A Roadmap for Recycling End-of-Life Vehicles of the Future

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About this Roadmap

Automobile manufacturers, suppliers, recyclers, and researchers participated in a workshop on September 6 and 7, 2000 to identify the R&D needed to recycle automotive materials and components that will reach end-of-life status in 2020. Recycling, as defined in this document, is any cost-effective use of automotive materials that would divert these materials from landfill, including re-use and remanufacture of parts and components, materials recovery, chemical/thermochemical conversion (e.g. pyrolysis) and thermal energy recovery. End-of-life vehicles in 2020 are expected to be similar to today's vehicles in terms of material constituency thus the challenges are similar to those the recycling industry faces today. This roadmap highlights the priority R&D and other activities needed to improve recyclability. Recognition and appreciation is extended to the workshop participants who volunteered their time to contribute valuable expertise to this effort.

U.S. Department of Energy's Office of Advanced Automotive Technologies and the Argonne National Laboratory sponsored the workshop and roadmap. Dr. Kenneth Uherka led the effort at Argonne National Laboratory. The workshop was organized and facilitated by Melissa Eichner and Ross Brindle of Energetics, Incorporated. The roadmap was prepared by Melissa Eichner of Energetics, Incorporated.

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Definition of Terms and Acronyms Used in this Roadmap

AA—Aluminum Association. A trade association for U.S. producers of primary aluminum, recyclers, and semi-fabricated aluminum products.

APC—American Plastics Council. A national trade association representing major plastic resin producers and distributors.

ANL—Argonne National Laboratory. A laboratory of the Department of Energy located in Argonne, IL.

APRA—Automotive Parts Rebuilders Association. An association of over 2000 member companies that rebuild automotive related "hard" parts, such as starters, alternatives, clutches, transmissions, brakes, drive shafts.

APME—Association of Plastic Manufacturers in Europe. A trade association representing over 40 companies representing over 90% of Western Europe's polymer production capacity.

ARA —Automotive Recyclers' Association. A trade association that represents about 12,000 auto dismantlers, the companies that typically recycle cars for used parts.

ISRI—Institute of Scrap Recycling Industries. A trade association that represents scrap material recyclers including about 200 shredder operators who recover recyclable metals and materials from obsolete cars.

Hulk. The obsolete car after reusable parts or components have been removed by an auto dismantler for reuse. The hulk is typically flattened for shipment to an auto shredder who shreds the hulk and recovers recyclable materials, predominantly iron, steel, aluminum and other metals.

Recycling. In this document, recycling is defined as any cost-effective use of parts, components or materials from an obsolete car that would otherwise be landfilled, including parts re-use and remanufacturing, materials recovery for reuse in an original application or for use in any other viable application, and materials recovery for thermochemicial conversion to fuels and/or chemicals.

SR—Shredder Residue. The reject material that is landfilled after processing by shredding of scrap (such as hulks from obsolete cars and appliances) for recovery of metals. Typically, shredders process a variety of feed materials to recover materials for recycling, including home appliances, demolition scrap, and industrial scrap in addition to obsolete cars and auto hulks.

SRI—Steel Recycling Institute. A unit of the American Iron & Steel Institute that educates the solid waste management industry, government, business and ultimately the consumer about the economic and environmental benefits of recycling steel. Through its regional offices, SRI works to ensure the continuing development of the steel recycling infrastructure.

VRP—Vehicle Recycling Partnership. An organization formed by General Motors, Ford, and DaimlerChrysler to promote and conduct research to enhance the recycling of obsolete automobiles. The VRP was formed in 1991 and has been conducting research in collaboration with organizations such as the AA, APC, ARA, ISRI, and the federal government through ANL since its inception.

1. Introduction

Automobile recycling[1] is the final productive use of end-of-life vehicles (ELV). The obsolete car has been a valuable source of recycled raw materials and useable parts for repair since cars have been mass produced. Today, cars that reach the end of their useful service life in the United States are profitably processed for materials and parts recovery by an existing recycling infrastructure. That infrastructure includes automotive dismantlers who recover useable parts for repair and reuse, automotive remanufacturers who remanufacture a full range of components including starters, alternators, and engines to replace defective parts, and ultimately the scrap processor who recovers raw materials such as iron, steel, aluminum, and copper from the remaining auto "hulk" after components have been recovered for recycling. Each of these activities contributes to the recycling of obsolete vehicles.

Today, less than 25 weight percent of obsolete cars is not profitably recoverable for recycling and is therefore landfilled. Over the past 10 years, the original equipment manufacturers (OEM)—Ford, GM and DaimlerChrysler—through the Vehicle Recycling Partnership (VRP)[2] and other organizations including the Aluminum Association (AA), American Plastics Council (APC), the Institute of Scrap Recycling Industries (ISRI), the Automotive Recyclers Association (ARA), the Automotive Parts Rebuilders Association (APRA), and the federal government have been working both collaboratively and independently to address technical, institutional, and economic issues that currently limit the recycling of ELV. Progress has been made in understanding some of these issues and technology has been developed that can impact the level of ELV recycling.

The recyclability[3] of ELV is presently limited by the lack of commercially proven technical capabilities to cost-effectively separate, identify, and sort materials and components and by the lack of profitable post-use markets. While nearly 75 weight percent of ELV are currently recycled in some form, the remaining 25 percent is sent to landfills each year. Over the next 20 years, both the number and complexity of ELV are expected to increase, posing significant challenges on the existing recycling infrastructure. The automobile of the future will use significantly greater amounts of lightweight materials (ultralight high-strength steels, aluminum, plastics, composites, etc.) and more sophisticated/complex components. New technology is and will continue to be needed to improve vehicle recyclability. Promising new technology is currently being developed.

The automobile recycling community would like to improve end-of-life vehicle recyclability, which will require them to unify and develop the necessary technology. The automobile recycling community includes the following:

- Automobile companies (i.e., OEM)
- Suppliers of materials and components
- Recycling industries involved in reuse, remanufacturing, and material recovery (i.e., the disassemblers who remove parts along with other materials and components that can be sold for remanufacture and after-market sales; auto body hulk crushers and truckers; and shredding and sorting facilities)

[1] Recycling is defined as products, parts or materials that are cost-effectively diverted from the waste stream and returned to use as a functional part or raw material for the manufacture or assembly of a new product. For the purposes of this document, recycling is defined in its broadest sense and therefore includes thermochemical conversion of materials (e.g. pyrolysis) and energy recovery as well as parts and components re-use and remanufacture and materials recycling.
[2] The Vehicle Recycling Partnership was formed in 1991 by Ford, GM, and DaimlerChrysler to conduct non-competitive research to improve automotive materials recycling.
[3] Recyclability is defined as the process of dismantling and/or separation of products or parts or materials with the goal of return (i.e., to use as a functional part or as a raw material, including chemical and/or energy feedstock, for manufacture or utilization in another product).

- Industries that use recycled materials (end markets)
- Researchers at national laboratories, universities, and institutes who can help solve the technical challenges

In response to the challenges associated with automobile recycling, the Department of Energy's Office of Advanced Automobile Technologies (OAAT) and Argonne National Laboratory (ANL) sponsored a workshop on September 6 and 7, 2000, at ANL in Chicago, Illinois. This event brought together 24 experts representing OEMs, material suppliers, recyclers, and researchers. In two facilitated groups, participants reached consensus on the goals, challenges, and critical needs for improving automobile recyclability. The output from the workshop was analyzed and incorporated into this document. An overview of the workshop, agenda, a list of participants, and the working group results are presented in the Appendix.

