The term "demanufacture" is appearing more and more, especially in the electronics industry (DEC, Motorola, AT&T, IBM), to characterize the process opposite to manufacturing involved in recycling materials and products.
Growing Importance of DFR

- Dwindling resources
  - Landfill space, especially in (over) crowded Europe
  - Raw material (lesser short term importance)
- For example:
  - Currently, around 80-90% of electronics are being sent to landfills!
  - The National Renewable Energy Laboratory estimates that 30 billion lbs. (14 billion kg) of plastics end up being landfilled each year, and only 1% of plastic waste is recycled.
- Social and political climate is changing
  - Big social and political push in Europe
  - Some states, US Congress and president may want to follow Europe’s lead.

European Take Back Legislation

- European “Take-Back Law” requires automobile (and other) manufacturers to take back all vehicles which were ever sold in that country.
- German regulation on electronic waste obliges the retailer to take back used electronic equipment from the end-user. The manufacturer/importer is obliged to take back the products from the retailer.
- Voluntary agreements have been widely accepted by industry and the threat of legislation has subsided slightly.
European Commission - Automobiles

- Objectives
  - Avoidance of waste
  - Reduction of landfill demand
  - Reduction of toxicity

- Recycling Targets
  - Maximum of 15% of car weight can be landfilled or incinerated without energy recovery.
  - For models beginning in 2002, maximum of 10% disposal.
  - Maximum of 5% of car weight disposal in 2015.
  - From 1995, cars must be depolluted before shredding.
  - From 1998, 100% of all wrecks to be collected.

A dream for politicians and a nightmare for car manufacturers? Maybe, but:
- In Europe, people are VERY serious about cleaning up the environment.
- The US is generally expected to follow European successes.

Cooperation in Automobile Industry

- Legislation has caused closer collaboration among vehicle manufacturers.
  - In Europe, several (international) collaborative projects are underway.
  - Daimler-Chrysler is the only company in US in EURHEKAR which is a consortium of non-German car manufacturers.

- BMW and Volvo seem to be leading in Europe

- In the US, largest companies formed the Vehicle Recycling Partnership and the Vehicle Recycling and Dismantling Center in Highland Park to look at recycling issues.

- 10 million vehicles are already recycled in the US annually.
• Recycle:
  – A series of activities, including collection, separation, and processing, by which products or other materials are recovered from or otherwise diverted from the solid waste stream for use in the form of raw materials in the manufacture of new products.
    » Materials which are diverted for use as an energy source should be documented separately under the category of energy recovery
    » US EPA uses the same definition.

• Re-use:
  – The series of activities, including collection, separation, and in some cases processing, by which products are recovered from the waste stream for use in their original intended manner.
    » Remanufactured components fall under the classification of re-use.
    » (Germans refer to this as “product recycling”.)

• Recyclable (recyclability)
  – Refers to products or materials that can be diverted from the waste stream and returned to use as functioning part or a raw material for the manufacture or assembly of a new product through a process that is currently and widely available.
    » If the infrastructure to recycle the product or material is limited, the claim should be so qualified.
    » Recyclability claims should be qualified on a weight basis or in terms of which portions of a product or package are recyclable.

  – In Europe, incineration with energy recovery (“energy recycling”) is also considered an option for recycling.
Common Errors and Mistakes

- Do not make unqualified claims! Always justify!
  - “this product is recyclable” (misleading; how much, what process?)
  - “90% of this vehicle by weight is recyclable” (prove it !!)
  - “parts are marked for recyclability” (justify implication that recycling is possible).

Post and Pre-Consumer Materials

- **Post-Consumer Materials**
  - Those products or materials generated by a business or consumer that have served their intended end uses and that have been recovered from or otherwise diverted from the waste stream for the purpose of recycling.

