Lecture #10

ERDM

Prof. John W. Sutherland

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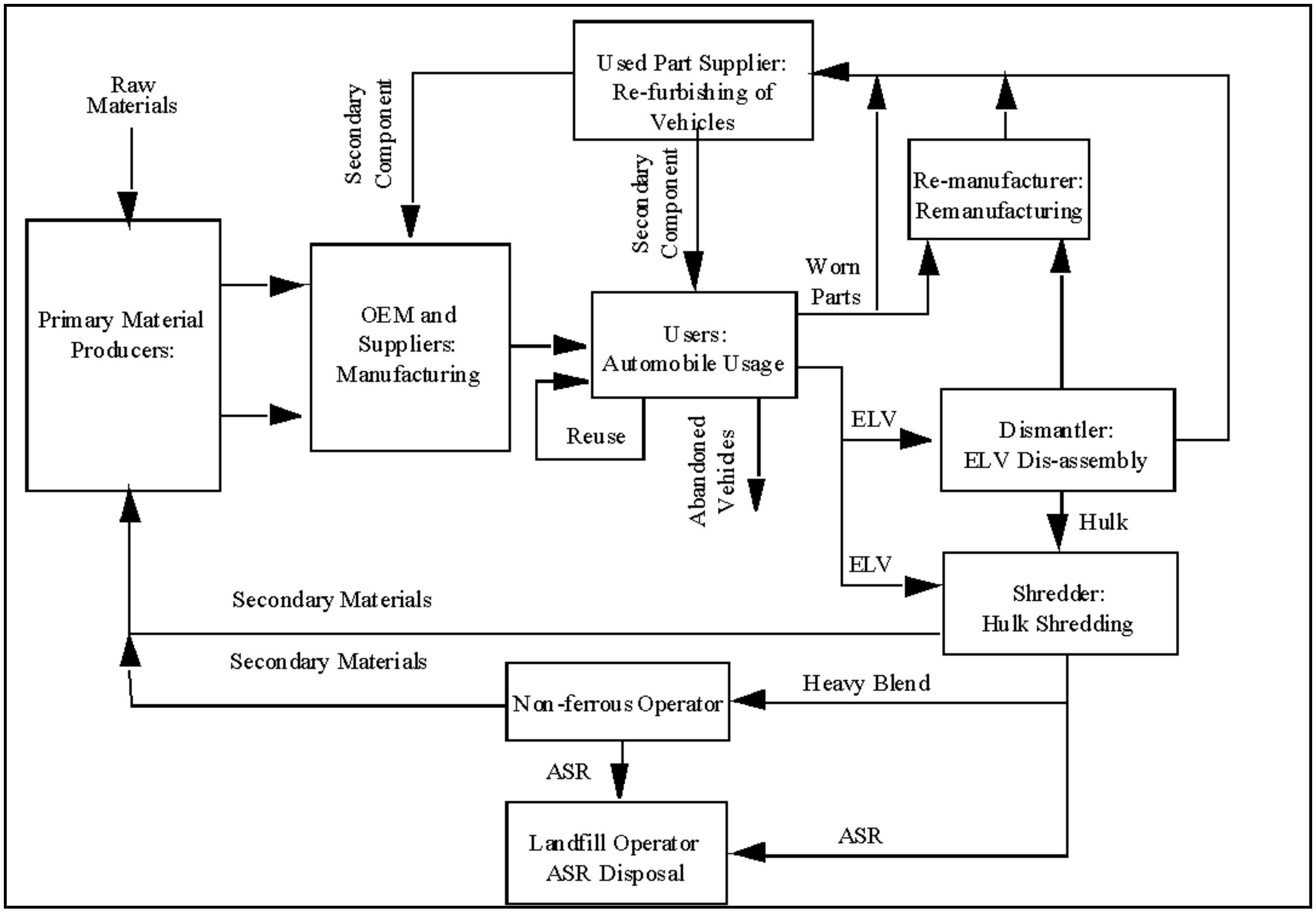
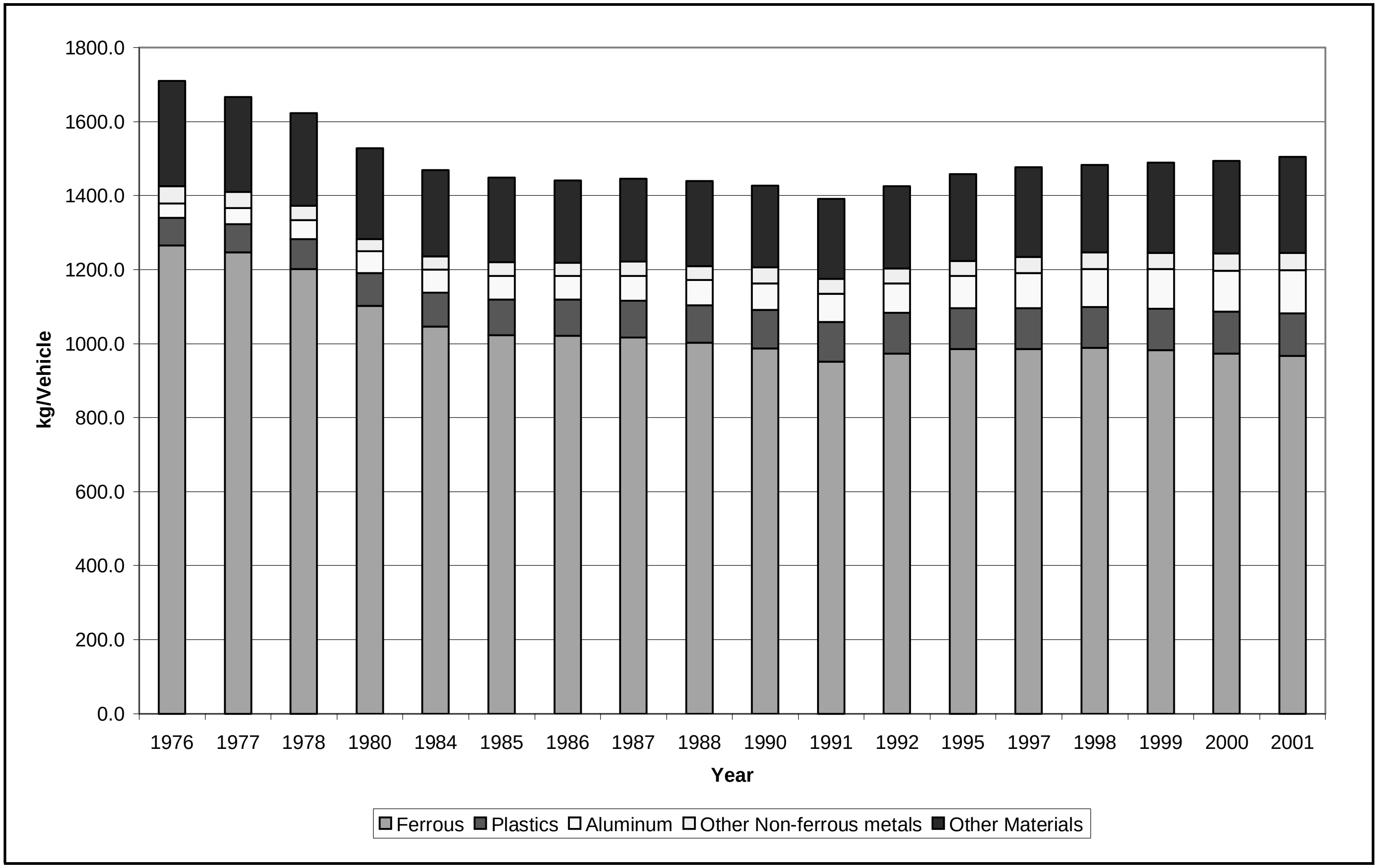
A Question??

