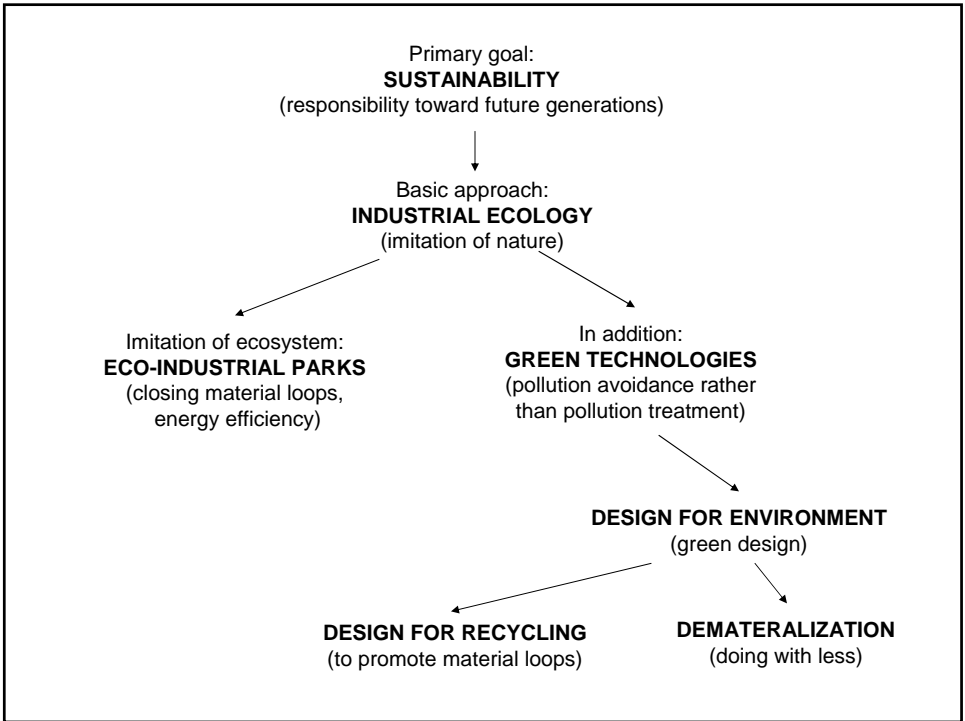




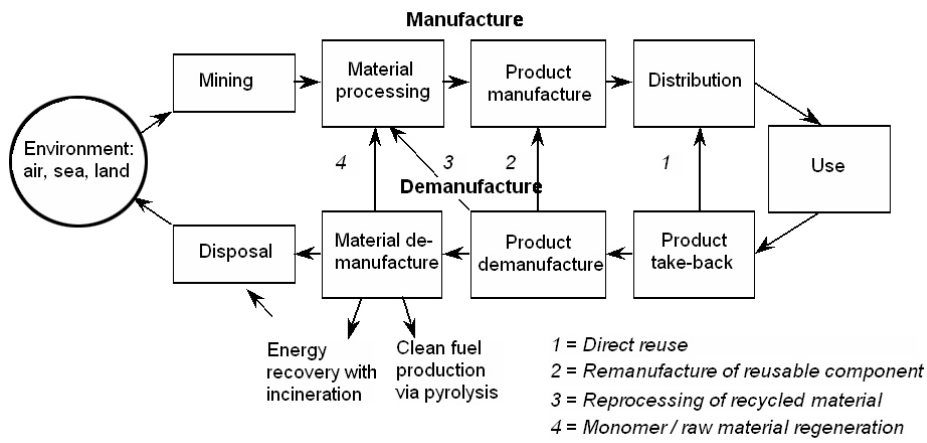
# Design for Recycling (DfR)

How does it work?

"This lecture contains 25% post-consumer recycled materials."



## A Product's Life Cycle – From Cradle to Re-incarnation



The term “demanufacture” is appearing more and more, especially in the electronics industry (DEC, Motorola, IBM), to characterize the process opposite to manufacturing involved in recycling materials and products. Companies (such as CinTech E-Waste) have sprung to corner the demanufacturing market.