- **Pre-Consumer Materials**
  - Those materials generated during any step in the production of a material or product that have been recovered or otherwise diverted from the waste stream for the purpose of recycling.
    - This does not include home scrap.
    - Pre-consumer materials are also referred to as rework, post-industrial, and post-process materials.
• **Home Scrap**
  - Those scrap materials, virgin material scrap, or by-products generated from and commonly reused by the industry within an original manufacturing process.
    » This cannot be claimed as recycled content.
    » Plastic regrind is an example of home scrap.

  • Because you cannot claim it as recycled content does not mean you should not recycle it!

• **Recycled Content**
  - The portion of a material’s or product’s weight that is composed of materials that have been recovered from or otherwise diverted from the waste stream either during the manufacturing process (pre-consumer) or after consumer use (post-consumer).

    » Distinctions should be made between pre- and post-consumer materials.

    » Unqualified claims can only be made if the entire product or package is made of recycled materials.

    » The term “recyclate” may be used to refer to a material that contains at least 25% post-consumer recycled content by weight. Not needed when recycled content is specified.

*We want to maximize recycled content as much as possible.*
• Recycling rate
  – The percentage by weight of a given product or material category that is recycled.

*We want to maximize the recycling rate as much as possible.*
Recovery Priorities

1) Re-use
   - Highest priority from environmental point of view
   - All resources (material and energy) put into product during manufacturing are preserved.
   - Requires non-destructive disassembly.

2) Material recycling
   - Most common.
   - Only materials are preserved, all geometric details are lost.
   - Allows for destructive disassembly.
   - Also done for recovery of valuable material (e.g. gold in electronics)

3) Energy recovery
   - Only energy embodied in materials is preserved through incineration or pyrolysis.

Basic Processes

- Disassembly is not the only process

- For remanufacture and re-use, the following processes are typically considered:
  - Non-destructive disassembly down to module level
  - Cleaning
  - Inspection and sorting
  - Part upgrading or renewal
  - Re-assembly.

- For material recycling:
  - Material separation (disassembly, destructive or not),
  - Sorting,
  - Reprocessing.
Shredding (destructive disassembly)

- Arguably, vehicle recycling became economically feasible with shredder technology.
- Shredders reduce vehicles to small fragments which may be sorted magnetically into ferrous and non-ferrous materials.
- Electronics industry is also using shredder technology.

Typical values for vehicles according to the AAMA brochure:

- Automotive Shredder Residue 24%:
  - Plastic 34%
  - Fluids 17%
  - Rubber 12%
  - Glass 16%
  - Other 21%

- Non-Ferrous Metals 5.6%:
  - Aluminum
  - Copper
  - Lead
  - Zinc

- Ferrous Metals 70.4%:
  - Iron
  - Steel

Note: Validity of some numbers has been questioned. Ex., fluid percentage is too high.

Computer Material Composition and Recyclability

- A Carnegie Mellon University study estimates that up to 150 million used computers will be piled in US landfills in 2005.
- Feasibility of recycling computers:
  - Also, about 50 percent of today’s personal computers are plastics, which can be returned to their original makers for recycling.
  - About 30 percent of a personal computer is steel, which fetches about 1.5 cents a pound.
  - 10 percent is aluminum, worth 11 to 23 cents a pound.
  - 10 percent is boards and miscellaneous wire, including 1 percent of gold worth about 90 cents a pound.
- Thus, effectively recycled, only about 0.5% of an entire computer system will actually have to go to landfill.
• Although high in value, plastics are unattractive to recyclers because of
  – the difficulties in separation and identification of the various types,
  – the contaminants used in most plastics.
• The challenge of using mechanical shredding (instead of dismantling) is that these products contain a variety of contaminants that threaten the purity of the plastics: acoustical foam, metal inserts, paint, brackets, coatings, and labels.

Currently, all metals (ferrous and non-ferrous) can be recycled.
Advanced Automated (Mechanical) Separation Techniques

• Many believe that manual separation is too expensive and will not be economically feasible.
• There is a need for cheap, reliable separation methods
• Promising separation techniques are primarily based on material properties, for example:
  – E.g., density-based float-sink separation techniques, Froth-floatation (based on surface properties), air classification, electro-static and magnetic separation.
• Also, more reliable identification techniques than human inspection are needed and being developed
  – E.g., FT-IR (Fourier Transform - Infrared), FT-NIR (same but uses Near Infrared light), FT-Raman (uses a YAG laser)
• However, there will always be a need for non-destructive disassembly if substances of concern have been used in the product.
  – Classic examples are batteries in electronic products.