This roadmap presents:

- ➤ Challenges impacting automobile recycling in 2020
- ➤ Targets for major steps in the vehicle recycling process to improve recyclability
- ➤ Strategies for increasing recyclability
- ➤ Priority R&D and non-R&D needs to improve recyclability
- ➤ Next steps for implementing roadmap priorities

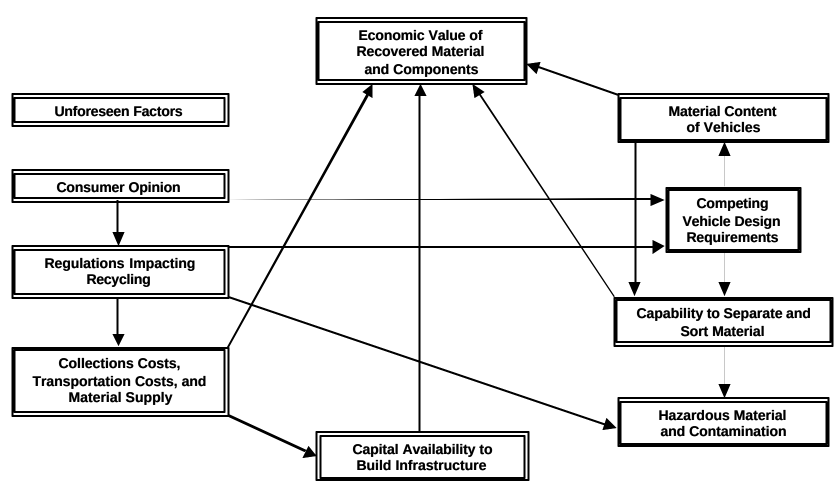
2. Challenges Impacting Recyclability in 2020

Numerous challenges exist that impact automobile recycling. Our success at addressing these technical, economic, institutional, and social challenges over the next two decades will impact the viability of ELV recycling in 2020. The top factors affecting vehicle recycling are listed in Exhibit 1. The ELV material constituency in 2020 (as a percent of vehicle weight) is expected to be similar to today's vehicles, as indicated in Section 3. This implies that the challenges and key factors that will affect ELV recycling for the next 20 years are similar to the key factors and challenges that the recycling industry faces today. The relationship among the top factors is presented in Exhibit 2. The success of material and component recovery depends on these complex interrelationships. Key issues associated with the top factors affecting vehicle recycling are highlighted below. Significant literature on automobile recycling technology exists, with recent data provided by APC, APME, ANL, and the VRP.

Exhibit 1.
Top Factors Affecting Automobile Recycling For the Next 20 Years

- Economic Value of Recovered Material and Components
- Material Content of Vehicles
- Competing Vehicle Design Requirements
- Capability to Separate and Sort Material
- Hazardous Material and Contamination
- Capital Availability to Build Infrastructure
- Collection Costs, Transportation Costs, and Material Supply
- Regulations Impacting Recycling
- Consumer Opinion
- Unforeseen Factors

Exhibit 2.
Major Interrelationships Among the Top Factors



➤ Economic Value of Recovered Material and Components

The economic value of recovered materials and components will shape the future recycling business. Markets for most non-metallic recovered materials do not exist today. Development of viable markets for recovered materials and components is critical to achieving any significant increase in the current level of ELV recycling. Without clear market drivers, creating the market pull needed to significantly improve recyclability will be impossible.

The types of materials used in vehicles determine recovery options. Even small changes in the vehicle material content will have a significant impact on the economics of the recycling stream. For example, the trend towards more plastics and composites with less metal in vehicles means that the hulk may be less valuable at end-of-life.

Low-cost raw material from nature competes with recycled material. Today, except for steel, iron, and non-ferrous metals, the cost of collecting, sorting, recovering and/or chemically converting some recyclable materials such as plastics exceeds the cost of virgin material. New technology is needed to make recovery cost-effective. For some materials, current technology does not produce recycled materials with the same characteristics and performance levels as new materials. Recent technology advancements are improving recyclability. For example, chemical recycling of some polymers can now produce plastics with properties equivalent to virgin resins. The high cost and scarcity of specialty materials used in advanced vehicles will require raw material management and this will encourage recyclability to offset the virgin material.

Industry standards for material performance do not exist across companies. These standards are needed to create test protocols to determine if recovered materials meet specifications. Establishing specifications is expensive, and developing cost-effective testing and sampling techniques will be difficult. Nevertheless, standards and tests are necessary to increase the amount of recycled material in vehicles and other applications. For example, increasing the use of recycled plastics in vehicles will require major testing and development costs.

Other barriers include the following: design for part reuse and remanufacturing is not emphasized by OEMs, and recoverability of parts is limited due to the lack of part product information and technology available to reprocess the parts; some non-metallic, composites, and commingled incompatible materials do not have secondary use markets (Alternative uses for materials may exist but recyclers are not aware of the opportunities.). End-market consumption of reprocessed material and parts will determine the economic viability of the industry. Their value as "green" products is not expected to create significant market impact. Changes in original material properties over time, while in original use or through multiple recycled uses, also affects the continuing recyclability of materials. Ultimately, some materials will reach a point at which they have no post-use value due to chemical and physical property changes.

➤ Material Content of Vehicles

The diversity and complexity of the materials used in vehicles make sorting bulk material and shredder residue (SR) challenging. Although OEMs have made efforts to decrease the absolute number of different materials used in cars, the trend is toward increased use of materials that currently have limited recyclability (e.g., plastics, composites) relative to traditional metals. This trend is driven by the need to meet increasing performance specifications including fuel economy and safety at lowest cost. As the number of incompatible materials increases, separating and sorting materials is more costly. Lot-to-lot material property variability increases, which impacts the success of an individual recycling stream.

An additional problem is that information on the types of material in vehicles is not available. This information could facilitate bulk material and post-sort recovery, along with material labeling such as resin typing on plastics.

➤ Competing Vehicle Design Requirements

When producing vehicles, vehicle designers must balance consumer demands such as safety, cost, and performance with regulatory requirements. Although the OEMs are committed to using recycled materials in their vehicles, design for reuse, remanufacturing, disassembly, and material recycling is not emphasized. Increasing pressure is placed on OEMs to provide warrantees of greater length and make vehicles less costly to repair. Intelligent disassembly is not expected to be available for the mass fleet. The environmental impact from competing design requirements is not well understood.

➤ Capability to Separate and Sort Material

The lack of technology capability to separate and sort non-metallic material could limit recycling in 2020. The capability to economically recycle today's SR has not been proven on a large scale. Considerable research has been conducted by the VRP, APC, and ANL to develop advanced technology to separate SR into recyclable constituents. While the technology developed at various organizations shows promise, full-scale commercial operation has yet to be demonstrated. The technology requirements to recycle more complex materials such as those used in hybrids and fuel cell vehicles have not been defined. Historically, the dismantling industry has been very creative in recycling vehicles they have never seen prior to entering the market. New processes such as marking plastic parts by resin type will facilitate sorting.

Strong material fastening methods are required to withstand vehicle demands. In some cases, joining techniques complicate or preclude cost-effective recycling. Cost-effective, accurate material identification and sorting techniques for non-metallics and commingled metallics do not exist. As a result, pieces of mixed material must be sorted by hand or else they will contaminate the recovery stream. The purification and cleaning technologies for metals and plastics are inadequate, resulting in contamination of recovered materials. As a result, post-recycling material purity requirements for many applications cannot be achieved.

Other barriers include the following: R&D costs to create new processes are high, and testing and development will take time; there is a lack of investment capital to launch technology R&D; there is also a lack of awareness of the technology that is available and what it can yield in terms of value (e.g., alternative product stream technology); there is no organized effort to foster technology transfer or to track overseas technology development; and there is limited capability to demonstrate an improved on-going recycling operation and new technology, which is needed to convince recyclers of opportunities.

➤ Hazardous Material and Contamination

Contamination of the shredder residual with toxic materials such as polychlorinated biphenyl (PCB) and heavy metals from electronic parts and other sources poses a significant challenge for material recovery. Unless they are prevented or eliminated up stream, these hazardous materials must be eliminated, managed, and processed by recyclers. Recycling technology for some contaminated parts such as plastic gasoline tanks do not exist. Contaminated SR entering landfills and incineration are restricted by regulations that vary by region and are subject to interpretation. Environmental concerns (e.g., dioxins) and capital costs necessary to make energy recovery facilities environmentally acceptable may limit energy recovery.

