
Battery Council International (BCI) (www.batterycouncil.org)	Trade association representing the international lead-acid battery industry with 175+ members worldwide
Consortium for Automotive Recycling and Disposal (CARE) (U.K.) (www.caregroup.org.uk)	Collaborative project involving 16 main UK motor vehicle manufacturers/importers (accounting for 90+% market share) and 30+ vehicle dismantlers. It's objective is to research and technically/ economically prove materials re-use and recycling processes aimed at reducing the amount of scrapped vehicle waste going to landfill. Aimed at meeting the requirements of the European Union's directive on ELV's.
Automotive Consortium on Recycling and Disposal (ACORD) – part of Society of Motor Manufacturers and Traders (SMMT) (www.smmt.co.uk)	ACORD is driven by the ACORD agreement, a volunteer agreement signed by various trade organizations involved in the ELV management in the U.K., committing to improving ELV material recovery figures. Divided into 3 groups: Policy Coordination, Vehicles Manufacturers, and Component Manufacturers. SMMT is the trade organization for the motor industry in the U.K.
European Thematic Network – Plastics In ELV (ETN) (www.plastics-in-elv.org)	Supported by the European Commission within its Thematic Network, this consortium is comprised of 40+ partners (auto manufacturers, dismantlers, shredders, recyclers, resin producers and molders, and research institutions). Acts as an information source. Divided into 3 working groups: Dismantling, Material Recycling and Shredder Residue Treatment/Use.
Association of Plastics Manufacturers in Europe (APME) (www.apme.org)	Trade association of plastic manufacturers in Europe, representing 40+ member companies accounting for 90+% of Western Europe's polymer production capacity.

6.4 UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH (USCAR)

The United States Council for Automotive Research (USCAR) was formed in 1992 by the “Big Three” US automakers (Daimler-Chrysler, Ford and General Motors) as a shared research center working on technological and environmental issues. USCAR also coordinates the automobile industry’s interaction with federal government researchers via the Partnership for a New Generation of Vehicles (PNGV), a program established in 1993 to develop technologies for a new generation of vehicles. Under the specific technologies explored by USCAR is “Recycling, Reuse, Recovery,” referring to work being performed to improve auto recycling technology and efficiency. Two specific USCAR technical teams are involved in this effort: the Vehicle Recycling Partnership (VRP) and the US Automotive Materials Partnership (USAMP). Each of these teams is addressed separately below.

6.4.1 Vehicle Recycling Partnership (VRP)

The Vehicle Recycling Partnership (VRP), founded in 1991, has a stated mission (per their website at www.uscar.org/consortia/con-vrp.htm) of:

> “Identifying and pursuing opportunities for joint research and development efforts pertaining to recycling, re-use and disposal of motor vehicles and vehicle components…(and) also will promote the increased use of recyclable and recycled materials in motor vehicle design.”

Specific goals of the VRP are to (per their website at www.uscar.org/consortia/con-vrp.htm):

- Reduce the total environmental impact of vehicle disposal.
- Increase the efficiency of the disassembly of components and materials to enhance vehicle recyclability.
- Develop material selection and design guidelines.
- Promote socially responsible and economically achievable solutions to vehicle disposal.

As the VRP has evolved, its work has focused on three main areas [Orr, 2000]:

- Development of “design for recyclability” guidelines and recyclability calculation methods.
- Reclamation of material from shredder residue.
- Disassembly of components in support of material processing.

Early studies conducted by the VRP included operating a center (the Vehicle Recycling Development Center; opened in 1994, closed in 1999) where up to 500 vehicles a year were dismantled to develop much of the basic methodology for separating the components into their basic materials. In addition, a fluid removal process was developed that reportedly halves the time required to remove fluids from a vehicle – from 45 minutes to 22 minutes – while also leaving less residual fluids in the vehicle and, perhaps most importantly, segregates the different fluids removed. Collaborators in VRP projects include the Automotive Recyclers Association (ARA), the American Plastics Council (APC), the Automobile Aluminum Alliance, the Institute for Scrap Recycling Industries (ISRI) and Argonne National Laboratory. (USCAR, 1998b)

In early 2000, the VRP announced it was realigning its research direction to address the recyclability of emerging materials and powertrain technologies such as advanced composites, batteries and fuel cells (USCAR, 2000a). This realignment was done in recognition that future vehicles will use many new, more exotic materials and different types of powertrains that rely more on electrical power than internal combustion engines. Thus, it was felt that to maintain current vehicle recyclability levels and achieve the future goals of USCAR and PNGV, the VRP needed to address the recyclability of emerging technologies.