Robotic Disassembly

• Robotic disassembly is being investigated, but requires much study and experimentation
  – The robot must be highly sensorized, flexible, and intelligent.
  – Disassembly cannot be regarded as reverse assembly because of the variety of products to be recycled and the uncertain state they come in.
• Some investigations conclude that robotic disassembly is possible, even if product conditions are uncertain.
• The main problems encountered are:
  – Fasteners that require high forces, such as glue
  – Accessibility to parts that are very close together
  – Jamming and wedging of parts
  – Uncertain object conditions
• Error detection and recovery needs to be looked into for the future.
• Also, robot systems need to be optimized for specific electronic product types
Computer Recycling Processes

- The large amount of ferrous metals, mainly steel, favors current recycling practices of shredding the product and sorting with a simple magnet.
- The printed circuit boards (PCB), plastic, and glass present the current challenges.
  - PCBs may contain valuable metals and reusable circuit components but must undergo expensive and labor intensive disassembly.
  - Plastics must be identified and sorted accurately to be recycled, and there are huge varieties used in today’s products.
  - In addition, many contain hazardous additives for flame retardation or other purposes.
- Finally, the last major portion of the computer is in glass, located in the monitor.
  - The obstacle here is finding a way to remove the lead, phosphorous, and other hazardous additives from the glass so that it can be recycled.

Procedures for Electronic Recycling
(from Resource Concepts Enviro)

1. Separate, segregate and track, by customer order, all incoming product.
2. Examine, identify and separate all incoming material into one of the following classifications:
   - A. Non-proprietary product that
     » Can be refurbished and remarke ted;
     » Has no resale value and must be disposed of in its entirety;
     » Has no resale value and contains hazardous materials
   - B. Proprietary product that (at customer discretion)
     » Can be refurbished and remarke ted with customer concurrence;
     » Must be disassembled and only the non-proprietary components refurbished and remarke ted;
     » Must be destroyed beyond all recognition.
3. Repackage all hazardous material for shipment to EPA registered recyclers
4. Return all ferrous and non-ferrous metal, plastic, wire, and cable to reuse through their respective closed-loop recyclers.
5. Ship de-populated Printed Wiring Assemblies to precious metal refiners for the metal recovery
6. Ship CRT’s to an EPA registered smelter for recycling lead and glass.
7. Ship batteries to approved EPA sites for reuse or disposal.
8. Provide a Certificate of Destruction to our customers for all material disposed of or destroyed beyond recognition.
Developing an End-Of-Life System for Product Demanufacture

– Basic Questions to Ask

• Draw up a profile of the product’s current end-of-life system
  – Who owns the product?
  – What kind of ownership is involved?
  – What is the price?
  – How big is the product?
  – What is the average life of the product?
  – What is the weight of the product?

• Analyse the main reasons why users dispose of the product
  – Is the product disposed of because of technical failure?
  – Is the product sensitive to trends?
  – Are there new products on the market which offer more features?
Developing an End-of-Life System (cont.)

• Determine what legislation and regulations affect the end-of-life system
  – To what extent is the manufacturer responsible for the end-of-life phase?
  – Does a take-back obligation already exist for discarded products?
  – How can the costs of returning and processing the product be financed?
  – What rules and prices apply with regard to product reuse, material recycling, incineration and dumping of residual wastes?

• Contact the suppliers
  – Due to specialized expertise, suppliers can usually achieve sub-assembly reuse, recycling more efficiently than the OEM

• Establish how the product can be collected
  – Consumer return system via recycling center
  – Pick-up from last user
  – Return system via retailers

Developing an End-of-Life System (cont.)

