B. Baseline Assessment of Recycling Systems and Technology

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Objective

- Establish the baseline or state-of-the-art for automotive materials recovery/recycling technology.

Approach

- Review the state-of-the-art of worldwide automotive materials recovery/recycling technologies.
- Develop technology profiles of emerging automotive materials recycle technology.
- Review international, federal and state regulatory information regarding vehicle recyclability, substances of concern, and recycle laws and mandates.
- Conduct life-cycle studies to quantify the environmental burdens associated with various end-of-life recycling technologies.
- Conduct reference case end-of-life recyclability studies.

Accomplishments

- Conducted a literature search that identified technologies that are being classified as mechanical, thermo-chemical conversion and energy recovery, and technology profiles are being developed.
- Characterized the existing U.S. recycling infrastructure and derived estimates of automotive recycle rates from the literature.

- Initiated a review of global regulatory requirements regarding end-of-life vehicle recycling; the review includes not only recycle mandates but also proposed and existing requirements regarding handling of substances of concern.
- Initiated life-cycle studies of selected alternative recycle technologies; the initial studies will provide a comparison of alternative mechanical recycle technologies relative to technologies proposed for the thermo-chemical conversion of shredder residue to fuels.
- Conducted reference recyclability calculations for reference cases and three lightweight alternatives: lightweight steel, composite, and aluminum.

Future Direction

- Prepare database of recycle technologies.
- Conduct CRADA-led visits to evaluate state-of-the-art material and energy recovery technologies, as appropriate in Japan and Europe.
- Continue life-cycle comparisons.
- Plan additional recyclability evaluations using the current study as a starting point for assessing recyclability of vehicles of the future.

Summary

The objectives of this project are to benchmark the automotive materials recycling industry and to compile information in an accessible format regarding the status of existing and emerging recycling technology and research.

The focus of the work under this activity will be to develop the tools and document the information necessary to make effective decisions relative to technology needs to facilitate sustainable future vehicle recycling and also to make effective decisions regarding allocation of R&D resources.

The state-of-the-art of worldwide automotive materials recovery/recycling technologies and associated resource recovery infrastructures will be reviewed to identify technology gaps and needs and to identify differences in automotive recycling strategies between the United States, Europe, and Japan. Technologies that will be included in this review include, but are not limited to, postshred materials recovery technologies, preshred materials recovery technologies, materials identification technologies, automated dismantling technologies, bumper recycle processes, fuel tank recycle technology, and thermochemical conversion technology.

Life-cycle analyses of alternative recycle technologies will be conducted to identify differences of technologies such as mechanical recycling vis-à-vis thermochemical recycling relative to energy and environmental benefits.

Regulations at the international, federal, and state level will be reviewed to identify the impact that proposed and existing regulations may have regarding recycling of automotive materials.

Reference case recyclability calculations will be undertaken to quantify the expected recyclability of alternative vehicle designs.

Infrastructure

The North American recycle infrastructure has been characterized (Figure 1). Material flows within the existing infrastructure are being quantified.

Technology Profiles

The recent literature has been reviewed, and summaries and profiles of available and emerging recycle technologies are being compiled into a database.