As part of this strategic realignment, the VRP identified the following major programs for development and future implementation (USCAR, 2000a):

- **End of Life Assessments**: Assessing advanced vehicle construction and propulsion technologies to determine their end-of-life recyclability potential in support of the PNGV.
- **USAMP/VRP Alignment:** Because future recycling projects are anticipated to be larger, more complicated and require many more partners to execute successfully, the VRP felt that it should seek to join the USAMP while still maintaining an independent partnership agreement, mission and budget.
- **Life Cycle Research and Material Development**: VRP's mission was expanded to include life cycle research and material development. This expansion includes examining "materials of concern" such as hexavalent chrome to determine what recyclable materials are available that can perform the same functions (Current hexavalent chrome applications include corrosion protection and decorative finishing).
- **New Fastener Technologies**: Seeking to develop new fastener concepts that will make it easier to dismantle future vehicles at their end of life.
- **Reassessment of Glass, Fuel Tanks and Elastomers**: Recent studies have indicated there are varying degrees of cost effectiveness for recycling glass, fuel tanks and elastomers. As a result, the VRP feels that the technologies for recycling these materials and components need to be reexamined to determine current recycling economics and their potential for the future.
- **Develop Uses for Shredded Material**: Develop useful applications for reusing the materials left in the automobile shredder residue once all the recyclable elements have been extracted (froth technology, for example, is being developed to extract useable plastic from ASR).

6.4.2 US Automotive Materials Partnership (USAMP)

The US Automotive Materials Partnership (USAMP), founded in 1993, has a stated mission of "conducting vehicle-oriented research and development in materials and materials processing." In terms of "recycling, reuse, recovery" efforts, USAMP led a 4-year effort to complete a Life Cycle Inventory of a generic car. A key finding from this effort was that the end-of-life phase contributed 7% of the total life cycle solid waste, primarily as automotive shredder residue [Sullivan et al, 1998].

7 KEY AREAS/ISSUES IN ELV MANAGEMENT

The following six key areas/issues in ELV management were identified from a review of the literature:

1. Plastics Recycling
2. Automotive Glass Mangement
3. Scrap Tire Management
4. Mercury-Containing Switches
5. Aluminum Scrap Sorting
6. Design for Recyclability

The first three issues deal with addressing solid waste streams generated as a result of ELV activities, while mercury-containing switches represent a toxic substance management issue. Aluminum scrap sorting is seeking to increase the efficiency of aluminum recovery, an emerging issue as more and more aluminum is substituted for steel in new vehicle designs. Finally, Design for Recyclability (DfE) seeks to enhance overall ELV recycling efforts and economies via "smart design" techniques. Each issue is briefly outlined below.

7.1 PLASTICS RECYCLING

Concern has been raised over the continued disposal of ASR generated from ELV processing. In addressing that issue, the primary focus has been on plastics, since they comprise the biggest fraction of ASR (48% according to Table 3.1). There has been additional concern expressed over the increased use of plastics in newer car designs [Orr, 2000], but that concern appears somewhat overstated – since 1985, the absolute amount of plastic in the average family vehicle has increased by only 15%, with the bulk of that increase having occurred between 1985 and 1992 – since then, the absolute amount of plastics has increased by less than 3% [AMM, 2000; TEDB, 2000 – Table 7.13]. Nonetheless, plastics remain a key management issue.

In response, a significant amount of work has been performed evaluating the viability of recycling plastics obtained from ELVs. However, recycling of automotive plastics raise complex issues, both technically and economically, including:

- Technical barriers
- Quality, quantity, and consistency concerns
- Competition with virgin materials

As a result, currently virtually all plastics from ELVs are disposed of as ASR in landfills, although scrap battery casings and some salvaged plastic bumpers are recovered for producing a select few minor automotive parts (e.g., splash shields, taillight housings, guide brackets, bumper reinforcements).