• Determine who is going to recycle or process the product
  – Should the product be processed in-house?
  – Should the product be processed by a third party?

• Select the most efficient end-of-life system
  – Use the answers to the preceding to establish an end-of-life scenario
  – Due to the uncertain nature, consider establishing several scenarios

• Some trends to keep in mind:
  – Users will think twice before discarding products
  – Governments will develop more regulations
  – The processing industry will become more effective
  – Technological options will be expanded, especially in mechanical waste processing
  – Market for recycled materials will improve
  – Incineration and burial of waste will be subjected to more regulations and become more expensive
Basic Cost Factors in Recycling

Profitability of Recycling

• We want to make recycling profitable:
  \[ \text{Profit} = \text{Revenue} - \text{Cost} \]

Revenues are obtained from:
• High value (high demand), undamaged recovered reusable components.
  – Additional processing (cleaning, inspection, upgrading, reassembly, and redistribution) adds to costs.
• High value, uncontaminated scrap materials.
  – Any contamination which reduces material properties depreciates the material value.
• Energy recovered and sold from incineration or pyrolysis.
  – Lowest revenue of all.
Common Cost Factors

• Buy back of product ($/product)
  – Dependent on condition and value of product type.

• Transportation costs ($/km)
  – May also dependent on weight and damage tolerated.

• Tip/storage fees ($/product), also for landfilled residue.
  – Strongly influenced by location of facility and local legislation.

• Labor cost ($/hour)
  – Dependent on level of skills required and location.

• Equipment investment cost ($)
  – Influenced by need for special (expensive) equipment.

• Equipment operating cost ($/car, $/hr)

• Time necessary to recover parts and materials (hr/product)
  – STRONGLY INFLUENCED BY PRODUCT DESIGN!

A Quick Costing Example

• Recovery of a dashboard:
  – Removal of dashboard from car = 35 min.
  – Removal of dash components = 35 min.
  – At $20/hour, labor cost = $23

• In order to break even with material recycling, more than 10 kg of copper (most valuable scrap material in table) would have to be recovered

• Or, dash components (gauges, etc) would have to be sold for re-use. Big questions:
  – What is the market willing to pay for recovered dashboard components?
  – How much value would remanufacture add to recovered components?

Material | Mass [kg] | Virgin price [$/kg] | Scrap price [$/kg]
---------|-----------|---------------------|------------------
Steel    | 104       | 0.12                | 0.12
Aluminum | 71        | 1.32                | 1.32
Zinc     | 34        | 0.03                | 0.03
Copper   | 25        | 2.20                | 2.20
Lead     | 10        | 8.25                | 8.25
Polyurethane foam | 12 | 2.20 | 2.20
Polypropylene | 14 | 1.10 | 1.11
Poly Vinyl Chloride | 11 | 1.00 | 1.22
ABS      | 13        | 2.50                | 2.75
Stainless steel | 10 | 5.00 | 5.00
Plywood  | 90        | 3.30                | 3.30
Polyurethane | 10 | 3.10 | 3.10
Polyethylene | 6 | 0.90 | 0.90
Polyester | 20 | 3.50 | 3.50
Other polymers | 25 | 2.10 | 2.10
Carbon   | 5         | 0.50                | 0.50
Aluminum | 5         | 0.50                | 0.50
Other materials | 5 | 0.50 | 0.50
Steel    | 50        | 0.00                | 0.00
Plastic Reinforced fiber | 5 | 0.50 | 0.50
Plastic Composite | 5 | 0.50 | 0.50
Tiles    | 50        | 0.00                | 0.00
Miscellaneous | 20 | 0.00 | 0.00

Total weight of car = 1395 kg

Typical 1990 vehicle material mix

Re-Design of dash is desirable! (Any suggestions how?)

DFR (1) - 16
Design for Recycling
–
Approach

Common “complaint”:
“I have to satisfy my customer demands, my boss, get the product out on time, meet all the deadlines, do DFMA, TQM, etc., and now I also have to worry about RECYCLING?”
DFR and DFE

• Most DFR and Design for Environment (DFE) guidelines also have other benefits (technical, economical, quality).