- What is the most highly recycled of all products?
- 95% of all automobiles enter the recycling stream (Aluminum cans: 63%)
- 75% of the automobile product is recovered
- 8 million cars recycled in U.S. each year
- Recovery of 12 million tons of steel and 800,000 tons of recycled nonferrous metals such as aluminum, copper, zinc, and lead

Automobile Recycling



What are the trends?



Where is the Industry Going?

PNGV's Vehicle Weight Reduction Targets [NRC, 1998]

Subsystem	Current Vehicle (kg)	PNGV Vehicle Target (kg)	% Mass Reduction
Body	516	257	50
Chassis	501	250	50
Powertrain	395	355	10
Fuel/Other	62	29	55
Curb "Weight"	1473	891	40

How do we intend to reach these targets?

Lighter Materials

- **Aluminum**
- **Magnesium**
- **Plastics**
- **Foams (both polymer & metal)**
- **Do we know the consequence of lighter vehicles on passenger safety?**
- **Metals are recovered. Unrecoverable material: ASR**

What is ASR

- Foams and fluff (40-52%)
- Metals (4-15%)
- Rubbers (18-22%)
- Plastics (20-27%)
- Majority of ASR is landfilled (3 million tons annually)

Summary

- **Use of plastics is increasing**
- **Difficult to recycle plastics**
  - **contamination**
  - **sortation challenges**
  - **bonding to other materials**

It seems that we better learn a little more about plastics!
(some material courtesy of Prof. Williams in ChE @ MTU)

Properties of Materials

Material	Cost $/lb	Modulus psi	Density g/cu cm
Steel	0.35	30.0 E6	7.86
Aluminum	1.50	10.0 E6	2.71
Polystyrene	0.41	450 E3	1.05
Polycarbonate	1.60	350 E3	1.20
Hardwood	0.25	1.3 E6	0.75

An Example
12x1” ruler -- 4” defl. at 10lb load

Material	Thick	Weight	Cost
Steel	0.045	0.153	0.054
Aluminum	0.048	0.056	0.085
Polystyrene	0.133	0.060	0.025
Polycarbonate	0.145	0.075	0.12
Hardwood	0.094	0.031	0.008

Changing Materials -- Changing Geometry

- Performance of plastics is more competitive if geometry used to stiffen section

- Stiffness is the product of
  - Modulus, E
  - Moment of inertia, I

- Use stiffeners and ribs

- Manufacturing cost of plastics is small relative to other materials

Manufacturing with Plastics

- Raw material supplied as granules
- Molded to final shape
- Rarely need assembly
- Rarely needs finishing
- Rarely needs coating/painting

Advantages of Plastics

- High speed manufacturing
- Elimination of assembly issues; tight tolerances not needed
- Light weight
- Resistance to corrosion
- Insulators
- Vibration damping

Disadvantages of Plastics

- **Previously identified recycling difficulties**
- **Lack of robustness to very high and low temperatures**
- **Relatively low stiffness and strength**
- **Viscoelastic behavior under load**
- **Degradation upon exposure to UV radiation**

Viscoelasticity

(from website at University of Wales Swansea)

A true fluid flows when it is subjected to a shear field and motion ceases as soon as the stress is removed. In contrast, an ideal solid subjected to a stress recovers its original state as soon as the stress is removed. Some materials exhibit viscoelastic characteristics having some of the properties of both a solid and a liquid. Two examples of viscoelastic behavior are:

- **The liquid in a cylindrical vessel is given a swirling motion by means of a stirrer. When the stirring is stopped, the fluid gradually comes to a rest and, if viscoelastic, may then start to rotate in the opposite direction (ie. to unwind).**
- **A viscoelastic fluid, on emerging from a tube or a die, may form a jet which is of larger diameter than the aperture. The phenomenon is referred to as 'die-swell' and results from the sudden removal of a constraining force on the fluid. Viscoelastic fluids are thus capable of exerting normal stresses**

Non-Newtonian Fluids

Hooke's Law: The power of the spring is in the same proportion with the tension thereof.

Newton's Law: The resistance which arises from the lack of slipperiness of the parts of the liquid, other things being equal, is proportional to the velocity with which the parts of the liquid are separated from one another.

In the development of classical mechanics, the distinction between solids and liquids was assumed distinct, with solids obeying Hooke's Law (1678), and liquids obeying Newton's Law of constant viscosity (1687). Between these extremes, lie materials of significant interest. If a small stress is suddenly exerted on a solid, a deformation will begin to occur; the material will continue to deform until molecular (or internal) stresses are established which balance the external stresses.

Non-Newtonian Fluids (cont.)