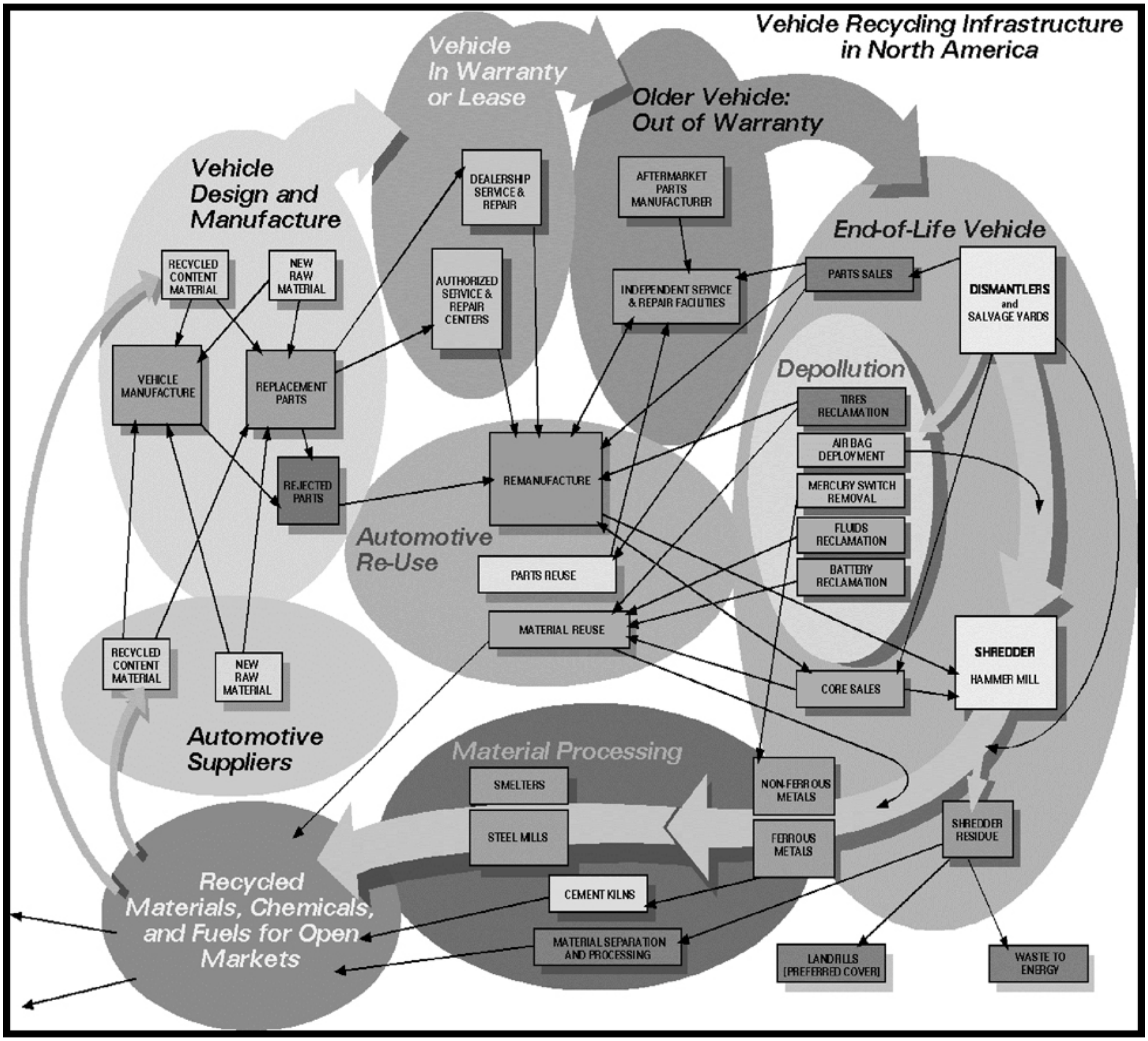

Figure 1. Representation of the North American recycle infrastructure.

A bibliography of abstracts of papers that discuss automotive recycling issues has been compiled. The bibliography is organized in the following sections:

- Recycle infrastructure
- Design for recycle
- Legal and regulatory issues
- Life-cycle analysis
- Research programs
- Substances of concern
- Disassembly technologies and case studies
- Reuse of automotive parts and subassemblies
- Remanufacturing
- Mechanical separation technology
- Thermochemical conversion technology
- Energy recovery technology
- Other technology
- Advanced materials recycle technology
- Case studies of materials recycled for auto applications

The bibliography was compiled from the following primary sources:

1. Society of Automotive Engineers (International) World Congresses from 1997 to 2004
2. Environmental Sustainability Conference and Exhibition, 2001
3. Society of Plastics Engineers
   - Automotive Research Consortium ’98 Conference
   - Automotive Research Consortium’99 Conference
   - GPEC 2002 Conference
   - GPEC 2003 Conference
4. Other conference proceedings
   - International Automobile Recycling Congress 2002
   - TMS Fourth International Symposium of Recycling of Metals and Engineered Materials, 2000
   - Ecomaterials and Ecoprocesses, The Conference of Metallurgists, COM 2003

Conference proceedings from the International Automobile Recycling 2001, 2003, and 2004 conferences have been ordered as have been the ARC 2000 proceedings for inclusion of relevant papers into the bibliography. At present, the bibliography includes 110 citations (Table 1).

