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Recommended Practice to Design for Recycling  
Proton Exchange Membrane (PEM) Fuel Cell Systems

## RATIONALE

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**TABLE OF CONTENTS**

|       |                                                                |    |
|-------|----------------------------------------------------------------|----|
| 1     | Scope .....                                                    | 3  |
| 1.1   | Mission Objective .....                                        | 3  |
| 1.2   | Scope of Recommended Practice .....                            | 3  |
| 1.3   | Limitations of Recommended Practice .....                      | 3  |
| 1.4   | Organization of Recommended Practice .....                     | 4  |
| 1.5   | How to Use the Document .....                                  | 4  |
| 2.    | References .....                                               | 5  |
| 3.    | Definitions .....                                              | 6  |
| 4.    | Section I .....                                                | 8  |
| 4.1   | Background .....                                               | 8  |
| 4.2   | Vehicle Recyclability Calculations .....                       | 8  |
| 4.3   | Fuel Cell System Recyclability Overview .....                  | 8  |
| 4.4   | Fuel Cell System Disassembly and Recyclability Ratings .....   | 9  |
| 4.4.1 | Disassembly Rating .....                                       | 9  |
| 4.4.2 | Recyclability Rating .....                                     | 10 |
| 4.5   | Design For Disassembly and Recyclability Recommendations ..... | 11 |
| 5.    | Section II .....                                               | 13 |
| 5.1   | PEM Fuel Cell System Recyclability Chart .....                 | 13 |
| 5.2   | System and System Components .....                             | 13 |
| 5.3   | Material Types .....                                           | 13 |
| 5.4   | Recyclability Issues .....                                     | 13 |
| 5.4.1 | Disassembly Issues .....                                       | 14 |
| 5.4.2 | Reuse or Alternative Use .....                                 | 14 |
| 5.4.3 | Technical .....                                                | 14 |
| 5.4.4 | Infrastructure .....                                           | 14 |
| 5.5   | Sustainability Issues .....                                    | 14 |
| 5.5.1 | Resource Depletion .....                                       | 14 |
| 5.5.2 | End of Life Environmental Issues .....                         | 14 |