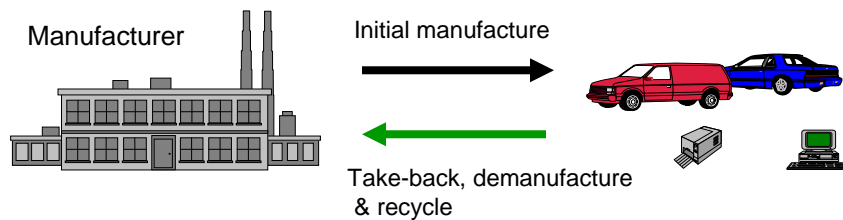
## Growing Importance of DfR

- Dwindling resources
  - Landfill space, especially in (over) crowded Europe
  - Raw material (lesser short term importance)
- For example:
  - Currently, around 80% of electronics are being sent to landfills
  - The US 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 (and other products) 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.

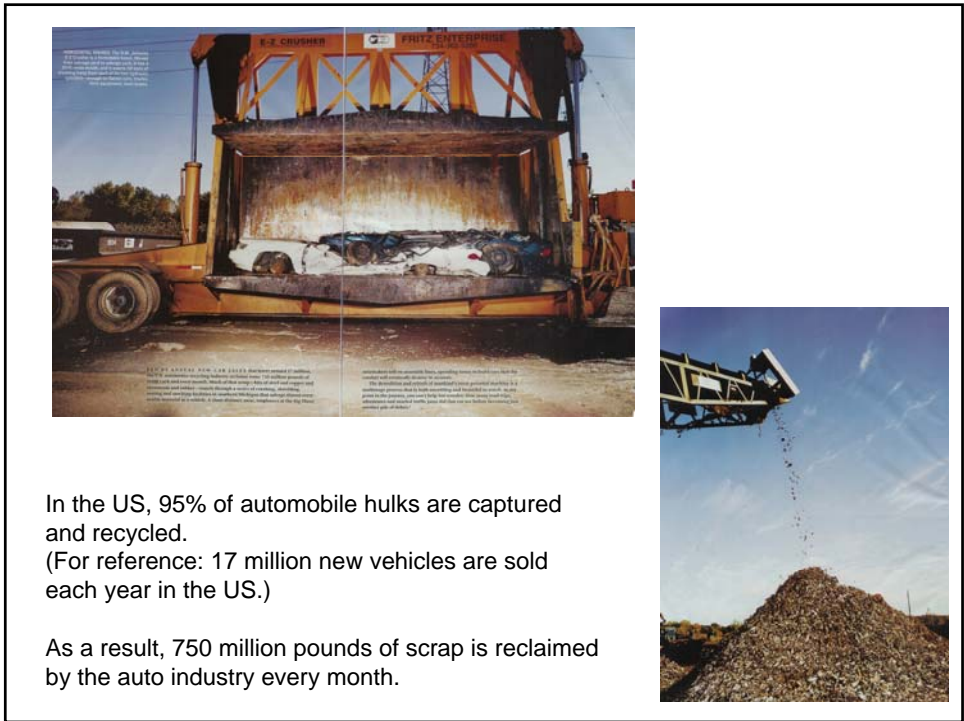


## European Union - Automobiles

- *Objectives:*
  - Avoidance of waste
  - Reduction of landfill demand
  - Reduction of toxicity
- *Recycling Targets:*
  - Maximum of 15% of car weight may 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 experience and successes.



In the US, 95% of automobile hulks are captured and recycled.  
 (For reference: 17 million new vehicles are sold each year in the US.)

As a result, 750 million pounds of scrap is reclaimed by the auto industry every month.