Most solids exhibit some degree of elastic response, in which there is complete recovery of deformation upon removal of the external stress. In a fluid, when external stress is exerted, deformation occurs and continues indefinitely until the stress is removed. The Newtonian fluid is the simplest example, where the rate of deformation is directly proportional to the stress applied to the fluid. However, many fluids exhibit a non-linear response to stress, and are called non-Newtonian fluids. Such fluids fall halfway between being a solid (where the stress depends on the instantaneous deformation) and Newtonian fluids (where the stress depends on the instantaneous rate of change in time of the deformation). For such `soft solids' or `elastic liquids', the stress depends nonlinearly on the history of the deformation.

Types of Plastics

- Thermoplastics (polymer chains - van der Waals)
  - Soften/melt on heating and resolidify on cooling
  - Polyethylene, polystyrene, etc.
  - Recycling possible

- Thermoset plastics (covalent bonding)
  - Undergo a chemical reaction during molding and cannot be remelted
  - Epoxy resins, unsaturated polyesters
  - Recycling?

- Elastomers (highly kinked chains - period xlinks)

Typical Plastics

- **Commodity plastics**
  Polyethylene, polystyrene

- **Engineering plastics**
  Polycarbonate, acetal, nylon, polyester

- **Specialty plastics**
  Polyimide, thermoplastic elastomers

- **Formulated plastics**
  Fillers, fibers, pigments/colorants
  Plasticizers, stabilizers, & other agents

Manufacturing Steps

- **Plastic resin creation. Plastic materials often have additives mixed with them to realize some final product characteristic.**
- **Molding operation. Examples include: compression molding, transfer molding, injection molding, encapsulation, and blow molding.**
- **Finishing. After a product is created, post-forming operations such as adhesive bonding and surface decorating may be undertaken to finish the product.**

Wastes/resources in four categories: Chemicals, Waste Water, Pellet Release, and Fugitive Emissions.

Plastic Resin Formulation

- **Lubricants - stearic acid, waxes, fatty acid esters, & fatty acid amines**
- **Antioxidants - alkylated phenols, amines, organic phosphites and phosphates, and esters**
- **Antistats - quaternary ammonium compounds, anionics, & amines**
- **Blowing/foaming agents - azodicarbonamide, modified azos, OBSH, and HTBA**
- **Colorants - titanium dioxide, iron oxides, anthraquinones, and carbon black**
- **Flame retardants - antimony trioxide, chlorinated paraffins, and bromophenols**
- **Heat stabilizers - lead, barium-cadmium, tin, and calcium-zinc**
- **Organic peroxides - MEK peroxide, benzoyl peroxide, alkyl peroxide, and peresters**
- **Plasticizers - adipates, azelates, and trimellitates**
- **UV Stabilizers - benzophenones, benzotriazole, and salicylates**

Wastewater

Contaminated wastewater can arise from three sources:

- **Cooling/heating water -- only a problem if water has directly contacted bis(2-ethylhexyl) phthalate (BEHP)**
- **Cleaning water -- found to contain oil and grease, organic carbon, phenols, and zinc (phenols and zinc are toxic pollutants). Result in high levels for biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD), and total organic carbon (TOC)**
- **Finishing water -- observed to contain BEHP, di-n-butyl phthalate, and dimethyl phthalate, all toxic pollutants.**
- **Pellet release -- ingestion by animals**

Fugitive Emissions

Under the high heat and pressure associated with the molding process: emissions.

VOCs

Because of the additives present within the plastic resin, emissions may also contain cadmium and lead.

Plastics Summary

Phase	Problem
Petroleum extraction, refining	**Leaks, spills, releases, solvents, energy, HAPs, VOCs, waste and wastewater, use of non-renewable, limited resource**
Primary conversion	**Toxic materials, energy usage, HAPs, VOCs, wastes and wastewater**
Processing	**VOCs, HAPs, energy, hazardous materials, wastes and wastewater**
Use	**Out-gassing, unreacted monomer, release of residual solvents, plasticizer, etc., degradation and failure of the product, energy usage, interaction with environmental liquids, acids, foods, etc.**
End-of-life	**Solid hazard, litter, leaching, hazardous release during incineration, landfill shortage, unsustainable**