|            |                                                                            |    |
|------------|----------------------------------------------------------------------------|----|
| 5.6        | PEM Fuel Cell Subsystems, Material, and Related Environmental Issues ..... | 15 |
| 5.6.1      | Gaseous Hydrogen Storage .....                                             | 15 |
| 5.6.1.1    | Type 1 Tank.....                                                           | 15 |
| 5.6.1.1.1  | System Components and Material Types .....                                 | 15 |
| 5.6.1.1.2  | Recycling Engineering Issues.....                                          | 15 |
| 5.6.1.1.3  | Recycling Environmental Issues .....                                       | 15 |
| 5.6.1.2    | Type 2 Tank.....                                                           | 15 |
| 5.6.1.2.1  | System Components and Material Types .....                                 | 15 |
| 5.6.1.2.2  | Recycling Engineering Issues.....                                          | 15 |
| 5.6.1.2.3  | Recycling Environmental Issues .....                                       | 15 |
| 5.6.1.3    | Type 3 Tank.....                                                           | 22 |
| 5.6.1.3.1  | System Components and Material Types .....                                 | 22 |
| 5.6.1.3.2  | Recycling Engineering Issues.....                                          | 22 |
| 5.6.1.3.3  | Recycling Environmental Issues .....                                       | 22 |
| 5.6.1.4    | Type 4 Tank.....                                                           | 22 |
| 5.6.1.4.1  | System Components and Material Types .....                                 | 22 |
| 5.6.1.4.2  | Recycling Engineering Issues.....                                          | 22 |
| 5.6.1.4.3  | Recycling Environmental Issues .....                                       | 22 |
| 5.6.2      | Liquid Hydrogen Storage .....                                              | 22 |
| 5.6.2.1    | System Components and Material Types .....                                 | 22 |
| 5.6.2.2    | Recycling Engineering Issues.....                                          | 22 |
| 5.6.2.3    | Recycling Environmental Issues .....                                       | 22 |
| 5.6.3      | Hydride Hydrogen Storage Systems .....                                     | 23 |
| 5.6.3.1    | Metal Hydrides.....                                                        | 23 |
| 5.6.3.1.1  | System Components and Material Types .....                                 | 23 |
| 5.6.3.1.2  | Recycling Engineering Issues.....                                          | 23 |
| 5.6.3.1.3  | Recycling Environmental Issues .....                                       | 23 |
| 5.6.3.2    | Chemical Hydrides.....                                                     | 24 |
| 5.6.3.2.1  | System Components and Material Types .....                                 | 24 |
| 5.6.3.2.2  | Recycling Engineering Issues.....                                          | 25 |
| 5.6.3.2.3  | Recycling Environmental Issues .....                                       | 25 |
| 5.6.4      | Onboard Hydrogen Reforming.....                                            | 25 |
| 5.6.4.1    | Fuel Processing .....                                                      | 25 |
| 5.6.4.1.1  | System Components and Material Types .....                                 | 25 |
| 5.6.4.1.2  | Recycling Engineering Issues.....                                          | 26 |
| 5.6.4.1.3  | Recycling Environmental Issues .....                                       | 26 |
| 5.6.5      | Balance of Plant.....                                                      | 27 |
| 5.6.5.1    | System Components and Material Type .....                                  | 27 |
| 5.6.5.1.1  | Oxidant Management .....                                                   | 27 |
| 5.6.5.1.2  | Water Management .....                                                     | 27 |
| 5.6.5.1.3  | Thermal Management.....                                                    | 27 |
| 5.6.5.1.4  | Power Conditioning and Electronics .....                                   | 27 |
| 5.6.5.1.5  | Piping Systems and Miscellaneous Mechanical Systems .....                  | 28 |
| 5.6.5.2    | Recycling Engineering Issues.....                                          | 28 |
| 5.6.5.3    | Recycling Environmental Issues .....                                       | 28 |
| 5.6.6      | Fuel Cell Stack.....                                                       | 28 |
| 5.6.6.1    | System Components and Material Types .....                                 | 28 |
| 5.6.6.2    | Recycling Engineering Issues.....                                          | 29 |
| 5.6.6.3    | Recycling Environmental Issues .....                                       | 30 |
| Appendix A | Section III .....                                                          | 31 |
| A.1        | Description of Plastics Compatibility Chart .....                          | 31 |

## 1. Scope

- 1.1 Mission Objective**—In 1999, the Society of Automotive Engineers established a Committee for Fuel Cell Standards. The Committee is organized in subcommittees that address issues such as Safety, Performance, and Recycling. The mission of the Recycling Subcommittee is to develop a recommended practice document that incorporates existing recycling practices and identifies technical and environmental sustainability issues and applies them to proton exchange membrane (PEM) fuel cell (FC) systems.

Recyclability is best considered early in the product engineering design/development process. The design engineer should be concerned with the product after its useful life and adopt a mindset of designing for disassembly and recycling.

The purpose of this SAE Recommended Practice document is to provide a tool that helps the FC system designers and engineers incorporate recyclability into the PEM FC design process. This document was derived by considering existing recycling recommended practices then applying them to assess and evaluate the recyclability of the PEM FC system. This document should be used to continually assess the recyclability of component and assembly designs during the early design phase, in order to reach optimized recyclability, recycled content, and minimized environmental impact associated with those designs. This document defines a PEM FC rating system that assesses the ease of removal of the PEM FC system and/or components from a vehicle; then upon removal from the vehicle, the ease of recycling those components and materials. The derived rating is used as a PEM FC component design tool for continual improvement opportunities and not for purposes of calculating recyclability of the entire vehicle. While other trade-offs such as mass, piece-cost, volume, etc. must also be considered when designing these systems, they are not discussed in this document.

- 1.2 Scope of Recommended Practice**—While there are various types of Fuel Cell architectures being developed, the focus of this document is on Proton Exchange Membrane (PEM) fuel cell stacks and ancillary components for automotive propulsion applications. Within the boundaries of this document are the: Fuel Supply and Storage, Fuel Processor, Fuel Cell Stack, and Balance of Plant, as shown in Figure 1.
- 1.3 Limitations of Recommended Practice**—There are numerous issues that affect recyclability: economics, infrastructure, market demand, technical feasibility and legislation. These are all closely related to making recycling possible, but are beyond the influence of the design engineer. This document addresses only end-of-life technical recyclability design practices. It does not address material preparation, component fabrication, or in-use environmental impacts. While there are environmental issues associated with these stages of material use, they are outside the scope of this document and are expected to be considered in design for the environment and environmental life cycle studies.