• It is argued that the biggest advantage of doing DFE is that it forces more creative thinking.
  – Some good examples of this can be found in automotive industry.

How to do DFX?

• Key to success in Design for X (DFX):
  – Know the process(es) you are designing for.
  – Know the critical technical and economic factors in these processes.

• If you are aware of the preceding issues, design guidelines are easy to postulate.

• Knowledge of corporate goals (and constraints) is also very useful.
Question:
- What would be important design attributes and corresponding “design guidelines” to ease each of the stages listed in this figure?
- Also, what trade-offs do they require?

German Engineering Standard VDI 2243
“Designing Technical Products for ease of recycling: Fundamentals and rules for design”

- Effort from German engineering society (VDI) to standardize notions about recycling.
- The purpose of VDI 2243 is to provide engineers a quick and relatively complete overview of useful issues to be considered in modern design for recycling.
- The 35 page long VDI 2243 guideline contains the following:
  - An introduction to recycling – motivation, application, terminology and definitions, and the general life cycle and design processes.
  - A short discussion on production waste recycling – waste streams in production and rules for the designer.
  - A discussion on product recycling (during a product’s useful life) – goals, processes involved, and rules for the designer.
  - A discussion on material and waste recycling (after a product’s useful life) – goals, processes involved, and rules for the designer.
  - A short discussion on the application of design for recycling rules.
- It contains a wealth of information and illustrates the state of the art in design for recycling in Germany. Needless to say it incorporates a lengthy bibliography of publications, however, mostly in German.
Recycling Loops according to VDI 2243

• VDI 2243 makes distinctions between primary and secondary re-use and recycling.

• Please note that the German use slightly different definitions (after translation).

• Stick to AAMA definitions!

A General Design for Recycling Approach

• Approach is very similar to DFE approach.

• Three phases:
  – Assessment and planning
  – Improvement
  – Implementation and documentation
Recyclability Assessment

US Vehicle Recycling Partnership Approach

• The US Vehicle Recycling Partnership is one of the few (if not the only one) industry organizations who have identified and recommended an industry wide recyclability assessment method

• To make a recyclability assessment, a four step approach should be followed:
  − 1) Data collection (identify the components, materials, and fastening mechanism in the assembly to be rated).
  − 2) Rate the components according to the rating scheme.
  − 3) Calculate the percentage recyclability by weight.
  − 4) Identify areas for improvement.

• Step 1 is an inventory step, but helpful in ensuring a complete and correct assessment.
  − The identification of materials) is also needed to determine whether any substances of concern have been used.
Step 1 - Data Collection

- General: Most, if not all, of the information can be obtained from the Bill of Materials.
- Materials: A proper identification of the materials used in a component is essential because these materials define its recyclability.
  - Surface treatments (like paints, varnishes) and bonding agents (glues) must also be identified because of their potential to contaminate materials (especially plastics) to be recycled. In some cases, one percent contamination is enough to ruin a batch of high grade plastics for recycling.
- Fasteners: A proper identification of fastening mechanisms is important because these largely define the separation process needed in case two components need to be separated for recycling.
  - Permanent connections (like welds, heat stakes) almost always require some form of mechanical separation.
  - Non-permanent mechanical connections (like bolted joints, screws) allow for manual as well as mechanical separation.
  - The fastener material and coatings need to be evaluated as well, because it may need separation to avoid contamination.