➤ **Capital Availability to Build Infrastructure**

Expanding vehicle recyclability will depend on the widespread use of yet-to-be-developed recycling technology. Today, a lack of financial return for recyclers has led to technology inertia for facilities and tooling (F&T). There are limited incentives to use new technology, especially considering the weak markets for some recyclable materials. Existing infrastructure will need to be expanded significantly to increase material and product recovery and adapted as different technologies enter the ELV stream, such as fuel cells and hybrids. These new technologies pose significant challenges for the recycling infrastructure. Opportunities for entrepreneurs will need to be fostered and capital raised to build the infrastructure. Innovative industry interfaces such as mobile shredders or granulators for plastics are needed to encourage a viable industry.

➤ **Collection Costs, Transportation Costs, and Material Supply**

An economically viable recycling industry will depend on cost-effective collection, transportation, and sufficient material supply. Parts and material must be collected, transported and consolidated. Currently, there is an insufficient quantity of materials to provide consistent feed streams and recycling infrastructure is not available in some regions. Reverse logistics (e.g., collection, participation), transportation economy, and landfill capacity will impact the ability to change the ratio between scrap and waste.

➤ **Regulations Impacting Recycling**

In the United States, recycling of ELVs is market driven. In Europe and Japan, a regulatory approach to eliminate most landfilling and encourage recycling is being used with recycling standards varying by region. These approaches are costly and their success is debated. There is concern that the strategies used abroad may influence U.S. regulators or public opinion, leading to less than optimal choices for the U.S. recycling industry. The recycling market is not well understood today and metrics of recycling performance do not exist (e.g., what is the objective, how to measure recyclability such as energy savings and life-cycle cost). As good corporate citizens, most OEMs are promoting recycling to avoid landfilling and a costly regulatory approach to recycling. As international companies, OEMs are challenged with meeting the requirements of each country.

Federal regulations and state and local regulations that vary from region to region significantly impact the recycling process. These regulations impact fluid recovery by dissemblers, emissions from incineration that prevent energy recovery, and allowable material content in landfills, for example. The lack of coordination among these regulations and the interrelated impact of requirements (safety, environmental, others) present challenges as well. There is increasing pressure to find alternative disposal due to decreasing landfill space. Competing environmental goals could influence the trend towards recycling, such as opposition to mining raw materials that recycled materials could displace.

➤ **Consumer Opinion**

Consumer opinion and concern for recycling could become significant drivers. The public has broad concerns about the environmental impact of vehicles and is concerned over types of materials ending up in landfills and the impact of energy recovery through incineration. The public likes "green" products. Nevertheless, there tends to be a perception that reused, remanufactured, and products with a "recycled content" are of lesser value or quality than new parts/products. Society as consumers and citizens will determine what is acceptable and influence future regulations.

➤ Unforeseen Factors

Unforeseen technical, economic, and social factors could influence vehicle material content and the future of recycling. For example, fuel price increases impact trends toward more energy efficient vehicles and increase the expected vehicle life. A trend toward increased leasing versus vehicle ownership could impact product and material recovery and impact recycling activities. A significant development in energy storage technology may change vehicle technologies. Major changes outside the automotive industry could modify some of the drivers for recycling such as if methane hydrates become feasible.

3. Strawman Goal and Targets for End-of-Life Vehicle Recycling

The vehicle recycling community has established the goal of improving ELV recyclability in 2020. A strawman scenario was developed to investigate the recovery requirements associated with establishing a specific goal and targets for material and component recovery along the recycling continuum. The scenario, along with assumptions on which the scenario is based, are presented in Exhibit 3A and Exhibit 3B. Under this scenario, 95 percent of ELV would be diverted from landfill in 2020. Although a consensus was ***not*** reached on the goal and targets, developing the scenario was useful. A baseline assessment that considers the mass balance of vehicles will need to be developed to establish a goal and targets that can be validated and used to monitor progress toward improved recyclability. Establishing a goal for sustainable recyclability will require an assessment of technical feasibility as well as economic and commercial feasibility. The target for each step, for example, would need to consider the critical volume of material needed to achieve commercial significance, as well as the impact of part reuse and remanufacturing credits and landfill avoidance credits.

Exhibit 3A. Strawman Scenario for Diverting ELV from Landfill: Targets for Major Steps in the Recycling Process to Achieve 95% Recyclability