Additionally this document does not provide the methodology for calculating the recyclability of a vehicle or its components per OEM calculation methods. In addition to the use of this recyclability design document for the development of a recyclability rating for FC system and components, calculation methods similar to those mentioned previously may be required by the OEMs for calculating the recyclability of entire vehicles. FC design engineers should reference specific automobile manufacturers' specifications and other industry standards (ISO 22628) for calculation methods and requirements.

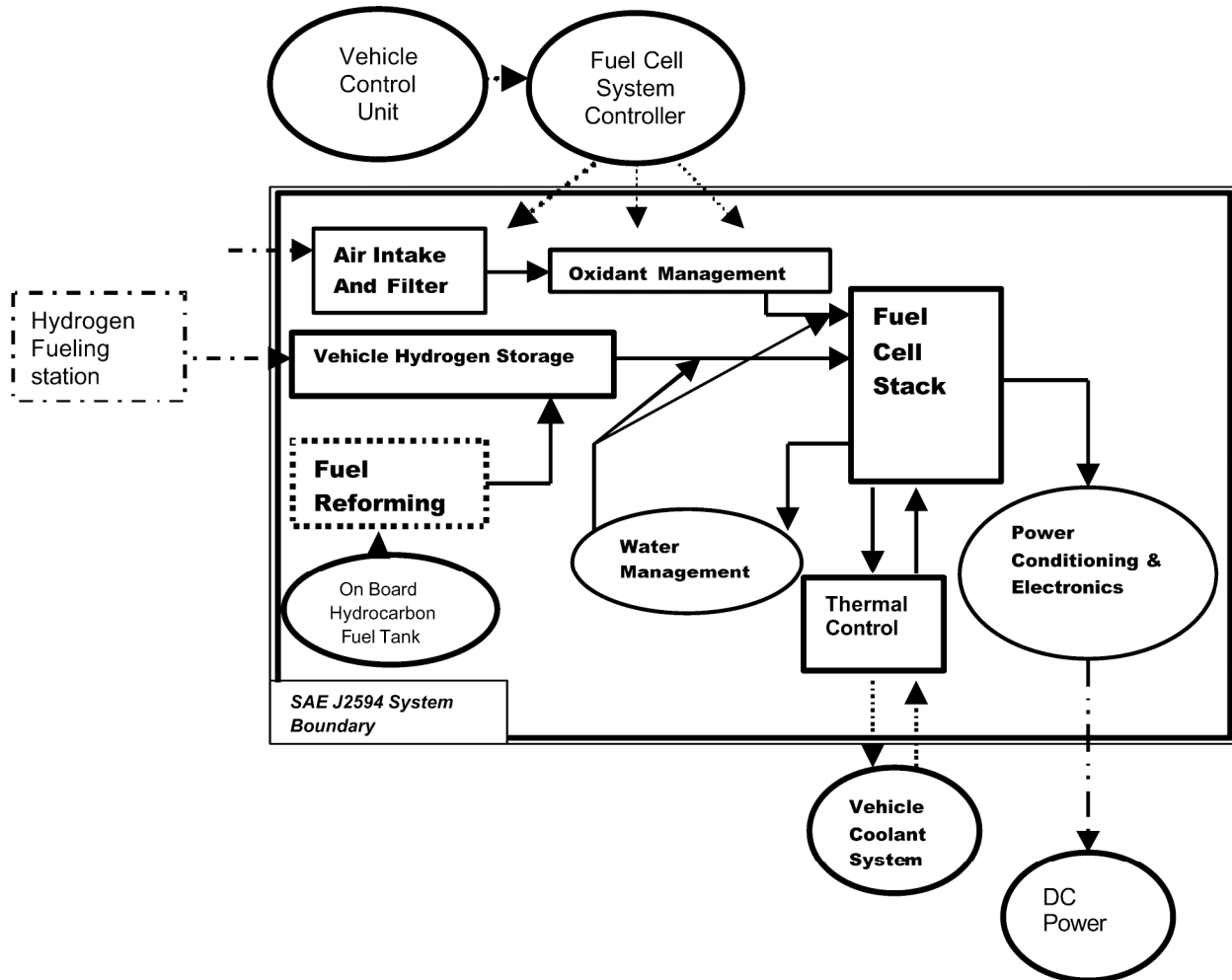


FIGURE 1—SCHEMATIC ILLUSTRATION OF THE PEM FUEL CELL SYSTEM BOUNDARY

**1.4 Organization of the Recommended Practice**—This document is organized to provide easy access for frequent as well as occasional reference. Chapter 3 provides a list of definitions. Chapter 4 provides guidance on handling fuel cell systems within the existing automotive recycling framework, a description and instructions on the use of Disassembly and Recyclability evaluation tables, and recommendations on design considerations for enhancing disassembly and recyclability. These tables allow the user to evaluate the recyclability of a new or existing fuel cell component/system design. A detailed chart describing materials of construction for fuel cell system components is presented and described in Chapter 5. An Appendix provides information on plastics compatibility.

**1.5 How to Use the Document**—This document can be used for new and existing designs. Uses of the document are described in Figure 2.