Leading the efforts into investigating ELV-derived plastics recycling has been USCAR's Vehicle Recycling Partnership (VRP). Building upon past work that studied specific vehicle parts to discover which materials could be removed and recycled, the VPR launched its' "US Field Trial for Plastics Recovery" in 1998. The US Field Trial is designed to determine the best way to remove and recycle different plastic parts (such as interior trim and engine components), the cost of recycling those parts, and how those parts should be transported (USCAR, 1999a). The VRP anticipates that this effort could lead to 50 additional scrap vehicle pounds being recovered, which would decrease ELV solid waste by about 7% overall.

7.2 AUTOMOTIVE GLASS MANAGEMENT

Currently, glass from ELVs is either selectively recovered by dismantlers as replacement parts for repairing working vehicles (a relatively rare occurrence) or ends up being disposed of in a landfill (for transportation to a shredder facility, ELVs are crushed, resulting in crushed glass, a portion of which is disposed of by the dismantler, while the rest travels with the hulks to the shredder and ends up in ASR).

Key barriers to recovery/recycling of automotive glass from ELV include:

- Collection Issues
- Technical Recycling Issues
- Recycling-Market Issues

In the US, the Vehicle Recycling Partnership sponsored a “Windshield Recycling Study,” a field-based test conducted in the Detroit metro area to assess the economic feasibility of recycling automotive windshields (USCAR, 1999b). The goal of the project was to recycle the glass generated at the glass repair shop at the same or lower cost than current disposal costs. However, it was found that collection and transportation costs were a strong economic deterrent – it was determined that to be economically feasible, more than three tons of material per hour would have to be picked up on a collection route. This would require many repair shops and vehicle dismantlers in a particular area to participate to make such recycling cost-effective.

The study did note the potential for the process to become more economically feasible as demand grows for the plastic laminates (polyvinyl butyral, PVB) used in windshields. Currently, recycled PVB is used in floor tile and plastic pallets. The challenge noted in this area is obtaining recovered PVB in a pure enough form to give it a significant value. However, the study notes that there is work being done (a separate VRP project) to develop methods of separating the plastics and glass in a windshield more completely, yielding a purer recovered PVB stream that would have a significantly higher monetary value.

7.3 SCRAP TIRE MANAGEMENT

In terms of ultimate disposition, the Scrap Tire Management Council (STMC) estimates that, at the end of 1998 [STMC, 1999]:

- Approximately 2/3 of generated scrap tires were "recovered" (used as a fuel, recycled, or reused), with nearly 2/3 of those "recovered" specifically used as a fuel in variety of industrial facilities (scrap tire rubber having a heating value of 15,000 Btu/lb, compared to 13,000 Btu/lb for coal).
- At least 12% of generated scrap tires were landfilled.
- Disposition of the remaining 22% (60 million scrap tires) is unknown (although they likely have been stockpiled, as historically has been practiced).

Assuming those figures hold when looking just at ELV-derived scrap tires (estimated to total 54 million per year – 13.5 million ELVs times 4 scrap tires each), this translates into 36 million ELV tires being recovered, at least 6.5 million being landfilled, and the rest (11.5 million) assumed stockpiled.

A significant complicating factor in dealing with the scrap tire generation problem is the continued existence of significant scrap tire stockpiles across the nation. At the end of 1998, the overall national stockpile was estimated to be around 500 million scrap tires (representing just under 2 years worth of scrap tires at the current generation rate of 270 million per year) [STMC, 1999]. This figure is down from 700-800 million estimated in 1994, but is obviously still a significant issue, especially with the frequency of occurrence of scrap tire stockpile fires (59 such fires occurred from 1996-98) and their associated burdens on the environment [STMC, 1999].

7.4 MERCURY-CONTAINING SWITCHES

Mercury, a toxic heavy metal, has been (and continues to be) used in a select few vehicle components. Automotive applications of mercury or mercury compounds that have been confirmed in current North American vehicles include various switches (for convenience lighting, antilock-braking systems, and active ride control systems), high intensity discharge (HID) headlamps, and other fluorescent lamps (for background lighting, speedometers, etc.). In addition, testing of various auto components has revealed the presence of mercury. Table 7.1 provides known past or present mercury use and/or presence in vehicles along with the estimated quantity of mercury present per application.