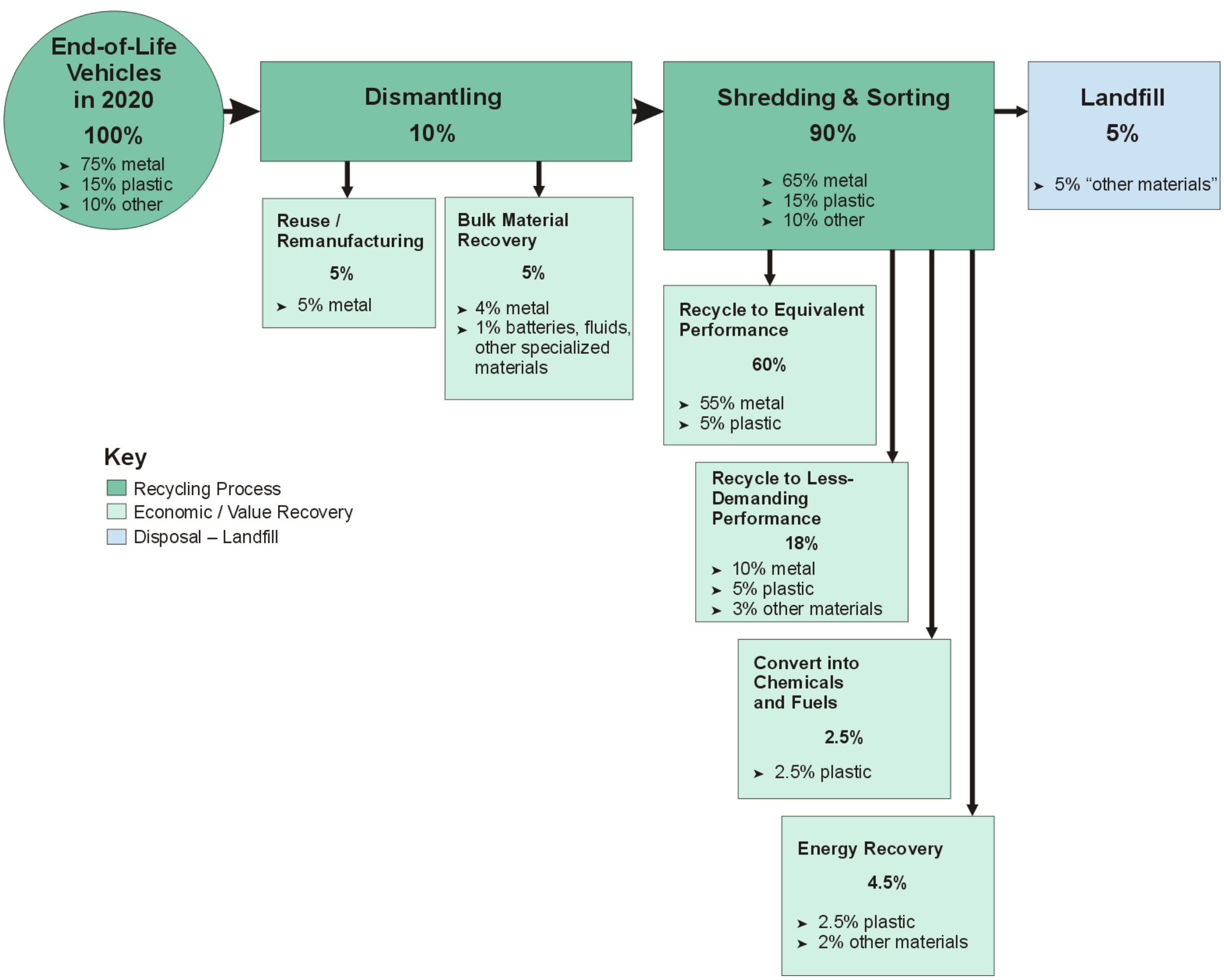


Exhibit 3B. Assumptions for the ELV Recycling Scenario

End-of-Life Vehicles in 2020

The ELV material constituency in 2020 (as a percent of vehicle weight) is expected to be similar to today's vehicles. Vehicles reaching end of life in 2020 will be produced between 2005 and 2010, assuming a 10-15 year life. Hybrid-electric, fuel cell vehicles, and other alternative vehicle platforms will not represent a substantial percentage of the total ELV stream. Steel and aluminum are expected to be the predominant metals, and the relative ratio will not impact recyclability. Plastics as a percent of weight are expected to increase by 3 percent compared to today and to continue to be a diverse mix of thermosets and thermoplastics. This implies that the challenges and key factors that will affect ELV recycling for the next 20 years are similar to the key factors and challenges that the recycling industry faces today.

Expected ELV Content by Weight in 2020

- 75% metal
- 15% plastic
- 10% other (glass, fluids, dirt, and other miscellaneous materials)

Dismantling

Dismantling in 2020 is expected to recover 10 percent of the total ELV on a weight basis, nearly all of which is expected to be metal. While greater than 5 percent of the total ELV mass is typically **reused or remanufactured**, the components cannot be reused/remanufactured indefinitely; the materials eventually end up in the recycling stream. Compared to parts and component recovery, **material** recovery from auto dismantling operations is small in comparison to materials recovery from shredding operations in the United States. **Bulk material recovery** from dismantling is expected to be on the order of 5 percent of the total mass recovered. The constituency will resemble today's material mix, predominantly metals, and small masses of other materials such as batteries, fluids, and specialized materials.

Shredding and Sorting

Most of the ELV mass – 90 percent – is expected to enter the shredding/sorting operation in 2020. Roughly 60 percent of the mass entering shredding/sorting is expected to be **recycled to equivalent performance**, and the other 20 percent is expected to be **recycled to less-demanding performance**. Since these two steps are the highest-value post-shredder recycling options, capturing as much mass as possible here is crucial. Nearly all the remaining metal, two-thirds of the total plastics, and one-third of the "other" are expected to be recovered. Recovering two-thirds of the plastic presents a significant challenge that will require considerable technology development. **Conversion into chemicals and fuels** and **energy recovery** are expected to capture 2.5 percent and 4.5 percent, respectively. These two recycling options will capture the remaining plastic, and a small portion of the "other" materials. This will ensure that all plastics in the ELV waste stream are recycled with virtually none entering landfills.

Landfill

By 2020, all of the metal and plastic entering the ELV waste stream is expected to be recycled. The 5 percent of the total ELV mass entering the landfill will be "other" materials for which there is no economic justification for recovery. The small percentage that will *always* end up in landfills is reserved for materials such as dirt that was picked up during vehicle life and has little or no value. Therefore, the 95 percent recycling goal approaches 100 percent value recovery.

4. Strategy for Increasing Recyclability

Overcoming the challenges to improve recyclability will require a carefully crafted strategy, dedication from the recycling community, and on-going dialogue to track progress. The strategy outlined below will help maximize the value recovered from ELVs.

- Come together as a unified recycling community to cost-share the development of required new technology and a baseline assessment of technology and operations and to promote recycling infrastructure development.
- Incorporate reuse, remanufacturing, and recycling into the design phase for cars whenever possible. This may include rationalization of some materials where feasible.
- Recycle as early in the recycling stream as possible while relying on the market to optimize the value and amount recycled at each step. Base decisions on fully accounted costs.
- Maintain a flexible recycling process that can adapt to diverse model lines fabricated with different techniques and materials from various suppliers.
- Develop automated ways to recover bulk materials.
- Emphasize R&D on post-shred material identification, sorting, and product recovery because this will have the greatest impact on raising the market value of the SR and help avoid landfilling and incineration.
- Focus R&D efforts on materials not recycled today by sorters (e.g., post-shred glass, rubber, fluids, textiles, plastics)
- Develop uses for recovered materials (whether in the same or different applications) and testing specifications.
- Encourage investment in the infrastructure needed to achieve the recyclability goal. Build on the existing infrastructure.
- Develop a means to prevent the entry of PCBs and other hazardous materials into the recycling stream and promote acceptable limits in the SR.
- Consider the recycling requirements of new technologies entering fleets as early as possible.

5. Priority Needs for End-of-Life Vehicles Recycling

The automobile recycling community has identified 21 priority activities that are needed to improve recyclability by 2020. The priority R&D and non-R&D needs that exist across the recycling spectrum, including design, dismantling, reuse and remanufacturing, post-shredder, and end-use are presented in Exhibit 4. The needs are categorized as to top, high, and medium priority and are aligned by time frame when useful results can be expected. For technology development, the timeframe is for production-ready technology with proven economies of scale and feasibility in real world commercial applications. It is assumed that the activities will begin within the next year. The rationales for the priorities are discussed briefly below.

Proactive Industry-Wide Action

The recycling community may form an alliance to implement this roadmap. Such an alliance will bring together automobile companies, suppliers, recycling industries, national labs, and universities to discuss challenges, set priorities, and cost-share and co-manage activities. Many alliances among these groups exist today. By sharing the risk and creating a common voice, the United States will be able to improve recyclability. This organization will assure that research plans are pursued with knowledge of other related activities, and that follow-up workshops are held regularly, especially as new technologies mature and enter the automobile market. Key non-R&D recycling issues will be pursued, including establishing goals for recycled material content and material compatibility, tracking technology development, making key information more accessible to recyclers, and developing standard metrics that eliminate the bias against lighter weight cars. Pursuing R&D priorities will be the primary focus area of the alliance (see Exhibit 4).

Industry-Wide Analysis

Tradeoffs are made among vehicle and material design, recycling technologies, and recycling process operation without understanding the impact on recyclability and the environment. Currently, the status of technologies used, existing process capabilities, and the mass balance flow of automobiles at end-of-life is not known with the level of confidence needed to assure that the industry is making the best choices to optimize recyclability. A better understanding of the interrelationships of all steps in the recycling process from a financial perspective will promote the development of an infrastructure capable of handling the volume and complexity of future fleets. The net environmental impact of recycling verses vehicle life cycle energy use and other parameters is also not known. Analysis of this data is needed to better understand the environmental and economic tradeoffs.

Lower the Risk of Technology Development and Purchase

The recycling industry will need to make enormous investments in technology to significantly improve recyclability. The market value of recovered components and material, especially the SR, is currently not high enough to create the necessary market pull. While the recycling community would like market forces to determine the value of recycled materials as much as possible, both demonstrations and tax incentives are needed to encourage investment to reduce the risks associated with R&D and technology purchases. Demonstrations will show the feasibility of new technology such as achieving a competitive recycled-material delivered price. Currently, a state-of-the-art facility that shows the capabilities of an ongoing recycling operation does not exist. Tax incentives will encourage innovative technology development and investment. Demonstrations and tax incentives will enable the significant level of investment needed to build the required U.S. recycling infrastructure.