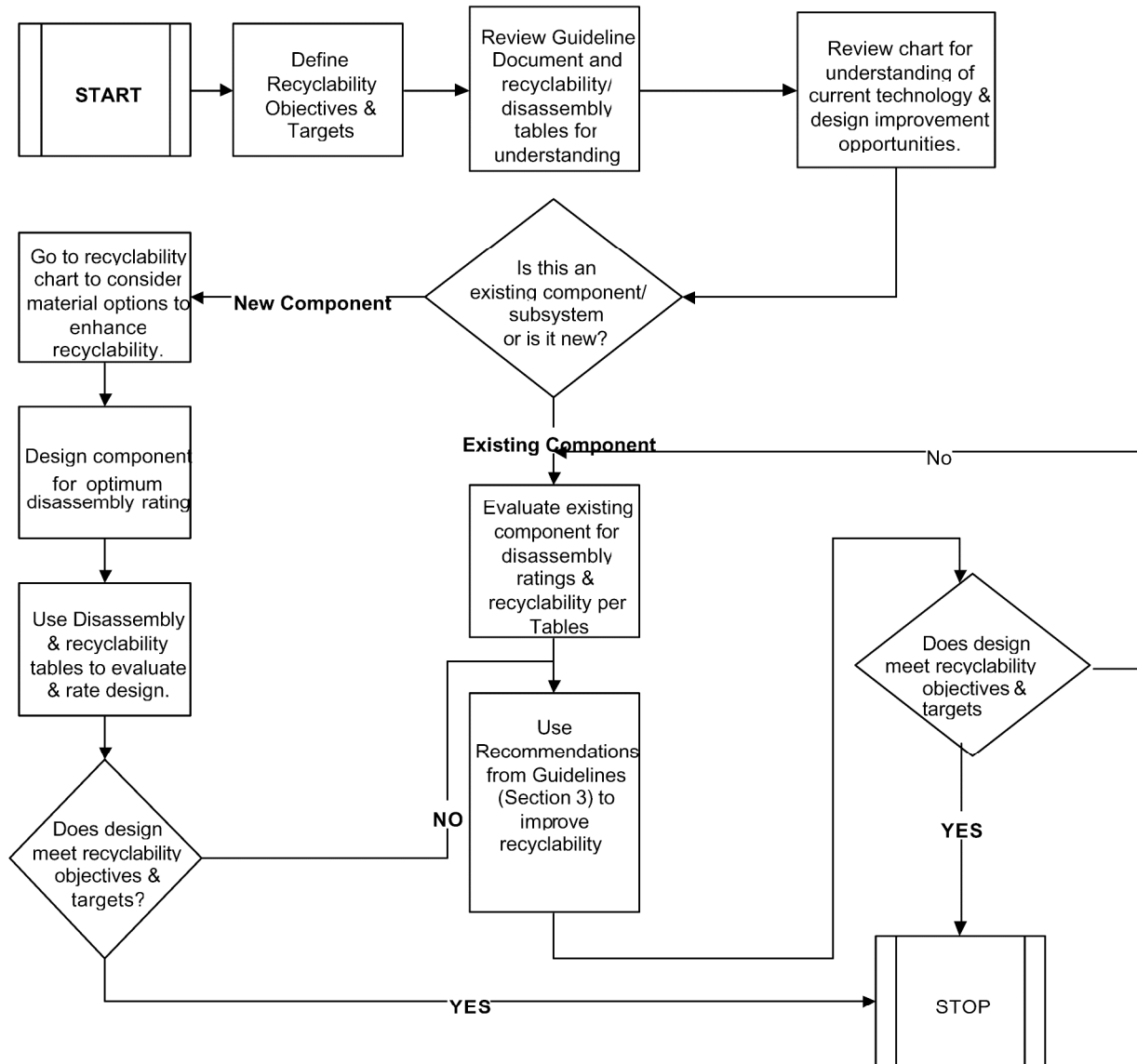


FIGURE 2—HOW TO USE THE FUEL CELL RECYCLABILITY RECOMMENDED PRACTICE: PROCESS FLOW CHART

## 2. References

**2.1 Applicable Publications**—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J2578—Recommended Practice for General Fuel Cell Vehicle Safety  
 SAE J2574—Fuel Cell Vehicle Terminology  
 SAE J1344—Marking of Plastic Parts

- 2.1.2 EC PUBLICATION—Available from European Union in Brussels. website: <http://europa.eu.int/abc/doc/off/rg/en/welcome.htm>.

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of-life vehicles, Official Journal of the European Communities, 21.10.2000.

- 2.1.3 ISO PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 22628:2002—Road vehicles—Recyclability and recoverability—Calculation method  
ISO 11469—Plastic—Generic identification and marking of plastic products  
ISO 1043—Plastics—Symbols—Part 1: Basic polymers  
ISO 1043-2—Plastics—Symbols—Part 2: Fillers and reinforcing materials  
ISO 1629-1—Rubber—Nomenclature—Part 1: Dry rubber and lattices  
ISO 1629-2—Rubber—Nomenclature—Part 2: Thermoplastic Elastomers Mark Rubber Parts

- 2.1.4 USCAR PUBLICATION—Available from USCAR, 1000 Town center, Suite 300, Southfield, MI 48075.

Design for Recycling Guidelines, Vehicle Recycling Partnership/USCAR, 1996, (<http://www.uscar.org/consortia&teams/VRP/preferredpractices.pdf>).

- 2.2 Related Publications**—The following publications are provided for information purposes only and are not a required part of this specification.