Table 7.1 Known Past/Present Mercury Use and/or Presence in Vehicles

Mercury Containing Products/Components	Uses	Estimated Quantity (per application)
SWITCHES		
Light switches	Activates convenience lights in trunk and under the hood	0.8 g
Antilock brake system (ABS) switches	Detects deceleration, taking the drive system out during slipping events.	3 g (3-1g switches)
Ride control system switches	Act as ride leveling sensors	2 g (2-1g switches)
LAMPS		
High intensity discharge (HID) headlamps	Part of illuminant (along with sodium, scandium, thorium oxide, and sometimes thallium)	0.001 to 0.002 g (2 headlamps)
Other fluorescent lamps	Provides background lighting.	0.001 to 0.040 g
OTHER COMPONENTS		
Paint, seatbelts, headliners, carpeting, seat foam, steering wheels, dashboards, body panels, bumpers	Unknown use of mercury – presence determined from testing of indicated components.	0.03 to 2.3 mg/kg (part-specific)

Compiled from: [Ecology Center et al., 2001]

Despite the relatively minor amount present (on the order a few grams per vehicle on average), the highly toxic and persistent nature of mercury causes this use to be a concern. In particular, mercury [Environmental Defense, 2001]:

- Can cause severe human health effects, with young children most affected.
- Can cause mental retardation, cerebral palsy, deafness and blindness in extreme exposures.
- Can cause exposed adults to exhibit impaired sensory and cognitive ability, tremors and the inability to walk.
- Remains in the environment for years, dispersing over a wide area.
- Is considered a persistent, bio-accumulative and toxic (PBT) pollutant by the US Environmental Protection Agency.

The main concern raised is the potential for uncontrolled release during ELV management operations, particularly during shredding and during subsequent processing of recovered ferrous scrap at steel smelters, specifically EAF facilities.

A recently released study on mercury in vehicles provided these key findings relevant to ELV activities (present and future) [Ecology Center et al., 2001]:

- Historically, mercury switches accounted for 99.9% of the mercury used in vehicles; this trend continues today.
- On average, 1 mercury switch (containing 0.8 grams of mercury on average) is found in vehicles (although, from a review of study data, it was noted that some vehicles may contain no mercury at all, while others can conceivable contain approximately 4 or more grams of mercury).
- Most switches (estimated at 87% for 1996 vehicles) were for convenience lighting. Nearly all the rest (12% for 1996 vehicles) were for ABS applications.
- While the number of mercury-containing convenience lighting switches has dropped dramatically from the 1996 to 2000 model years (from 12 million to less than 5 million – roughly 0.25 switches per vehicle on average), the number of such switches used in ABS applications has more than doubled in that same time frame (from 1.7 million to at least 4 million – roughly 0.3 switches per vehicle).
- The current US vehicle fleet (estimated at 210 million vehicles):
  - Contains approximately one mercury- containing switch on average containing 0.8 grams of mercury on average.
  - Is estimated to contain overall from 153 to 178 metric tons of mercury.
- The mercury content of ELVs processed in the US – assuming 11 million ELVs processed and from 0.73 to 0.85 grams of mercury present per vehicle – is 8.0 to 9.4 metric tons. (Note that, from Chapter 1, the number of ELVs processed was estimated at 12.5 million – using that figure, the amount of mercury would be 9.1 to 10.8 metric tons).
- A preliminary mass balance taken for a specific shredder indicated that over 50% of mercury present ended up in ASR, 40% in metal scrap and 7.5% emitted to the air. The average mercury content found in the ASR was 1.15 ppm, while 0.20 ppm was found in the metal scrap. (The study notes that these are preliminary results which will be updated in the future.)
- Mercury can also be released at dismantling sites.
- While removal of mercury switches from convenience lighting applications is a fairly simple procedure, very little known recovery actually occurs. Even less likely is recovery of ABS mercury switches.

Thus, two basic management concerns exist:

- Ensuring that existing significant sources of mercury in ELVs (i.e., switches used in convenience lighting and ABS brake systems) are removed prior to shredding operations (preferably before the dismantler crushes the vehicle for transport to the shredder), thus eliminating the main potential for uncontrolled mercury releases to the environment.
- Minimizing/eliminating the use of mercury in new vehicle design.