Table 1. Citations included in the recycle bibliography (as of September 2004)

Bibliography section	Number of citations
Recycle infrastructure	4
Design for recycle	1
Legal and regulatory issues	16
Life-cycle analysis	5
Research programs	7
Substances of concern	2
Disassembly technologies and case studies	6
Reuse of automotive parts and subassemblies	1
Remanufacturing	0
Mechanical separation technology	13
Thermochemical conversion technology	5
Energy recovery technology	7
Other technology	17
Advanced materials recycle technology	7
Case studies of materials recycled for auto applications	18
Total citations	110

Regulatory Situation

The European Union has issued End-of-Life Vehicle Recycle Directives. The enforcement of these directives is, however, the responsibility of each member state. The status of the member states’ position relative to the directives and the policies for implementing the directives are under review. While the United States has not developed a federal policy or mandate, regulations at the federal and state level can impact the technology needs for recycling automotive materials. For example, U.S. Environmental Protection Agency (EPA) regulations regarding polychlorinated biphenyl (PCB) disposal limits the concentration of PCB on recycled materials to below 2 ppm. State regulations regarding mercury and polybrominated diphenyl ethers (PBDEs) can also impede materials recycling. A review of the regulatory arena is ongoing to identify the impacts of regulations relative to technology options for recycling.

Life-Cycle Studies

The objective of this project is to use life-cycle analysis to assess the environmental impacts of various mechanical separation technologies and alternative end-of-life recycling technologies used with automotive shredder residue. This information will then be used to create a flexible, computerized, life-cycle inventory model, which is process specific and yet can be modified to include additional recycling technologies and various material inputs. Life cycle involves assessing all of the upstream burdens associated with the production of the materials and energies used in the process, including the transport of all materials to the facility.

The Vehicle Recycling Partnership (VRP) contracted PE Europe GmbH, a company that is experienced in conducting life-cycle assessments and in model development using their own GaBi (Ganzheitliche Bilanzerung) software, to assess Salyp NV’s mechanical separation process and create a flexible end-of-life module based on this scenario.

Salyp NV's separation process, the first technology examined as part of this project, combined equipment developed by Argonne National Laboratory and others to create a facility that currently separates shredder residue into discrete fractions of metals, foam, mixed plastics, fiber-rich, and dust streams.

Because a life-cycle inventory requires the collection of primary data on each process, including all energy, water, and material inputs plus data on emissions to air and water, wastes, and products produced, these data were collected for the Salyp separation process and then input into the GaBi software to create a flexible model of the process. Table 2 shows the percentages used for the creation of the model, and Figure 2 shows the mass flow of the material as depicted in the GaBi software.

Table 2. Average shredder residue composition: basis used for LCA modeling

Material	ASR (%)
Plastic	34.0
Ferrous metals	33.4
Sand, dirt	15.7
Unknown	4.0
Glass	3.4
Wood	2.8
PU foam	2.8
Nonferrous metals	2.2
Copper	1.1
Stainless steel	0.6

Three different scenarios for handling the various materials recovered from the separation