- 2.2.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

J.C. Alonso, et al. Proceedings of the 2002 Environmental Sustainability Conference and Exhibition, Society of Automotive Engineers, 2002.  
Analysis and Assessment of Automobiles with Regard to the Requirements of Design for Recycling, J. Boes, et al., Proceedings of the 2002 Environmental Sustainability Conference and Exhibition, Society of Automotive Engineers, 2002.  
Analysis and Assessment of Automobiles with Regard to the Requirements of Design for Recycling, J. Boes, et al., Proceedings of the 2002 Environmental Sustainability Conference and Exhibition, Society of Automotive Engineers, 2002.

- 2.2.2 ALLIANCE OF AUTOMOBILE MANUFACTURERS PUBLICATION—Available from Alliance of Automobile Manufacturers, 2000 Town Center, Suite 1140, Southfield, MI 48075.

Automotive Facts and Figures, Alliance of Automobile Manufacturers, 2001.

- 2.2.3 OTHER PUBLICATIONS

Impact of the European Union vehicle waste directive on end-of-life options for polymer electrolyte fuel cells, C. Handley, et al., Journal of Power Sources, 2002  
Practical guide to environmental management, 8th Edition, May, 2000, Environmental Law Institute  
Integrating LCA and DfE in the Design of Electrical and Electronic Products in the Automotive Sector

- 3. Definitions**—The primary reference for fuel cell terminology is the SAE J2574. Several additional definitions required for the recycling of PEM Fuel Cell Systems are included here and listed as follows.