Step 2 – Rate the Components

- The calculation used to evaluate vehicle recyclability is based on two ratings for each component:
  - a recyclability rating, and
  - a material separation rating
- Rating Scales:
  - A rating of 1 is the best.
  - A rating of 1, 2, or 3 for both recyclability and separability is considered acceptable for the European market and should be strived for.
  - Ratings of 4, 5, and 6 are considered poor.
  - In contrast, the United States Federal Trade Commission (FTC) rules are stricter. At the moment, the FTC only considers products/component with a recyclability rating of 2 to be called recyclable.
Material Recyclability and Part Remanufacture Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Part is remanufacturable – Example: starter, transmission</td>
</tr>
</tbody>
</table>
| 2        | Recyclable – infrastructure and technology are clearly defined.  
|          | Part is completely recyclable, infrastructure clearly defined and functioning.  
|          | Example: Body sheet metal. |
| 3        | Technically Feasible, infrastructure not available.  
|          | Collection network not defined or organized, technology for material recycling has been established.  
|          | Example: Plastic interior trim. |
| 4        | Technically feasible, but further process or material development is required.  
|          | Technology has not been commercialized.  
|          | Example: Backlite glass. |
| 5        | Organic material for energy recovery, that cannot be recycled.  
|          | Known technology/capacity to produce energy with economic value.  
|          | Example: Tires, rubber in hoses. |
| 6        | Inorganic material with no known technology for recycling.  
|          | Recycling technology not known. |

Category 3 is a prediction of materials that are technically feasible to recycle.

Categories for Ease of Disassembly for Material Separation in a Component

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1        | Can be disassembled easily, manually.  
|          | Approximate disassembly time is one minute or less.  
|          | Example: “A” pillar trim cover |
| 2        | Can be disassembled with effort, manually.  
|          | Component may contain compatible coatings or adhesives.  
|          | Approximate disassembly time is one to three minutes.  
|          | Example: fan shroud. |
| 3        | Disassembled with effort, requires some mechanical separation or shredding to separate component materials and parts.  
|          | Component may contain non-compatible coatings or adhesives.  
|          | The process has been fully proven.  
|          | Example: seat assembly, windshield glass. |
| 4        | Disassembled with effort, requires some mechanical separation or shredding to separate component materials and parts.  
|          | Component may contain non-compatible coatings or adhesives.  
|          | The process is currently under development.  
|          | Example: instrument panel. |
| 5        | Cannot be disassembled.  
|          | No known technology for separation.  
|          | Example: heated backlite glass. |

Note: It is assumed that the assembly or part being rated has already been removed from the vehicle.
### Rules of Thumb for Recyclability Ratings

<table>
<thead>
<tr>
<th>Component/assembly material</th>
<th>R.R.</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Single metal</td>
<td>2</td>
<td>Technology and recycling infrastructure in place.</td>
</tr>
<tr>
<td>2 Single thermo-plastic</td>
<td>3</td>
<td>Technology available, but no infrastructure in place.</td>
</tr>
<tr>
<td>3 Single thermoset</td>
<td>4, 5</td>
<td>Some technology under development. Incineration may be possible.</td>
</tr>
<tr>
<td>4 Multiple metals</td>
<td>2</td>
<td>Technology and recycling infrastructure in place.</td>
</tr>
<tr>
<td>5 Single or multiple metals with single thermo-plastic</td>
<td>3, 4</td>
<td>Shredding and magnetic separation allow for separation of metals, depending on number and types. Resulting residue consists of a single plastic which may be recyclable.</td>
</tr>
<tr>
<td>6 Multiple thermo-plastics: All compatible</td>
<td>3, 4</td>
<td>Technology is available or under development to recycle this plastic mix, but no infrastructure exists.</td>
</tr>
<tr>
<td>7 Multiple thermo-plastics: Incompatible</td>
<td>4, 5, 6</td>
<td>At best, technology is under development to recycle/separate this mixture. Incineration may be possible, dependent on composition.</td>
</tr>
<tr>
<td>8 Multiple thermosets</td>
<td>4, 5, 6</td>
<td>At best, some technology is under development to recycle/separate part of this mixture. Incineration may be possible, dependent on composition.</td>
</tr>
</tbody>
</table>