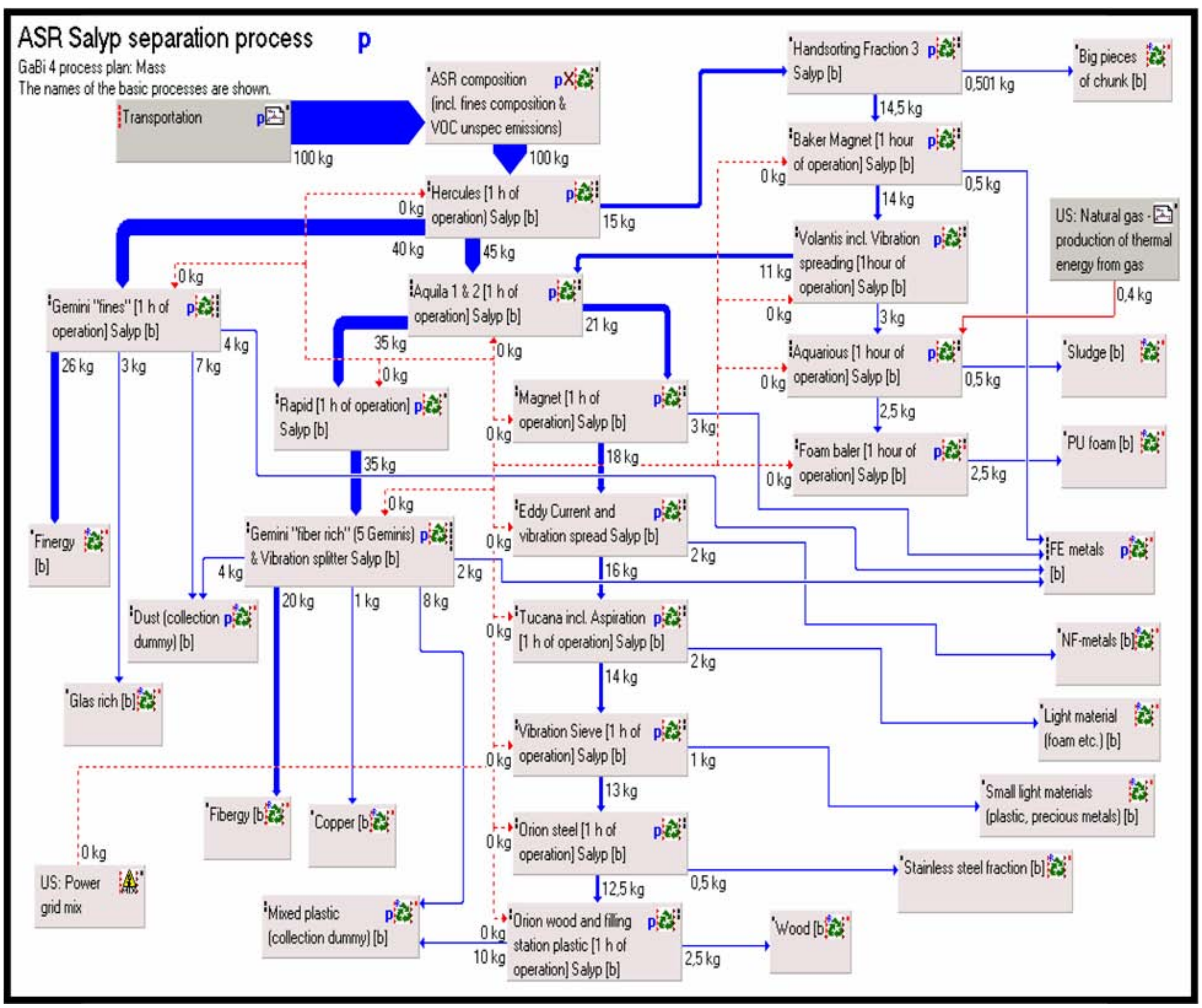

Figure 2. Life-cycle analysis mass flow representation of Salyp separation process.

process were determined along with their market values. These included waste treatment such as material recovery, energy recovery, turning specific material fractions into oil for cement kilns, as well as material substitution using mixed plastics to replace products such as wood pallets and polypropylene (PP) pellets. GaBi allows for the analysis of the various scenarios in a range of impact categories, including primary energy demand, photochemical ozone creation potential, and CO_2 emissions. All of these scenarios can be changed within the GaBi software to account for different or new types of treatments that arise in the future, which could lead to different impacts on the environment.

The model allows the user to run simulations on shredder residue separation within different boundary conditions. The following boundary conditions can be modified: (1) shredder residue composition, (2) location of the facility, (3) type and distance of transportation, (4) market values for the separated fractions, (5) new potential applications for separated fractions, and (6) utilization ratio of the facility.

Additional life-cycle studies are underway to compare mechanical separation to other thermal/chemical conversion technologies. When completed, the goal is to have a comprehensive end-of-life model that will allow us to rapidly and accurately assess the potential environmental impact of various material/design changes in our future vehicles.

Recyclability Studies

Recyclability studies are being conducted to examine the effect of using automotive lightweighting material on recyclability. A Toyota Prius hybrid was selected for a reference case. This vehicle is a second-generation hybrid with a gas/electric powertrain. Evaluating the recyclability of this vehicle and its new technology will be a step in identifying changes that will impact end-of-life recycling of vehicles of the future.

In collaboration with Johnson Controls, Inc. (JCI), the VRP dismantled the vehicle according to VRP procedures to single material components and entered data for each part into a database. A material list that identified the breakdown of materials into separate classifications such as ferrous and non-ferrous metals, as well as composte materials and plastics was prepared. The materials breakdown is summarized in Table 3 and shown in Figure 3. In comparison, the materials composition of a production Ford Taurus is summarized in Table 4 and Figure 4.