- 3.1 Automotive Shredder Residue (ASR)**—The material in a vehicle that is not sold for reuse after dismantling, or separated for recycling after shredding and is typically land filled. This material contains about 34% plastic, 17% fluids, 12% rubber, 16% glass, 21% other contaminants (e.g., fibers, dirt, foam).

- 3.2 Dismantling**—Process of removing component parts from the vehicle.
- 3.3 End-of-Life Vehicle (ELV)**—A vehicle that has completed its useful life and is taken out of service for disposal.
- 3.4 Post-Consumer Recycled Content**—The portion of a material's or product's mass that is composed of materials that have been recovered from or otherwise diverted from the solid waste stream after consumer use.
- 3.5 Post-Industrial Recycled Content**—The portion of a material's or product's mass that is composed of materials that have been recovered from or otherwise diverted from the solid waste stream during the manufacturing process (pre-consumer).
- 3.6 Recyclable Material**—Material which can be diverted from an end-of-life stream to be recycled.
- 3.7 Recycled Content**—Proportion by mass in a product or material that is composed of materials that have been recovered from or otherwise diverted from the waste stream.
- 3.8 Post-Consumer Recyclate**—Material generated by a business or consumer that has served their intended end-uses and has been recovered or otherwise diverted from the waste stream for the purpose of recycling.
- 3.9 Post-Industrial Recyclate**—Material generated during any step in the production of a product or material, including intermediary steps in the process, that has been recovered or otherwise diverted from the waste stream for the purpose of recycling.
- 3.10 Recovery**—Reprocessing waste materials for original use, for other purposes, or as a means of generating energy.
- 3.11 Recyclability**—The potential to recover or otherwise divert products or materials from the waste stream for purposes of recycling.
- 3.12 Recyclability Rate**—Percentage by mass of the vehicle that can potentially be recycled, reused, or both.
- 3.13 Recyclability Rating**—The numeric value (as defined in this document) given to assess the potential to re-use, remanufacture, recycle, or recover the parts or materials from a vehicle.
- 3.14 Recycling**—Reprocessing waste materials for the original purpose or for other purposes, excluding the processing as a means of generating energy.
- 3.15 Recycling Engineering Issues**—A reference to issues of potential concern or attention to design engineers related to the ease of dismantling various components of PEM fuel cell systems.
- 3.16 Recycling Environmental Issues**—A reference to issues of potential concern or attention to design engineers related to the potential impacts of recycling various components of PEM fuel cell systems.
- 3.17 Residue Treatment**—Any process applied to ASR to further separate, recycle material(s) or recover energy contained therein, including landfilling the residue.
- 3.18 Re-use**—Any operation by which component parts of end-of-life vehicles are used for the same purpose for which they were initially intended.
- 3.19 Remanufacture**—The process of restoring used durable product to a “like new” condition.

#### 4. Section I

- 4.1 Background**—Automobile recycling has been practiced since the early 1900s, shortly after the first automobiles were built, specifically in the area of metals recovery. Generally, over 94% of all End of Life Vehicles (ELVs) are recycled with an average rate of recycling of 75% by weight per vehicle. The remaining 25%, made up primarily of foam, glass, plastic, and rubber, is known as Automotive Shredder Residue (ASR) and is usually disposed of in landfills. Worldwide, approximately 30 million end-of-life vehicles and 8 million tons of ASR are generated annually. This is an issue due to limited landfill space in some areas and has resulted in legislation in various regions around the world. In other areas, ASR is legally permitted as a landfill day cover.

The handling of an entire end-of-life vehicle is a four-step process: pre-treatment (depollution), dismantling (also known as disassembly), metal separation (shredding), and residue treatment. Within each step of the ELV process, a variety of vehicle components and/or materials are recovered for reuse, recycling, remanufacture, or energy recovery.

- 4.2 Vehicle Recyclability Calculations**—An international industry work group was formed, under the International Standards Organization (ISO) to develop a calculation method for determining the recyclability/recoverability rate of end-of-life vehicles, ISO 22628. This method is based upon the 4 main stages of ELV treatment and proven recycling technologies. This is the preferred industry standard used by the OEMs to calculate the recyclability of the entire vehicle.