7.5 ALUMINUM SCRAP SORTING

Currently, most aluminum from scrapped vehicles – everything from low-cost castings to expensive alloys – is shredded and recycled together into foundry casting alloys, which are primary used in auto applications such as transmission housings and engine blocks. With the ever-increasing usage of aluminum as a weight-saving substitute for steel in vehicle design (the absolute amount of aluminum in a typical family vehicle has increased from 97 to 246 pounds from 1977 to 2000 [AMM, 2000]), combined with its relative worth (the increased content in new vehicles puts its scrap value equal to that of steel present), this practice is coming into question.

As a result, the "Aluminum Scrap Sorting Project" was initiated to develop methods for rapid, high-volume sorting of aluminum scrap, both in terms of separating cast aluminum from wrought alloys and in sorting different wrought alloys from each other (USCAR, 2000b; USCAR 2000c). Specifically, the Automobile Aluminum Alliance (which includes USCAR's VRP and USAMP teams as members) is currently working jointly with Huron Valley Steel Corporation on a pilot project demonstration of the following two proprietary technologies (developed by Huron Valley): 1) Color Sorting (based on chemical etching of aluminum alloy particles) and 2) Laser-Induced Breakdown Spectroscopy (a laser pulse hits scrap pieces, causing a plasma light (ionized gas) to be emitted which is analyzed by a spectrometer to precisely identify the piece for sorting purposes. It is estimated that the first commercial sorting center will be able to analysis and sort 100 million pounds of aluminum per year.

7.6 DESIGN FOR RECYCLABILITY

Design-for-Recyclability (DfR) is a product design tool that considers the materials from which a product is manufactured and how these materials are assembled. If applied during a product's conception and carried through to its design, assembly, and ultimately disposal, these criteria can be an effective tool to minimize wastes and maximize the reuse of materials.

Because of its usefulness, all three US automakers have had DfR programs and associated design guidelines in place for many years. In addition, development of DfR guidelines and recyclability calculation methods has been a focus area of USCAR's Vehicle Recycling Partnership (VRP).

General DfR criteria applied to automotive design for end-of-life recyclability include:

1. **Use recyclable materials.**
   Design products using materials that can be recycled and for which materials collection and recycling technologies currently are available and commonly used. Generally, metals are easier to recycle than nonmetals, and thermoplastic resins are more desirable than thermoset plastics. Alternatively, set up an effective materials collection system (e.g., offer to accept used lead-acid batteries when new batteries are purchased).

2. **Use recycled materials.**
   Select materials that contain a high percentage of recycled content, as this supports the recycling process for which a product is being designed. Steel and aluminum are materials that are often recycled.

3. **Reduce the number of different materials used within an assembly.**
   Reduce the number of materials used to manufacture a component or assembly. Reducing the number of materials also simplifies the separation process and supports recycling.

4. **Mark parts for simple material identification.**
   Mark all materials with standard material identification codes. Although this process is most feasible for plastic parts, it can be expanded to metals, composite materials, and coatings currently used in vehicle manufacturing.

5. **Use compatible materials within an assembly.**
   Select materials that do not need to be separated for recycling. Generally, mixtures of dissimilar plastics cannot be recycled. Similarly, nonferrous metals (e.g., aluminum, chromium, or zinc) can contaminate and thus decrease the recyclability of ferrous metals (i.e., iron and steel), and vice versa. Layers of paint or plated metal over a base material also represent contaminants not compatible with recycling. If a coating on metal cannot be removed, the paint or metal plating will be a contaminant that decreases the metal's recyclability and/or the applications for which the recycled metal can be used.

6. **Make it easy to disassemble.**
   Also called Design for Disassembly, this criterion guides a designer away from complicated products and assembly processes. Using snap fits and nut/bolt assembly techniques whenever possible assists in disassembly, as does avoiding adhesives, particularly when bonding two incompatible materials or if the adhesive will contaminate the materials so they cannot be recycled.

To be effective, these criteria must be used as a set, not individually. For example, if recyclable materials (following Criterion 1) are used to manufacture a complex component that cannot be disassembled (not following Criterion 4), the goals of DfR will not be achieved.

Although extremely useful, DfR needs to be practiced within the overall context of life cycle design, rather than just focused on one stage of the life cycle (i.e., just end-of-life); otherwise burdens may just be shifted upstream in the lifecycle, rather than reduced overall. Furthermore, burdens are unevenly spaced over a lifecycle; focusing on one portion that makes a relatively small contribution overall may not be the best use of resources. Table 7.2 provides the results of USAMP's Life Cycle Inventory (LCI) for a generic US family sedan (Sullivan et al., 1998) considering total waste generated. That data indicates total waste generated during the end-of-life is less than 10% of the overall life cycle burden.