Table 3. 2004 Toyota Prius materials breakdown

Materials	Mass (kg)	Percent
Ferrous metals	776.94	60.55
Nonferrous metals	229.99	17.92
Plastics	154.85	12.07
Elastomers	39.66	3.09
Inorganic material	34.71	2.71
Other	28.21	2.20
Organic materials	18.84	1.47
Vehicle mass (less fluids)	1283.1	100.00

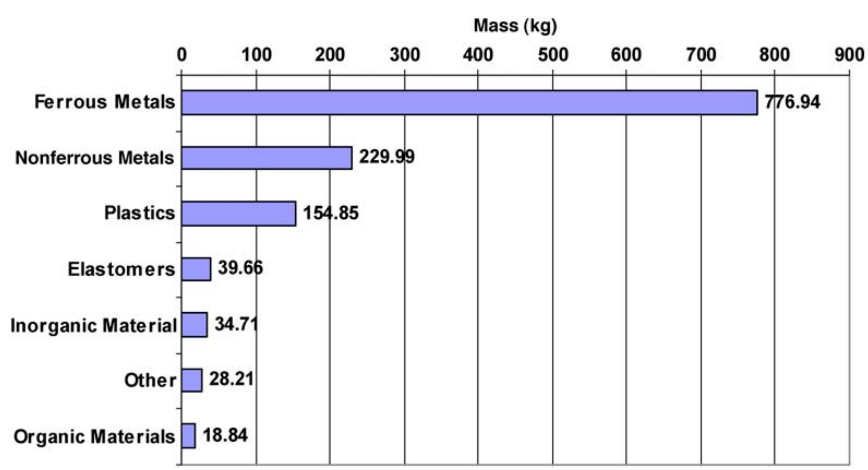

Figure 3. 2004 Toyota Prius materials breakdown.

Table 4. 2004 Ford Taurus materials breakdown

Materials	Mass (kg)	Percent
Ferrous metals	1008.28	70.37
Plastics	154.41	10.78
Nonferrous metals	141.43	9.87
Elastomers	68.71	4.80
Inorganic material	40.91	2.86
Other	17.45	1.22
Organic materials	1.66	0.12
Vehicle mass (less fluids)	1432.86	100.00

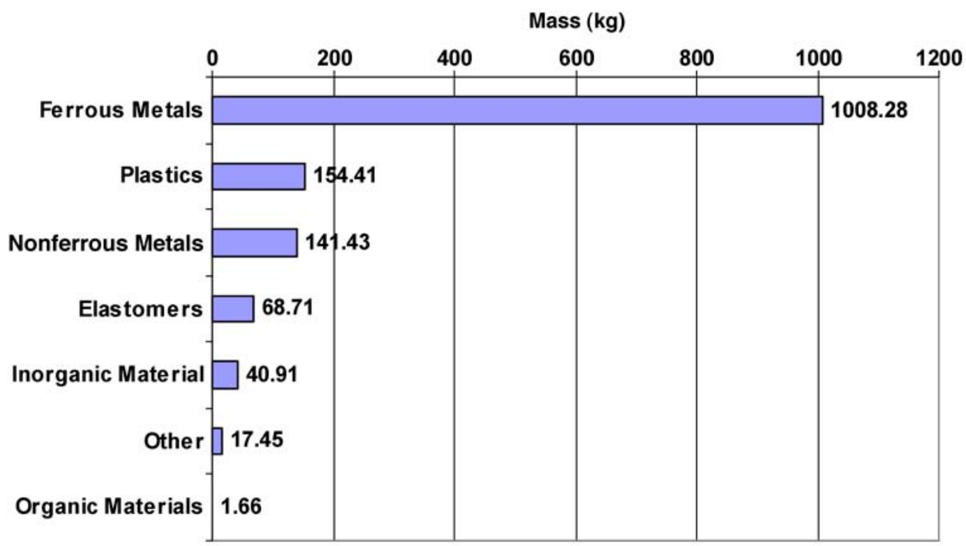

Figure 4. 2004 Ford Taurus materials breakdown.