### Rules of Thumb for Separability Ratings

<table>
<thead>
<tr>
<th>Situation</th>
<th>S.R.</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Fasteners are made of same material as parts being joined.</td>
<td>5</td>
<td>No disassembly required. All can be recycled as a single part. Preferred situation.</td>
</tr>
<tr>
<td>2 Fasteners are made of material compatible with material of parts being joined</td>
<td>5</td>
<td>No disassembly required. All can be recycled as a single part.</td>
</tr>
<tr>
<td>3 Fasteners are incompatible with parts being joined, but easily removable</td>
<td>5</td>
<td>Fasteners can be removed manually. Part material can be separated manually.</td>
</tr>
<tr>
<td>4 Fasteners are incompatible with parts being joined, but removable by force (e.g. severe heating)</td>
<td>5</td>
<td>Fasteners can be removed manually. Part material can be separated manually or mechanically if material properties allow.</td>
</tr>
<tr>
<td>5 Fasteners are made of ferrous material and easily removable and parts being joined are made of compatible or same plastic</td>
<td>5</td>
<td>Fasteners can be removed manually. Plastic parts are recycled as a mix.</td>
</tr>
<tr>
<td>6 Fasteners are non-removable/permanent/molded in, but made of ferrous material and parts being joined are made of compatible or same plastic</td>
<td>5</td>
<td>Fasteners can be removed by shredding and magnetic separation. Plastic parts are recycled as a mix.</td>
</tr>
<tr>
<td>7 Fasteners are non-removable/permanent/molded in, but made of ferrous material and parts being joined are made of incompatible plastics</td>
<td>5</td>
<td>Fasteners can be removed by shredding and magnetic separation. Plastics may be separated through density separation, number and density allow.</td>
</tr>
<tr>
<td>8 Fasteners and part materials are incompatible and fasteners are absolutely non-removable (e.g. adhesives).</td>
<td>5</td>
<td>No separation possible and fastener will cause part material contamination if should. In limited cases, (chemical) separation technologies are under development.</td>
</tr>
<tr>
<td>9 Part materials are same or compatible, but incompatible with fastener: However, fastener mass is so small that no separation will occur.</td>
<td>5</td>
<td>All can be recycled as a single part. Advice from Materials Engineering should be sought.</td>
</tr>
</tbody>
</table>
Step 3 – Calculating Percent Recyclability by Weight

- The recyclability for an entire assembly is calculated on a “percent recyclability by weight” basis.
- The weights of all components with a recyclability rating of 1-3 and a separation rating of 1-3 are summed.
- The resulting weight number is then divided by the total weight of all components in the assembly.
- The subsequent number represents the percentage (by weight) of the assembly that is technically feasible to recycle.
- The calculation provides a quantitative value, but the additional discussion of the good and bad points of the system and/or components is, in general, much more informative than this value.

\[
\text{Percent recyclability by weight} = \frac{\text{Total weight of components with R.R. of 1-3 and S.R. of 1-3}}{\text{Total weight of all components in assembly}}.
\]

Step 4 – Identify Areas of Improvement

- In general, any components with recyclability and/or separability ratings of 4 are immediate candidates for improvement, especially if a component’s recyclability rating is 3 but its separability rating is 4.
- Furthermore, components with a relatively large weight should be investigated first since they provide the (potential) highest increase in percent recyclability by weight.
- This step is a precursor to Task 2.c (Identify and Prioritize Limiting Factors) if improvements are needed.
Activity-Based Costing Dismantling Assessment

- In any “detailed” assessment, uncertainty should be taken into account!

Activity-Based Costing Shredding Assessment

- Shredding cost less than manual dismantling in this case, which is not surprising.
- Note the sensitivity of the cost with respect to the product pay-back price.
Involving the Suppliers

- Suppliers need to be involved as well because of outsourcing in modern companies.

- Big issue: How to get not only the products from the supplier, but also the necessary information?

Supplier Regulated Substance and Recyclability Data Collection and Reporting System

- To avoid mistakes and costly errors down the road, a computer-based Supplier Regulated Substance and Recyclability Data Collection and Reporting System is being developed.

- The idea is that suppliers will answer questions and fill out forms in the software.

- DaimlerChrysler is using it.