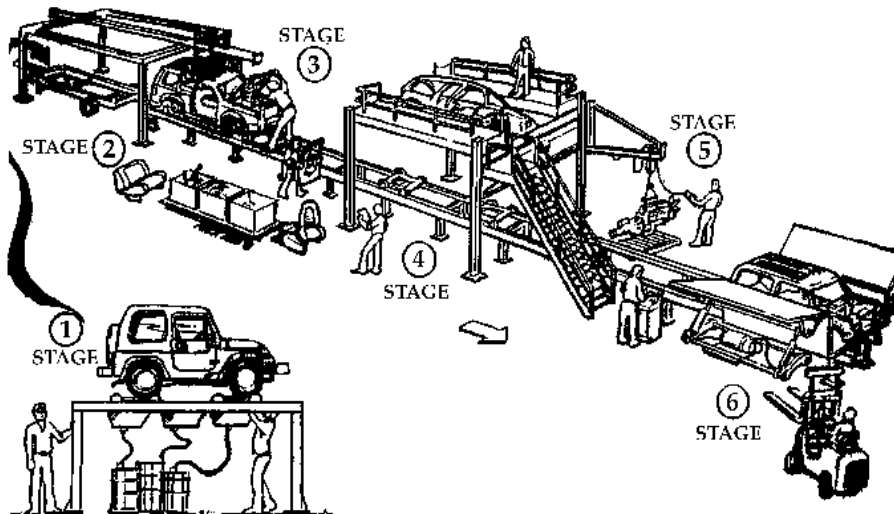
The various steps in auto recycling

The last owner

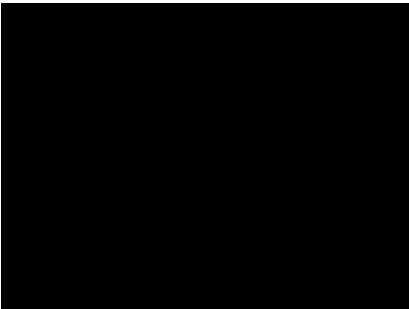
Only when the last owner turns over the end-of-life vehicle to an officially authorized recycler is due process of recycling assured. Recyclers and their partners are then responsible for all further steps.



Semi-Automated Disassembly Line and Center (De Mosselaar BV)



Sometimes disassembly can be very quick!



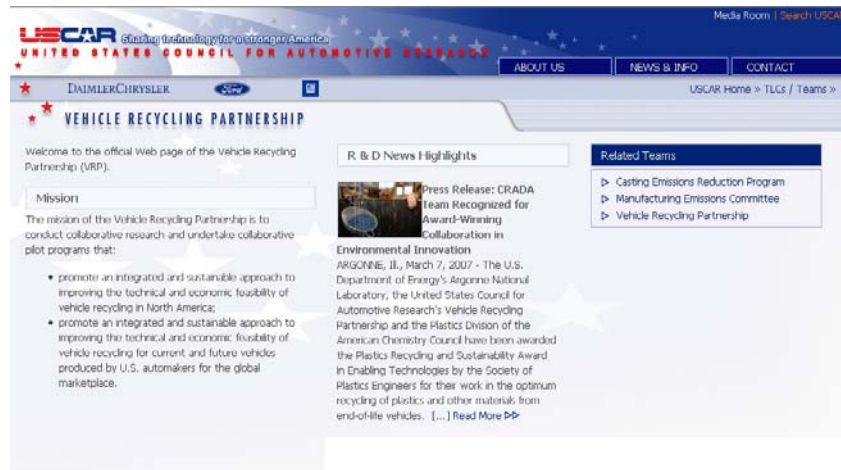
Airplane recycling in France



Planes at stages of dismantling at the airport in Châteauneuf, France. It takes as long as six weeks to break down the average commercial aircraft. Photograph by Jean-Pierre Pélissier/Reuters

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.

More than 10 million vehicles are already recycled in the US annually.



Today, **more than 95% of all vehicles in the United States go through a market-driven recycling infrastructure, with no added cost or tax to consumers. More than 75%, by weight, of each end-of-life vehicle (ELV) is recycled.** The CRADA team is working to raise that percentage to as close to 100% as conceivably possible.

*"The USCAR Vehicle Recycling Partnership, Argonne and the American Plastics Council really are taking a national leadership role, addressing the entire lot of shredder residue, regardless of its source," Gouse added. "They are working to implement sustainable recycling solutions that keep waste out of landfills, save energy and put materials into reuse."*

Thus far, the CRADA team impact has been broad and diverse and includes:

- Establishing and publishing preferred practices for recycling.
- Establishing efficient fluid removal processes.
- Running a licensed Vehicle Recycling Development Center to establish procedures that optimize materials recovery in vehicle dismantling.
- Researching separation technologies for commingled material streams.
- Initiating efforts targeted at removing substances of concern from shredder residue, regardless of its source.