Such an LCI analysis can also be performed on a vehicle component basis as well; for instance, Keoleian et al. (1998) investigated fuel tank design, comparing a HDPE versus a steel tank. In that case, while both tank systems generated roughly the same amount of solid waste over the full life cycle, the bulk was generated in the material production phase for the steel system, while the bulk was generated at end-of-life for the HPDE system (reflecting the fact that steel tanks are recycled, while plastic tanks are disposed of al solid waste).

Table 7.2 Total Waste Generated During the Life Cycle of a Generic US Family Sedan

Life Cycle Phase	Total Waste Generated	
	Weight [kg]	% of Total
Materials Production	2554	58%
Mfg. & Assembly	408	9%
Fuel Use	812	19%
Maintenance & Repair	277	6%
End-of-Life	326	8%
TOTAL For Vehicle	4376	100%

Based on USAMP project [Sullivan et al., 1998] as reported by Keoleian [personal communication].

8. CONCLUSIONS

Despite general public perceptions of waste and inefficiency, the ELV management industry in the US today is a relatively efficient process, with 75% of the overall content of an original ELV reclaimed or recycled, including virtually 100% of the iron and steel content. Still, three key issues remain: disposal of scrap tires, potential mercury releases during ELV processing, and disposal of ASR.

In regards to the scrap tire issue, the contribution from ELVs is relatively small (making up about 20% of the total scrap tires produced annually) and one that is currently principally focused on trying to rectify past disposal practices (i.e., stockpiling of scrap tires).

In regard to the mercury release issue, it appears to be a potentially explosive issue in terms of potential mercury contamination at ELV management facilities (particularly at shredder facilities). Such contamination issues, if real, can have potentially enormous financial implications to such operations (i.e., required Superfund-type cleanups).

The last issue, landfill disposal of ASR, is perhaps the most challenging. The focus in attempting to address the issue has been on recycling of plastics, but a host of technical, economic, and logistical/infrastructure challenges must first be met.

In that regard, recent developments have sparked hope that the ASR challenge can be met as well as overall improvements made in the present ELV management system:

- A growing acceptance and institutionalization of Design for Recycling ideas and programs within auto manufacturers, bringing with it the promise of increased efficiency and/or expanded applications (such as recycling plastics).
- The direct involvement of automakers in ELV management (i.e., Ford's initiative to purchase dismantling operations). By bringing such operations "in-house," this leads to direct, market-driven incentives for manufacturers both to design for recyclability and to explore recycling options (such as plastics recycling).
- The growing inherent value of ELVs, both because of the recent trend towards larger vehicle (particularly SUV) production and the increasing use of high-value aluminum (for weight-saving purposes) in vehicle design. Such increased value is likely to attract more interest in the industry (witness Ford's entry into dismantling operations) and should lead to improvements and increased overall efficiency.

Finally, on the legislative front, given the European Union's recent passage of the ELV Directive, increased pressure will fall on the US to legislate ELV management. However, rather than following the European model, it is more likely that the US, through the US Environmental Protection Agency or individual state-led initiatives, would issue regulations restricting landfill disposal of ASR, thereby creating an immediate incentive to investigate and implement alternative means of dealing with ASR. . The European Union guidelines are also influencing US OEMs. Given the global nature of the industry, US manufacturers are setting internal guidelines based on the European targets for reducing the amount of ELV waste sent to landfill.

In the end, however, the EU ELV Directive appears to have opened at least one automaker's eyes as to opportunities ELV management has to offer. Regarding the new EU ELV Directive, Bill Ford, current Chairman of Ford Motor Company, is quoted as saying [Ecology Center et al., 2000]:

> "We see it as an opportunity in the US where we are getting into the recycling business. We're presently considering the European market situation. And there will be major changes. Future transportation may not involve owning a car. Instead, you may own the right to transportation. We will make vehicles and either lease or loan them to you. We'll end up owning a vehicle at the end-of-life and have to dispose of it. We will treat it as a technical nutrient, making it into a car or truck again. We're getting ourselves ready for a day when this is truly a cradle-to-cradle. We're not fighting it, we're embracing it."

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