Exhibit 4. Priority Needs for End-of-Life Vehicle Recycling

Proactive Industry-Wide Action

- Develop an industry-wide partnership to synergistically address recycling issues (PNGV-type)
- Encourage the entire automobile industry to establish goals for recycled material content to create market pull and for minimizing material incompatibility
- Track new technology and R&D in the U.S., Europe and other countries
- Develop a web-based system to make information available to the recycling industry (e.g., reuse/remanufacture specifications, technology availability)

Industry-Wide Analysis

- Develop a baseline assessment of existing automobile recycling systems to understand the state-of-the-art and identify what is needed
- Develop a model of the net environmental impact of automobile recycling, including the tradeoff between life cycle energy use and increased recyclability

Lower the Risk of Technology Development and Purchase

- Foster the development of tax incentives to encourage investment in recycling infrastructure for dismantling, separation, identification, and sorting
- Demonstrate the entire recycle stream to show complexity and process optimization (including non-organics)
- Demonstrate broader applications of existing technology and new technology

Material Design

- Design recyclable plastic parts and systems for ease of bulk and post-shred recovery

Pre-Shred Recovery

- Develop a low-cost dismantling process to improve material and component recovery using an industrial engineering approach
- Develop recycling technologies for new challenging materials (e.g., fuel cells, powder metals)
- Develop and validate reuse and remanufacture techniques

Post-shred Material Identification and Sorting

- Develop the ability to sort post-shred non-metallic and comingled metallic material at high speed (e.g., plastic, rubber, glass, organics)
- Continue R&D on rapid identification and sorting of polymers, especially mixed polymers with densities > 1.15 g/cc
- Develop methods to remove PCBs and other toxic materials in the shredder residue

Increase End-use Value of Recovered Materials

- Continue R&D on polymer compatibilizers to ease separation requirements
- Develop methods to separate fiber from resins for reuse (e.g., metal matrix composites, carbon-reinforced composites, glass-reinforced composites, rubber)
- Develop a general-purpose product from recycled material and find applications to create an economic pull for recycling
- Develop post-use applications for glass
- Develop post-use applications for rubber (e.g., tires, window strip, hoses)

Key

- Top priority need
- High priority need
- Medium priority need
- No Border: Near term (0-3 years)
- Midterm (3-10 years)

Material Design

Automobile manufacturers design new vehicles with available materials that meet the required specifications at the lowest cost. With technology advancements, plastic components and systems can be investigated to meet the specifications and be recovered in bulk and from the SR.

Pre-Shred Recovery

Dismantling is labor-intensive so improving its efficiency will help make material and component recovery more economical. New technologies that are anticipated to be in end-of-life vehicles after 2010 will require unique recycling technologies in order to recover valuable materials and avoid contamination of the post-shred residual. In addition, increasing the value and scope of reused and remanufactured parts and components will foster pre-shred recovery.

Post-Shred Material Identification and Sorting

Eventually, almost everything in a vehicle will reach its end-of-life and be shredded or otherwise processed as scrap. The capability to quickly separate, identify, and sort materials into piles that have economic value–including the removal of contaminants – will largely determine if recyclability can be significantly improved. Metallics, especially steel and iron because of magnetics are easy to separate. Non-metallic materials such as plastics, rubber, glass, and organics are difficult to separate. Plastics require additional separation to be of value because of polymer incompatibility. Currently, there is no commercially proven way to separate all of the polymers that are or will be used in cars.

Increase End-Use Value of Recovered Materials

Maximizing the value of sorted post-shred non-metallic materials will create the market pull necessary to prevent disposal through incineration or land filling. Cost-effective applications for rubber, glass, and other materials are needed. Today, a mixed polymer stream has a limited market value. If polymer compatibilizers were available, they could negate the need for costly polymer separation processes in some cases. The ability to separate higher value materials, such as material composites, could lead to a reuse market that could create economic incentives for the entire sort stream.

6. Next Steps for Implementing Roadmap Priorities

This roadmap sets forth the priority needs and direction for how the recycling community will improve vehicle recyclability over the next 20 years. The priority needs and direction are summarized in the body of this roadmap as well as highlighted in Appendices D and E. Consensus research needs will be communicated throughout the industry so that collaborative projects may begin. In addition, the roadmap will be used to fortify support from all stakeholders and Congress. Successful achievement of the R&D and non-research activities is expected to have significant near-term and long-term impacts on recyclability. In the months ahead, a plan for implementing this roadmap will be established.

Achieving significantly improved recyclability on the order discussed in Section 3 is currently not technically and economically feasible. Improving recyclability significantly by 2020 will require the participation of the diverse range of stakeholders. These stakeholders include:

- Recycling Industry – Transporters, Dismantlers, Reuse/Remanufacturers, Shred/sorters
- Equipment Manufacturers
- Automobile Companies
- Material and Component Suppliers
- Trade Associations
- Government Research Programs
- National Laboratories
- Universities
- Independent Research Institutes

A key priority to improve recyclability is the formation of an industry-wide alliance to synergistically focus efforts toward achievement of the common goal of improving recyclability. This alliance could coordinate a diverse range of activities among the stakeholders in pursuit of the priorities. Projects are expected to be funded on a project-by-project basis, and financial contributions are expected to come from relevant stakeholders, including the recycling industry, equipment manufacturers, automobile industry, material suppliers, trade associations, and government research programs. All the stakeholders are expected to participate in research activities, especially the national laboratories, universities, and independent research institutes.

Special efforts will be made to link the pursuit of these roadmap goals with the research program of the DOE Office of Advanced Automobile Technology (OAAT). OAAT is pursuing activities to support the development of recycling capabilities for advanced automotive technologies. As a sponsor of this roadmapping effort, OAAT recognizes the recycling challenges that exist with vehicles now and in the future. Continued government leadership from OAAT is essential to achieving significant improvements in recyclability. Specifically, the recycling community would like OAAT to assist with the following:

- ➤ Assist with the formation of a more comprehensive automobile recycling alliance
- ➤ Use the priorities in this roadmap to guide OAAT program activities
- ➤ Co-fund R&D projects at national laboratories and universities – Priority areas include lowering the risk of technology development and purchase, specifically demonstrating the entire recycle stream, and post-shred material identification and sorting
- ➤ Assess progress periodically so this effort is kept up-to-date as new materials and technologies are incorporated in new fleets
- ➤ Encourage participation of all stakeholders

Government Involvement is Essential

A large percent of the nonmetallic components of ELV are entering the waste stream today, requiring landfill space. Cost-effective markets do not exist for this material. Government involvement is needed to reduce the social and environmental impacts from this waste.

New ELV material streams will require new recycling technology and economies. Market drivers to encourage the R&D that is needed do not currently exist. The needed R&D will require long-term time frames and high-risk efforts that the industry is reluctant to pursue alone. New technology purchases in the scale needed to improve recyclability nation-wide could not happen fast enough to significantly improve recyclability by 2020.

Different steps in the recycling process have different economies, issues, and priorities. For example, from a shredder's perspective, design is not a factor. Government can serve as a catalyst to bring together the diverse perspectives across the recycling and automobile industries, while allowing these industries to lead the effort to ensure optimal decisions. Neither the recycling industries nor the automobile industry should be expected to independently fund and/or undertake all of the needed research.

Independent, unbiased source of data is needed to help the recycling and automobile industries come together and to provide credible data to Congress and the Environmental Protection Agency. Government involvement can assure credible data and help keep partnerships pre-competitive. Regulatory barriers to inhibiting environmentally sound and economically sustainable recycling may need to be addressed.

Automobile companies are international, and they need to reach economies-of-scale and design to all markets. As these companies face competitive pressures, technological solutions may come from overseas where landfill costs are higher and markets for recovered products are more competitive. Government involvement can ensure optimal decisions for recycling in the United States and promote the understanding of how other countries have different markets and different needs.