- 4.3 Fuel Cell System Recyclability Overview**—The term PEM FC recyclability as used in this document refers to the reuse, remanufacturing, recovery, and/or recycling of materials used in the components of the PEM FC system. Fuel cell system and subsystem recyclability depends on two main factors: the ease of disassembly (part removal) from a vehicle, and the inherent recyclability of the components/materials. For the entire fuel cell system, a variety of recycling methods may be applied to the various subsystems and components. These include manual separation (where a dismantler removes the sub-components by hand), chemical recovery (thermal, chemical or electro-chemical separation to recover materials such as precious metals), and mechanical treatment (where materials are separated and/or shredded together then separated by material properties e.g., magnetic, density, etc.). It may be possible to selectively remove sub-components containing a number of mixed materials so that the remainder of the fuel cell system can be recycled more easily. High value materials may be manually separated, with the balance of the system being recycled along with the bulk of the vehicle during the shredding process.

Reuse of parts is the highest form of recycling (parts may be used directly without any additional processing, e.g. fender, trim, tail light lenses) and depends on the ease of disassembly, market demand for use in repair or replacement, part durability, cost of a new part, and the existing infrastructure for collection, distribution and service for part replacement. Other parts may be remanufactured by restoring original quality and performance levels through the replacement of all worn or deteriorated components and re-tested to Original Equipment (OE) specifications. This reuse saves energy, natural resources, landfill space, and cost.

Factors influencing remanufacture are similar to reuse. Material recycling is based on technology available to process the material, the existence of a supporting infrastructure, cost of virgin material, the ability to separate the materials into pure streams, any hazardous materials content and the inherent economic value of the material. These points are discussed in more detail throughout this recommended practice.

- 4.4 Fuel Cell System Disassembly and Recyclability Ratings**—Disassembly rating refers to the ease of removing the component/assembly from the vehicle. In general, the disassembly of the component/assembly from the vehicle is dependent on the part location/accessibility on the vehicle, its value, and the treatment method used. Recyclability ratings refer to the ability to re-use, remanufacture, recycle, or recover the materials in the component/assembly, after removal/disassembly from the vehicle.

The following FC Disassembly and Recyclability Tables (Tables 1 and 2) should be used as an example of one method of calculating disassembly and recyclability ratings since several methods exist within the industry and may not be consistent with OEM specific methods. FC system and component designers and engineers can use these examples along with other methods to evaluate their current design. The disassembly rating is best applied from the system perspective rather than evaluating each individual component. System “design for disassembly” efforts should concentrate on parts and materials that have significant value and/or mass. The recyclability rating is applicable to components within the system. These rating tools should be used together for comparison of alternative materials and designs and for the identification and evaluation of system and component recyclability opportunities. In each case a lower rating is preferred.

- 4.4.1 DISASSEMBLY RATING**—The Disassembly Table (Table 1) is a tool for evaluating joining aspects and configurations of fuel cell parts and components as to their suitability for disassembly. Fuel cell designers can use the results of this tool along with other industry and OEM specific tools to estimate ease of disassembly of fuel cell components from end-of-life vehicles for reuse, remanufacturing or material recycling. Once the disassembly potential is evaluated, fuel cell designers may consider changes or improvements to increase disassembly potential.

The table addresses joining aspects, joining configurations and ratings for each selected parameter. Joining aspects include factors such as location, disconnectability, accessibility, number of joinings, joining tools and joining types. Joining configurations describe possible designs to facilitate disassembly and ratings are assigned for evaluating designs. Desirable designs are given low numerical ratings and a low total rating indicates better design for disassembly. Although a low total rating indicates better design for disassembly, the individual joining aspects should be evaluated as well for ways to improve the disassembly potential.