A plastics sorting Pilot Plant in operation at Argonne is one of the more visible demonstrations of the CRADA team's research in action. "While the CRADA team is benchmarking and evaluating a range of technology options for sustainable recycling of ELV, the facility at Argonne serves as a focal point for the team's work," said Ed Daniels, director, Energy Systems Division at Argonne and head of the vehicle recycling research effort at the Lab.

## Recovery Priorities

### 1) Re-use:

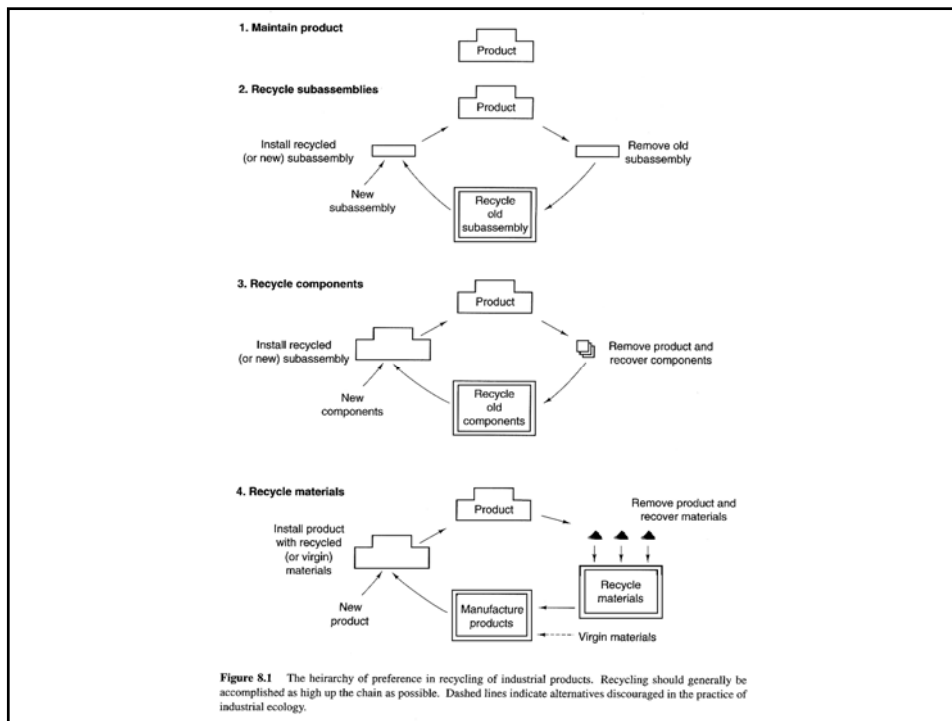
- Highest priority from environmental point of view
- All resources (material and energy) put into product during manufacturing are preserved.
- Requires non-destructive disassembly.

### 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 (ex. gold in electronics)

### 3) Energy recovery:

- Only energy embodied in materials is preserved through incineration or pyrolysis.





## Definitions

### Re-use:

The series of activities, including collection, separation, and in some cases processing, by which products are recovered from the waste stream for new use in their original intended manner.

*Remanufactured components fall under the classification of re-use. (Germans refer to this as "product recycling".)*

### 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 diverted for use as an energy source are considered separately under the category of energy recovery*

## Recyclables vs. non-recyclables

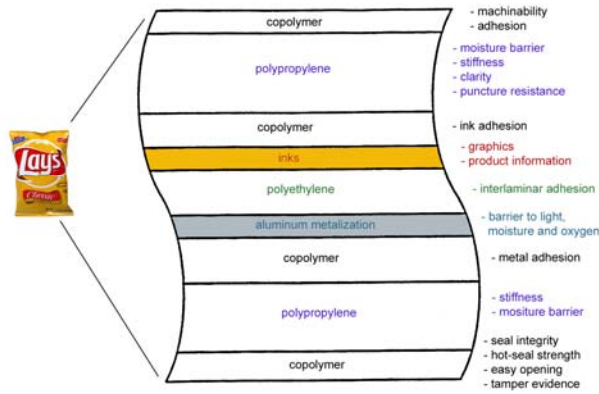
Class of non-renewable material	Recycling technically feasible?	Recycling economically feasible?	Examples
I	Yes	Yes	Most industrial metals Catalysts, some solvents
II	Yes	No	Packaging materials Refrigerants, some solvents
III	No	No	Coatings, pigments Fuels, lubricants Pesticides, herbicides, fertilizers Reagents, explosives, detergents

Problem! None of these materials is renewable!