Three different recyclability calculations were made (Table 5). The Federal Trade Commission (FTC) recyclability number is the percentage by weight of the material that is currently being recycled, and it includes metals, fluids less fuel, and batteries. The European guidelines include FTC materials plus fuel at 90% of a full tank, plastics that could be recycled, and up to 10% by weight energy recovery. Note that Europe requires 95% recyclability for new vehicles. The feasible-to-recycle number includes the FTC materials plus plastics that can be recycled. Changes to the current infrastructure would be required to increase recycling beyond the current FTC percentage.

Table 5. Reference case recyclability: 2004 Toyota Prius

Federal Trade Commission	80.86%
European	97.61%
Feasible to recycle	85.58%
Ref. 2000 Ford Taurus Federal Trade Commission	80.50%

To establish an indication of the impact of lightweight materials on the reference case recyclability calculations, the production Toyota Prius is compared to a proposed aluminum-intensive lightweight vehicle and a proposed composite lightweight vehicle based on the 2004 Toyota Prius. The production 2004 Toyota Prius hybrid vehicle body was steel with aluminum hood and decklid. The suspension was of steel except for an aluminum steering knuckle on the front suspension. This was used as the base for this study.

The aluminum alternative is for a 2004 Toyota Prius with an aluminum body and magnesium engine cradle and rear axle substituted for the production parts. In addition, seat frames, body brackets, and the instrument panel cross car beam have been changed from steel to aluminum. As a result the weight has been reduced by approximately 630 lb or 21%. Because the weight reduction is entirely in the currently recycled portion of the vehicle, the recyclability is adversely affected and is reduced from 80.86% to 76.10%. No changes were made to the currently nonrecycled portion of the vehicle. Aluminum replaced steel at 50% by weight of the original steel.

The composite alternative is for a 2004 Toyota Prius with a carbon fiber body with 40% carbon fiber and 60% thermoset polyurethane/urea resin by volume, 49.72% carbon and 50.28% thermoset polyurethane/urea resin by weight, and magnesium engine cradle and rear axle substituted for the production parts. In addition, seat frames, body brackets, and the instrument panel cross car beam have been changed from steel to composite. As a result the weight has been reduced by approximately 711 lb or 24%. Because the weight reduction is entirely in the currently recycled portion of the vehicle, the recyclability is adversely affected and is reduced from 80.86% to 57.20% if none of the composite is recycled or 74% if all of the composite material is recycled. No changes were made to the currently nonrecycled portion of the vehicle. The composite material replaced steel at 40% by weight of the original steel.

There are reductions in all three recyclability calculations for lightweighted vehicles, even though there is no change to the rest of the vehicle (Table 6). Where the aluminum and composite material is being recycled, the same amount of material would be landfilled in each of the three scenarios. The only difference is that the recycled portion of the lightweighted vehicles would be lighter. While the recyclability would be less, there would be no difference in landfill, and the lighter vehicles would use less fuel during their life. As can be seen, lightweighting presents challenges in the European market. Note that these calculations do not take into account downweighting of related components that would accompany any lightweight vehicle, such as powertrains, brakes, tires, etc. Because the downweighted components are high in metallic content, downweighting will further reduce recyclability and make it difficult to meet the European 95% requirement.

Table 6. 2004 Toyota Prius recyclability, reference case vs aluminum and composite body materials

	As produced (%)	Aluminum body (%)	Composite body (%)
FTC	80.9	76.1	74.0[a]
European	97.6	96.0	94.5[a]
Feasible to recycle	88.3	85.6	83.9[a]

[a]If the composite material were not recycled, then the numbers would be FTC—57.2%, European—78.2%, and Feasible to Recycle—67.1%. Recycling of the composite material would require significant changes in the current recycling infrastructure. In addition, a market for the recycled carbon fibers would need to be developed. Current technology for recycling carbon fibers results in a 20% loss in fiber length and properties, which would limit their reuse in the original applications.

In conjunction with this study, additional evaluations are planned using these data as a starting point for assessing recyclability of cars of the future. The impact of vehicle lightweighting and material selection on recyclability will be evaluated. In addition, powertrain changes including hybrid and fuel cell alternatives will be compared to current vehicles. An assessment of various alternatives on recycling and the effect on the current recycling infrastructure will be produced. No downsizing of other components was included in this study. Future studies will reflect downweighting of powertrains, brakes, tires, and other components in recyclability calculations. Items requiring further study resulting from these assessments will support future projects to determine the feasibility of various alternative vehicle configurations and material selection choices.