Appendix A. Overview of the Roadmapping Workshop

The New Generation Vehicle and Advanced Automotive Technologies (NGV/AAT) are expected to enter the market in the next 10 years. Consequently, they will reach their end-of-life by 2020. The DOE Office of Energy Efficiency and Renewable Energy (EE), Office of Transportation Technologies (OTT) is pursuing activities to support the development of recycling capabilities for the advanced automotive materials and components. Argonne National Laboratory (ANL)–a research laboratory for OTT's Office of Advanced Automotive Technologies (OAAT)–lead the effort to develop a technology roadmap for recycling advanced automotive materials and components. A workshop was held to gather the input for the roadmap on September 6 and 7, 2000, at ANL in Chicago, Illinois. An initial goal of 85 percent recyclability (up from today's level of 75 percent) when the first waves of vehicles reach end-of-life status in the 2020 time frame was selected to guide and facilitate the roadmapping process. The workshop brought together the recycling research community and industry experts (who are knowledgeable of the advanced materials and components that will be used in future automobiles) to discuss the anticipated needs in areas involving design, disassembly, dismantling, reuse, remanufacturing, shredding and post shredder operations. The agenda is provided in Appendix B and a list of participants is provided in Appendix C.

The workshop included a plenary session, two working breakout sessions, and a summary session. Energetics, Incorporated provided professional facilitation designed to gather and analyze ideas. The participants were divided into two groups that met separately and worked concurrently on the same questions using the same process. Each group identified drivers impacting recyclability, targets for recycling, barriers, and R&D needs. The results from the two working groups are presented in Appendix D and E. The results of each group were reviewed during the summary session. The workshop results were analyzed and compiled to draft this roadmap.

Appendix B. Agenda from the Roadmapping Workshop

Automobile Recycling Roadmap Workshop

Time	***Session***	***Location***
Wednesday, September 6		
7:30 – 8:30	Registration and Continental Breakfast	Building 401 Room A-1100
8:30 - 10:00	**Plenary Session** 1) *Welcome and Introduction* by Kenneth Uherka, ANL and Joseph Carpenter, DOE/OAAT 2) *Recycling Challenges Expected in PNGV and Other Advanced Automotive Technologies* – presentation by Gerald R. Winslow, DaimlerChrysler Corporation and USCAR/VRP 3) *Research on Advanced Automotive Material Recycling: A Status Update* – presentation by Edward Daniels, ANL 4) *Overview of the Facilitated Sessions* by Melissa Eichner, Energetics, Inc.	Building 401 Room A-1100
10:00 - 10:15	Break	Outside E-1100 and E-1200
10:15 - 12:30	**Facilitated Sessions** – *goals and drivers*	Building 402 Rooms E-1100 and E-1200
12:30 - 1:30	Lunch	Building 402 Gallery
1:30 - 3:00	**Facilitated Sessions** – *barriers and R&D needs*	Building 402 Rooms E-1100 and E-1200
3:00 – 3:15	Break	Outside E-1100 and E-1200
3:15 - 5:00	**Facilitated Sessions** – *continued*	Building 402 Rooms E-1100 and E-1200
6:30 – 8:30	Dinner (Dutch Treat)	Guest House Dining Room
Thursday, September 7		
7:00 - 8:00	Continental Breakfast	Building 401 Room A-1100
8:00 - 10:45	**Facilitated Sessions** – *R&D priorities, time frames, implementation*	Building 402 Rooms E-1100 and E-1200
10:45 - 11:00	Break	Outside E-1100 and E-1200
11:00 - 1:00	**Summary Session** *Findings of Breakout Sessions* and *Closing Comments*	Building 401 Room A-11000
1:00	Adjourn	

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Appendix D. Workshop Results from Working Group A

Issues, Trends, and Drivers Most Likely to Influence Recycling of Advanced Materials and Components

✪ = Most Influential Driver

Society	Economics	
	Infrastructure	**Technology**
• Value of competing environmental goals – sustained opposition to mining ✪✪ • Government regulation ✪✪ • Consumer opinion (e.g., recycled content) ✪✪ • Society as consumers/citizens ✪ • Preconceived ideas about quality of recycled material ✪ • U.S. OEM interest in non-landfilling • Desire to reduce energy consumption • Vehicle ownership vs. lease • Real or perceived increase in litter • Job creation • Wealth creation	• Economics – cost ✪✪✪✪ • Reverse logistics (e.g., collection, participation) ✪✪✪ - Transportation economy - Landfill capacity ✪ - Change ratio between scrap and waste • Technology available for reuse and remanufacture ✪ • Recovered material value • End-market consumption • Investment in capital and need to get return – technology inertia for facilities and tooling (F&T) • Raw material management (offset virgin material • Entrepreneurial opportunity	• Chemistry of materials impacting reclaimed material ✪✪✪✪✪ - Separation technology - Material selection - Applications for recycled material • Foreign technology development • Fastening methods • Alternative sources of raw materials • Hazardous output from recycling • Competing design goals

Targets
• Build on existing infrastructure (shredding and sorting new materials) • Environmental friendly automobiles • Economically viable automobile recycling industry • Fully accounted costs and inefficiencies—base decisions on this • Develop alternative uses for materials • Encourage design for reuse and remanufacturing • Automated ways to recover bulk materials • Focus on materials not recycled by sorters (e.g., post-shred glass, rubber, fluids, textiles, plastics) • Specifications to allow testing for reuse/remanufacture • Increase the value and quality of materials (whether used in same or other application)

Barriers to Achieving 85% Recyclability

- = Non-technical ✪ = Technical

<table>
<tr><th colspan="4">Non-Technical Barriers</th><th rowspan="3">Technical Barriers</th></tr>
<tr><th rowspan="2">Society Perceptions</th><th colspan="3">Institutional/Regulatory</th></tr>
<tr><th>Recycling Industry</th><th>Auto Industry Cooperation</th><th>Government</th></tr>
<tr>
<td>Perception of energy recovery through incineration ♦♦
Low cost raw material from nature that competes with recycled material ♦♦
Consumer and market perception of reused and remanufactured products ♦♦
Inexpensive landfill ♦
Consumer perception of value of recycled plastics, rubber
Conflict: What is acceptable and what is not varies by person</td>
<td>“Show me” attitude – lack of an operating pilot to provide sustained demonstration ♦♦♦
Lack of knowledge of recycling market today and how it fits into stream ♦♦
• Lack of clear markets or performance standards and specifications for recycled material and products ♦
• Lack of investment capital to launch new technology ♦
• Lack of infrastructure that is geographically balanced</td>
<td>• Lack of metrics of recycling performance (e.g., what is good, how to measure 85%) ♦♦♦
• Lack of industry standards across companies (e.g., material, performance) ♦♦
• Failure to or resistance to embrace design for recycling ♦♦
• Lack of part product information ♦
- Lack of information on materials in vehicles recycled today
• Lack of endorsement and design for remanufacturing and reuse ♦
• Introduction of new materials to provide unique characteristics—proliferation of new material--innovation</td>
<td>• Regulated substances in recycle stream – interpretation of regulations ♦♦♦
• Premature government action in response to problems, European action, etc. ♦♦
• Different regulation requirements in different states ♦
• European legislation action influencing U.S. decision-making – could lead to less than optimal choice ♦
• State regulation barriers to energy recovery ♦
• Government lack of understanding of true impact of requirements (safety, environmental, others)</td>
<td>• Lack of cost-effective technology for sorting non-metallics and commingled metallics ✪✪✪✪✪✪
• Lack of assessment of technology available and what it can yield in terms of value (e.g., alternative product stream technology) ✪✪✪✪✪
• Lack of communication about the technology that is available
- Technology transfer
- Incentives to apply it
• Markets for recycled material ✪✪✪✪
• Joining technology leads to difficulty when separating and sorting ✪✪✪✪
• Economic/physical feasibility of achieving 85+% recyclability ✪✪✪✪
• Variability of incoming material properties (lot-to-lot or load) ✪✪✪✪
- Diversity of materials in auto
- Complexity of polymers used
• Test methods for quality of products and material recovery✪✪✪
• Unknown contaminant tolerances in polymers (e.g., quantities) ✪✪
• Cost-effective sampling ✪
• Industry interfaces not provided for plastics (e.g., no mobile shredders, granulators) – expand existing infrastructure for new material and product recovery
• Types of contamination in varied material entering the sort
• Use of toxics and contaminated material
• Other vehicle requirements (e.g., design tradeoffs)</td>
</tr>
</table>