(From Ayres, 1994)

Some products just can't be recycled!

Cross-section of a bag of potato chips



*Solution:* These products need to be redesigned to become recyclable.

Often, however, the problem is not a complex assembly of materials, but a mixture of materials that, if separated, can be individually recycled.

Some existing separation techniques

Riddle	Small-size particles pass through a grid while larger particles don't. Often used with multiple riddles in a cascade fashion.
Wind sifter	Solids are separated by gravity in a wind stream according to density, form and dimension; light particles are blown away while heavier particles settle.
Gas cyclone	Separates dust from an airflow by means of a centrifugal force.
Hydroclone	Same as gas cyclone but used to removed particles from water.
Float-sink	Solid particles are separated according to density by immersion in a fluid of intermediate density.
Magnetism	Ferromagnetic elements are lifted away by means of a magnetic field.
Eddy current	An eddy current is passed through the mixture of metal particles in the presence of a fluctuating magnetic field. Conducting particles are deflected from the flow path while non-conductive ones aren't.
Electrostatic precipitator	Small particles are electrically charged and then removed by an electric field.

If separation can be performed, it is at a cost of energy because the natural tendency of things is to mix rather than un-mix (second law of thermodynamics).

There is a theoretical minimum amount of energy,  $E_{\min}$ , required to separate an element in concentration  $c$  in a containing material:

$$E_{\min} = -\frac{RT}{c} [c \ln c + (1-c) \ln(1-c)]$$

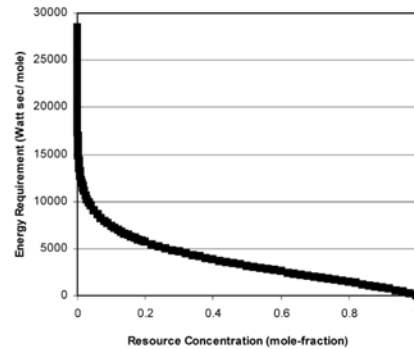


Fig. 2. Relationship between energy requirement and resource concentration at 273 K according to Eq. (1). (based on Fig. 4.5 in Faber et al. 1995)

## Plastics Recycling

There are essentially three kinds of plastics:

### Thermoplastics

- become soft or "plastic" when heated
- are molded or shaped with pressure in the plastic state
- solidify when cooled
- allow reversible (physical) transformations
- are recyclable.

### Thermosets

- can be softened and molded, then hardened or "set" when heated once
- are branched polymers with three-dimensional, cross-linked networks
- have no melting point (burn before melting)
- are more stiff, ideal for product covers
- are not recyclable.

### Elastometers

- are rubber-like material
- are not recyclable.



Type	Name	Abbreviation	Uses
1	Polyethylene terephthalate	PETE	Soda and water containers, some water-proof packaging
2	High-density polyethylene	HDPE	Milk, detergent and oil bottles, toys, plastic bags
3	Vinyl / Polyvinyl chloride	V / PVC	Food wrap, vegetable oil bottles, blister packages
4	Low-density polyethylene	LDPE	Plastic bags, shrink wrap, garment bags
5	Polypropylene	PP	Refrigerated containers, some bags, most bottle tops, carpets, some food wrap
6	Polystyrene	PS	Throwaway utensils, meat packing, protective packing
7	Other	---	No recycling potential <i>NEW:</i> Biodegradable plastics

Few plastics are compatible with one another...