For example, fuel cell components which are located (aspect) in a visible (configuration) area (rating = 1) are more desirable than a covered (rating = 2) or hidden (rating = 3) location. Covered parts may be partially visible behind another component, while hidden parts cannot be seen and would require the removal of other components. Accessibility (aspect) may be direct axial (configuration) which allows direct-line access to the part (rating = 1) for dismantling, or indirect axial which allows access with greater effort (rating = 2), or radial access which is the most difficult (rating = 3). Number of joinings refers to the advantages of fewer attachments to secure the part, and joining tools describes the degree of standardization of disassembly tools needed for part removal. Standardization in this case means the tool is the same for all joinings on a part (rating = 1), the tools are the same type for all joinings on a part (rating = 2) or tools required are of multiple types for different joinings on a part (rating = 3). Types of joinings refer to the method of attachment. The best type (rating = 1) is no fastener (e.g., pressure or snap fit). Other methods include screws, bolts, clips (rating = 2), and the least desirable are bondings such as rivets, welding, soldering and adhesives (rating = 3). However, any joining method selected must consider safety and integrity of the system as a priority.

The disconnectability aspect is more subjective and addresses less well-defined criteria for nondestructive disassembly of the part (rating = 1), partial part destruction (rating = 2), or removal only by part destruction (rating = 3). This requires more speculative engineering assessments and decisions.

**TABLE 1—FUEL CELL SYSTEM DISASSEMBLY RATING**

| Joining Aspects                     | Joining Configuration                  | Joining Score | Joining Score | Joining Score |
|-------------------------------------|----------------------------------------|---------------|---------------|---------------|
| 1. Location                         | Visible                                | 1             |               |               |
|                                     | Covered                                |               | 2             |               |
|                                     | Hidden                                 |               |               | 3             |
| 2. Disconnectability                | Disconnected nondestructively          | 1             |               |               |
|                                     | Partial destruction                    |               | 2             |               |
|                                     | Disconnected only by part destruction  |               |               | 3             |
| 3. Accessibility                    | Direct axial direction                 | 1             |               |               |
|                                     | Indirect axial direction               |               | 2             |               |
|                                     | Radial direction                       |               |               | 3             |
| 4. Number of Joinings               | One or few joinings                    | 1             |               |               |
|                                     | Low number of joinings                 |               | 2             |               |
|                                     | High number of joinings                |               |               | 3             |
| 5. Joining Tools                    | Joining elements standardized          | 1             |               |               |
|                                     | Standardized within type of joining    |               | 2             |               |
|                                     | Not (or almost not) standardized       |               |               | 3             |
| 6. Joining types                    | Pressure fit, snap fit, or no fastener | 1             |               |               |
|                                     | Clips, screws, bolts, etc.             |               | 2             |               |
|                                     | Rivets, welding, soldering, adhesives  |               |               | 3             |
| Total Score (Lower score is better) |                                        | +             | +             | =             |

- 4.4.2 **RECYCLABILITY RATING**—The recyclability table (Table 2) is a tool for evaluating the ability to re-use, remanufacture, recycle, or recover the parts and/or materials in fuel cell components/assemblies subsequent to disassembly from the vehicle. Once the recyclability potential is evaluated, fuel cell designers may consider changes or improvements to increase the recycling potential.

There are six recyclability categories and ratings in the table, which may have different ratings and definitions from other categories within the industry or OEM specific categories. The most favorable recycling category is re-use, rating 1. For example, some parts (e.g., fender, trim, tail light lenses) from ELVs may be used directly without any additional processing. Other parts must be remanufactured (rating 2) by restoring to original quality and performance levels through the replacement of all worn or deteriorated components and re-tested to OE specifications. The potential for remanufacturing and re-use is dependent on the remaining safe and useful life of the component. This in turn is dependent upon such factors as model/platform match, time in service, use/abuse, exposure to various environments, service/warranty history, and other factors.

Parts with a rating of 3 include parts and materials that are currently recycled in an established infrastructure. This includes all metallic content, batteries, catalytic converters, and fluids. Materials with a rating of 4 can technically be recycled, however no infrastructure currently exists to economically recycle them. Materials in this category have the potential to be economically recycled once sufficient volume and an infrastructure is in place to support recycling. This category may include many plastic parts, especially those of substantial mass that are readily accessible for disassembly from the vehicle. Some examples may include bumper/fascia, door panels, and body side moldings. Ratings of 5 and 6 are less desirable and attempts should be made to avoid these ratings through design improvement opportunities.