Activities (R&D and Non-R&D) Needed to Achieve the Goals

✪= Top Priority Need, ¯ =High-Priority Need

	Models/Assessments		Technology Development		Demonstrations	Information Exchange
	Technical Assessment	**Market Development Model**				
NEAR-TERM (0-3) YEARS)	Assess performance of recycling systems to determine a baseline ✪✪✪♦♦♦♦N – Maintain infrastructure to assure flexible material/component response, e.g., if take metal out could impact shed/sort value and upset the economy – Models to understand environmental impact of recycling ✪♦♦ – Study to avoid conflict between life cycle energy use and recyclability ✪♦♦N Assessment of technology available including economics and scale considerations (consider other industries) ✪♦♦N Have the National Academy of Engineers conduct an independent assessment of gasification technology for post-use polymers (not direct combustion) ♦♦N	Analysis of complexities of niche industries (including installation issues) to develop post use markets N	Methods to separate fiber from resins and reuse both ✪✪✪♦♦N Ability to sort non-metallic materials at high speed ✪✪♦♦N Separation technology for mix polymers with densities >1.15 g/cc ✪✪♦♦N Recycle plastic gas tanks that absorb gasoline and slowly emit fumes too inexpensive to recycle complex shapes ✪♦N	Develop standard metrics for recycling that accounts for reuse and remanufacturing (e.g., percent bias against lighter weight cars) ♦✪N Develop integrated design tools for reuse and remanufacturing and recycling and integrate into other automobile design tools N	Aluminum alloy separation[1] ♦♦♦♦♦♦N Demonstrations to explore new technology ♦ [1] Huron Valley Steel is currently building a plant in Europe to demonstrate aluminum alloy separation.	

	Models/Assessments		Technology Development		Demonstrations	Information Exchange
	Technical Assessment	Market Development Model				
	Assess breakthrough technologies to increase opportunities for recycling ♦N Comparable “inductive” industry analysis (e.g., lessons learned in municipal recycling such as impacts of artificial influences) ♦N					

	Models/Assessments		Technology Development		Demonstrations	Information Exchange
	Technical Assessment	Market Development Model				
MID-TERM (4-10 YEARS)			Applications for rubber (tires, weather strips, other components) ✪✪✪♦M Post-use applications for glass ✪✪♦♦M Performance properties of material as a function of contamination levels ✪♦♦M	Rapid cost-effective methods for separating adhesively joined materials ✪M Separation of metal matrix composites ♦♦M Methods to manage heavy metals in shredder residue ♦♦M Develop techniques to identify a shard that is a joint—(non-homogeneous contaminant material piece) M		<u>RECYCLING INDUSTRY</u> Web-based system to make information on reuse/remanufacturing available (e.g., increase quality and percentage recycle, past performance assessment) ✪♦♦♦M Clearinghouse for information on existing technology for recyclability ♦♦♦M Web-based information on dismantling systems (e.g., information on material use in each vehicle type, material identification code, including videos) ♦M Global industry standards for plastics like what exists for steel and aluminum (suppliers) M

	Models/Assessments		Technology Development		Demonstrations	Information Exchange
	Technical Assessment	Market Development Model				
START MID TERM	Once baseline is established develop econometric model to analyze options (e.g., determine efficiencies from integration) SM-Ongoing	Identify synergy in small businesses for reuse/remanufacturing to enhance infrastructure and identify R&D needs (diversity of 5-6 industries linked small parts) ✪SM-Ongoing Analysis of cost-effective sort streams - How many piles to sort into? (e.g., sort by exception) SM-Ongoing				
LONG-TERM			R&D to depolymerize economically ✪♦♦♦L			
ONGOING (ALL TIME FRAMES)					Demonstration to explore broader applications of existing technology and new technology ✪✪✪✪✪♦♦♦ N-Ongoing Pilot demonstration of entire recycle stream to show complexity ✪✪♦♦M-Ongoing	<u>PUBLIC</u> Public education to change perception—e.g., recycled content is not inferior ♦Ongoing

Proposed Role for OAAT
• Use roadmap report that is issued from industry • Develop execution plan • Actively promote to attract funding • Assess progress to make sure this effort is kept up-to-date as new fabric and materials are incorporated into new fleets • Encourage new material recycling prior to shredding

Need for Government Involvement
• Recycling industries and automobile industries alone will not take action to bring whole process together • Unbiased • Scale needed • Reducing landfill is in society's interest • Non-metallics do not have economical infrastructure to create market "pull" for recycled materials/products • Low pay back, high risk • From shredders perspective, design is not a factor • Government ensures fairness and plays a role with Europeans who have different markets and different needs • Competitive pressures on companies – technological solutions may come from overseas where landfill costs are higher and markets for recovered products are more competitive • Companies are global therefore they need to reach economies of scale and design to all markets • Lack market drivers to encourage R&D • Longer term time frame needed • Outcomes impact and result in benefits to other industries • New material streams require new technology and economies • Government serves as catalyst to bring industries together – but industries lead effort

	Top Priority Needs	Who Could Participate in and/or Fund Activities?[1] (P = participate; F = fund)								Risk 1 (lowest) – 5 (highest)	
		Recycling Industry	Auto Industry	National Lab	Universities	Independent Research Institutes	Material Suppliers	Government	Equipment Manufacturers	Technical Risk	Commercial Risk
Near Term	Develop baseline assessment of existing automobile recycling systems	P	F,P	P	P	P	F,P	F	F	1	N/A
	Demonstration broader applications of existing technology and new technology	F,P	F,P	P	P	P	F,P	F	F,P	3	5
	Develop model of environmental impact of automobile recycling including conflict between life cycle energy use and increased recyclability	F,P	F,P	P	P	P	F,P	F		2	N/A
	Develop the ability to sort non-metallic material at high speed (post-shred) R&D	F,P	F	P	[P	P	F	F	F,P	3	5
	Develop separation technologies for mix polymers with densities >1.5 g/cc R&D	F,P	F	P	P	P	F	F	F,P	4	4
Mid Term	Demonstrate entire recycle stream to show complexity (including non-organics) and process optimization	F,P	F,P	P	P	P	F,P	F	F,P	2	3
	Develop methods to separate fiber from resins and reuse both	P	F	P	P	P	F	F		2	3
	Develop post-use applications for rubber (tires, window strip, etc.)	P	F	P	P	P	F	F	F	2	3
	Develop post-use applications for glass	P	F	P	P	P	F	F	F	2	3

[1] The VRP has funded and will continue to fund research in these areas. OEMs should not be expected to fund all the research proposals listed.

Appendix E. Workshop Results from Working Group B

Issues, Trends, and Drivers Most Likely to Influence Recycling of Advanced Materials and Components

✪ = Most Influential Driver

• Regulatory drivers ✪✪✪ • Balancing consumer demands (strong car, safe, etc.) with regulatory requirements ✪✪✪ • Public concern for recycling influences political decisions ✪✪ • Impending European, Japanese regulations may influence U.S. regulators or public opinion • Reducing obsolescence by producing a car that consumer is happy with for longer • Good corporate public relations will drive recycling to avoid "polluter" image • Availability of capital to build new infrastructure ✪ • How to use constituents to make them useful after recycling – Decreasing material availability if they are not recycled • Increasing pressure to avoid disposal due to decreasing landfill space • Different regional/global recycling standards • Future car may be mix of different technologies (fuel cells and hybrids, etc.) – Can recycling infrastructure handle it? • Ability of vehicle to not contribute to physical waste in its disposal • Fear: – Public for dirty planet – Current infrastructure losing business • Ability for new materials to be recycled to same characteristics/ performance ✪✪	• Multiple new recycling infrastructures may develop (one for hybrid, one for fuel cells, etc.) • Technology may limit recycling in 2020 – needs to be developed • Public concern over types of materials ending up in landfill • Mix of materials will become more complex • Customers will demand high recyclability • Major changes outside the automotive industry could reduce the need for recycling – e.g., methane hydrates become feasible • Major energy storage technology development may change vehicle technologies • Time it takes supply base for new materials to be available may limit rate of new material utilization • Fuel price increases may lengthen vehicles life • Developing the capability to economically recycle new mix of materials in future cars ✪✪✪ • Economic value of materials being recycled will shape recycling business ✪✪✪ • Less metal in vehicles means less value in hulk; recycling business will be affected ✪