TABLE 9.15  
Material compatibility chart for co-processing of recycled plastics

Matrix Material	Additive											
	PE	PVC	PS	PC	PP	PA	POM	SAN	ABS	PBTP	PETP	PMMA
PE	■	□	□	□	■	□	□	□	□	□	□	□
PVC	□	■	□	□	□	□	□	■	●	□	□	■
PS	□	□	■	□	□	□	□	□	□	□	□	□
PC	□	○	□	■	□	□	□	■	■	■	■	■
PP	■	□	□	□	■	□	□	□	□	□	□	□
PA	□	□	○	□	□	■	□	□	□	○	○	□
POM	□	□	□	□	□	□	■	□	□	○	□	□
SAN	□	■	□	■	□	□	□	■	■	□	□	■
ABS	□	●	□	■	□	□	○	□	■	○	○	■
PBTP	□	□	□	■	□	○	□	□	○	■	□	□
PETP	□	□	○	■	□	○	□	□	○	□	■	□
PMMA	□	■	○	■	□	□	○	■	■	□	□	■

Key: ■ Compatible ● Compatible with limitations ○ Compatible only in small amounts □ Not compatible  
Source: Adapted from Bras and Rosen, 1997.

(Source: Paul Bishop, Pollution Prevention, McGraw-Hill, 2000, p. 401)

... Therefore: Avoid mixing plastics or use fewer different plastics.

**"Green" Recycling of Polyester using Petretec(sm)**



This "green" technology, Petretec(sm), recycles all forms of polyester, "unzipping" it into monomers suitable for repolymerization or other uses. It avoids environmentally intrusive landfill or incineration. The monomers are FDA approved for all end-uses including food contact applications. Quality is equivalent to virgin monomers. Feedstocks include cotton blends, resins, films, belts, fibers, etc. This technology has been commercially demonstrated, and is particularly well suited to operate integrated with standard PET polymerization facilities using the DMT synthesis route.

**Benefits Summary**

Benefits summary was not provided for this TechPak.

**Development Summary**

Development information was not provided for this TechPak.

**IP Summary**

This technology is supported by 1 US patent. The most recent year of issue is 1999.

**Technology Benefits Description**

Petretec<sup>sm</sup> process has been approved by the US Food and Drug Administration so that PET manufactured from DMT and EG regenerated by this technology can be used in food contact applications without qualification  
 Dramatic reduction in cradle to grave environmental impact  
 Higher value than landfill or incineration  
 Ability to tightly integrate with existing manufacturing facilities

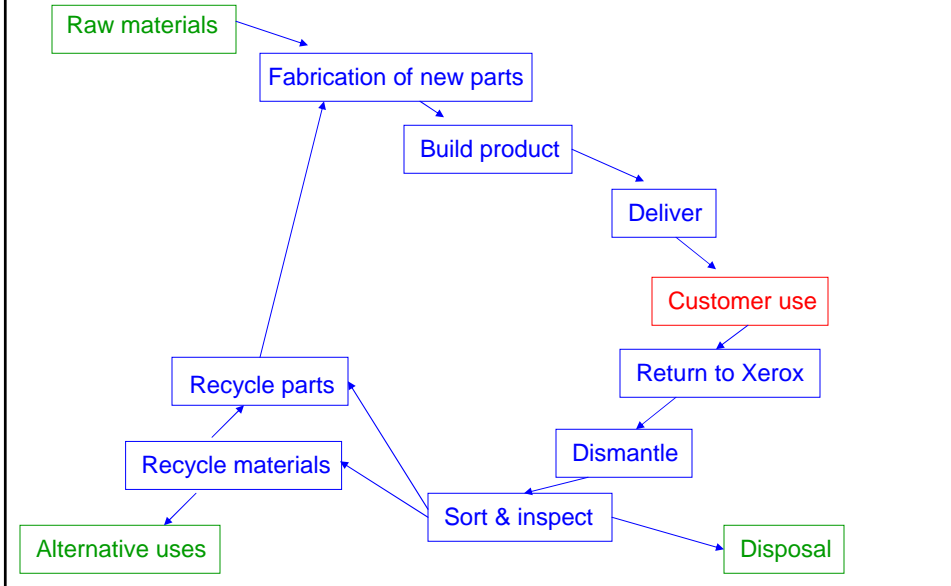
<http://www.technologybank.dupont.com/t2h/page/techpak?id=35545&sid=330&abc=0&page=tpprint>

**Closing the loop: Putting recycled materials in new products**



Recycled plastics (shown in green) in the BMW 3-series

### XEROX Equipment Recovery & Parts Reuse/Recycle Process



Wall Street Journal  
26 September 2007

IT USED TO BE  
A MINIVAN.



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