Barriers to Achieving 95% Recyclability[1]

- = Non-Technical ✪=Technical

Non-Technical Barriers			Technical Barriers	
Regulatory	**Infrastructure**	**Economic**		
No North American legislation exists that requires recycling ♦♦♦♦♦	Recycling infrastructure not in place for sorting plastics or light metals by alloy ♦♦♦♦♦♦ "Green" products do not necessarily enjoy increased sales ♦♦ Insufficient quantity of materials to provide consistent feed stream ♦ Lack of involvement of suppliers – Existing supply base does not want to change No secondary use market for some non-metallic and composites Recyclers do not like long-term contracts, despite a well-defined feedstock stream Recyclers do not take full advantage of opportunity to use materials to realize other gains – Use it instead of trees	Lack of economic drivers – Recycle cost is greater than virgin material – Lack of market for recovered materials – Regulations ♦♦♦♦♦♦ Capital and R&D costs of creating new processes is high ♦♦♦♦ – Testing and development takes time – Using recycled plastics in autos require major testing and development costs Large number of incompatible materials make separation more costly ♦♦♦ Chemical conversion costs are greater than virgin materials (especially with oil prices today) ♦ Lack of quality standards for new materials – Making specifications is expensive ♦ Large virgin plastic producers may not support recycling due to fear of loss of business No market for incompatible materials that are combined together	Inadequate, costly separation and purification technologies ✪✪✪✪✪✪✪✪✪ – Cleaning liquid metal and process materials – Impurities in metals and plastics Cost-effective, accurate material identification techniques do not exist ✪✪✪✪✪ Shredder residue contamination with toxic materials (e.g., PCB) heavy metals – Particularly electronic parts Environmental concerns (e.g., dioxins) and capital cost to make incinerators environmentally acceptable may prohibit energy recovery	Cars are not designed for reuse, remanufacturing, and recycling ✪✪✪✪ – Design for disassembly is not common – New materials and alloys are challenging Proliferation of material types in vehicles ✪✪✪✪✪ – Great diversity of plastic materials Uncertainty in recycling opportunities for second, third vehicle life ✪ Lack of process to recycle plastics to equivalent performance ✪ Inability to recycle/reprocess "specialty" materials (e.g., metal matrix composites, powder metal parts)

1 The working group started with an initial goal of 85 percent recyclability. Collectively, they decided to pursue a goal of 95 percent recyclability.

Activities (R&D and Non-R&D) Needed to Achieve the Goals

✪= Top Priority Need, ¯ =High-Priority Need

	Technical		Economic	Regulatory	Infrastructure	
NEAR-TERM (0-3 YEARS)	Continued R&D effort on automotive separation (e.g., skin flotation, etc.) ✪✪✪✪✪✪✪✪✪✪✪ – High tension separators – In conjunction with industry – Including separation of SR – Plastics-specific – Metals-specific – Continue and demonstrate separation of aluminum (cast from wrought) and other light metals ✪✪	Additional R&D on compatibalizers to ease separations requirements ✪✪✪✪✪✪✪✪✪	Develop low-cost dismantling processes prior to shredding (industrial engineering approach) ♦♦♦♦♦♦♦♦ – Study how to streamline dismantling process ♦ Better understand interrelationships of all steps in recycling process from a financial perspective to cultivate infrastructure	Encourage tax incentives to encourage investment in recycling equipment ♦♦♦♦♦♦♦♦♦	Develop a general-purpose product from recycled material and find applications based on its properties ♦♦♦♦♦♦ – Opposite of “normal” marketing – Material standards for general recycled materials (e.g., polypropylene)	Entire auto industry should state their goals for recycled material content ♦♦♦♦♦♦♦♦♦ – Demonstrate that a market exists – Lay out a business plan
MID-TERM (4-10 YEARS)	Develop recycling technologies for challenging materials (e.g., Metal matrix composites, powder metals, fuel cell materials) ✪✪✪✪✪✪✪ – Carbon-fiber reinforced, glass-fiber reinforced	Continued research in rapid identification and sorting of plastics ✪✪✪✪✪✪✪✪✪ Identify barriers to recycling early in development for new technologies (e.g., fuel cells)				

	Technical		Economic	Regulatory	Infrastructure	
ONGOING (ALL TIME FRAMES INCLUDING LONG TERM)	Keep abreast of R&D in Europe and other nations ✪✪✪✪✪✪✪ Continue to minimize incompatibilities and proliferation of materials ✪✪✪✪✪✪ Design recyclable plastics (Design for Environment) ✪✪✪✪✪✪ Government-sponsored research to create/validate recycling/remanufacturing/techniques ✪✪✪✪✪✪ Investigate alternate reaction mechanisms for recycling plastics back to raw materials ✪✪✪✪✪♦		Investigate economics of all recycling technologies at large scale (10 million cars/year) ✪♦♦♦♦♦	Create a preference for governmental purchase of recycled/ remanufactured materials and remove barriers to their purchase ♦♦♦♦♦	Educate public on the success of current recycling technologies ♦♦♦♦♦♦ Look for materials that have dual uses (non-auto applications) that would use existing infrastructure ♦♦♦♦♦♦ Synergistic effort of all players to address recycling (PNGV-type partnership) ♦♦♦♦♦♦♦♦♦♦ – Include designers early to consider recycling – Include manufacturers (stampers, etc.) because they will incur costs due to recycling or design changes	Improve opportunities for remanufacturing by reducing design changes ♦♦♦♦♦♦ Need for product specifications of components to avoid reverse engineering in remanufacturing

Implementation Strategy and Recommendations

Top Priority Needs	Why is government involvement needed?	What role should government play?	What happens if there is no government involvement?	Specific recommendations to OAAT/ANL
Continue R&D effort on automated separation techniques	• Going to waste stream today; high risk, low return; social and environmental implications • No defined market now for recycled materials	• Form industry-lab consortia	• No economic justification to conduct R&D; it will only be developed where there is clear economic advantage	• Develop program/ project plan; conduct meeting to develop a business plan
Tax incentives to encourage investment in recycling infrastructure	• Provide incentive; investments are very high for recyclers • Encourage auto manufacturers to accept recycled materials • Social responsibility jobs	• Enact legislation	• Much slower, less investment, more pollution	• Provide credible data to Congress, industry
Continue research on rapid identification and sorting of plastics	• Environmental, social responsibility jobs, similar to 1 • Going to waste stream today; high risk, low return social, and environmental implications • No defined market now for recycled materials	• Build consortia for demonstrations, support basic research (government, industry, academia)	• Much slower technology development	• Develop program/ project plan; conduct meeting to develop a business plan
Develop recycling technologies for challenging materials (e.g., Metal matrix composites, P/M, fuel cell materials, composites)	• It is basic research; industry will not do it alone	• Fund internal and external R&D, university work with labs, help develop workforce	• No technology development, lose valuable, irreplaceable materials	• Fund research projects
Work on PCB, other toxic materials in SR (current legislation limits PCB)	• EPA set regulation, industry is afraid to address this issue	• Honest broker of data that supports the truth, partner with industry for data	• Show stopper – this may stop all recycling efforts if not addressed	• Build consortium of parties to generate data and speak to EPA
Synergistic effort of all players to address recycling issues (PNGV-type Partnership)	• They can be the broker—keep partnership pre-competitive	• Broker partnership	• Takes longer, may never happen; landfill goal is not achieved	• Continue to encourage interaction—conferences, workshops, articles, etc.