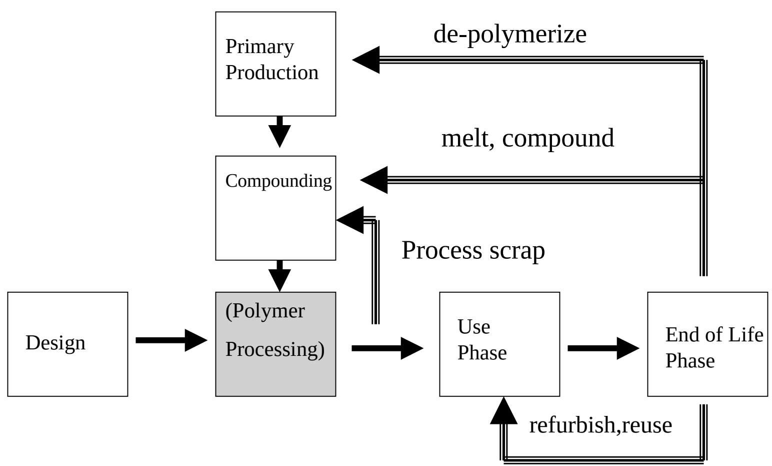
"Environmentally Benign" Polymer Processing

Timothy G. Gutowski
Laboratory for Manufacturing and Productivity
Massachusetts Institute of Technology
77 Mass. Ave Rm. 35-234
Cambridge, MA 02139
Gutowski@mit.edu

Polymer Product Activities and Ecological Material Flows



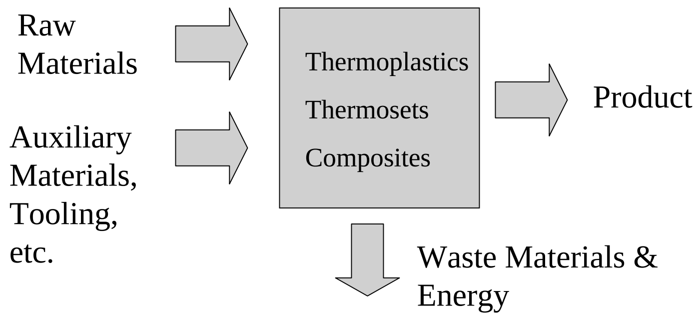
Polymer Processing

- **Thermoplastics Processing** (PP,PS,PE,PET,PC,ABS...)
  - Cool to solidify, heat to melt; $T_{process} > T_m > T_g$
- **Thermoset Processing** (epoxy, phenolic, polyester……)
  - Chemistry to solidify, won't melt; $T_{process} \cong T_g$
- **Composites Processing** (glass, carbon, aramid……)
  - Wet out fibers,fillers →use low viscosity polymer

Polymer Processes

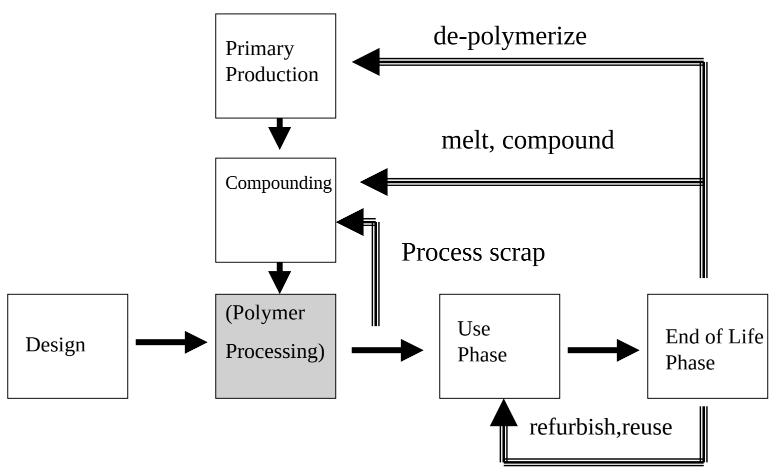
- Thermoplastics Processing: extrusion, thermoforming, injection molding, blow molding, casting, coating,spinning, rolling,etc.
- Thermoset Processing:compression molding, transfer molding, casting, coating, injection molding, reaction injection molding, lamination, etc.
- Composites Processing: hand lay-up, spray-up, lamination, pultrusion, automated lay-up, resin transfer molding, film infusion, autoclave curing, diaphragm forming etc.

Polymer Processing Schematic



Reduce/Eliminate Wastes, Pollutants, Improve Efficiency

Polymer Product Activities and Ecological Material Flows



Polymer Processing at 10,000m

- Usage increasing
- Continuing primary processing challenge
- New materials development (benign & performance)
- End of life treatment
- Collection infrastructure and technology
- Design for end of life
- Process level improvements

New Materials for Benign Processing

- Natural fibers
- Synthetic, biodegradable materials
- Thermoplastic composites
- Water-base systems
- Powder coatings
- Polymer coatings vs. lubricants
- Processable containers (DuPont “Rotim”)

End-of-Life Treatment

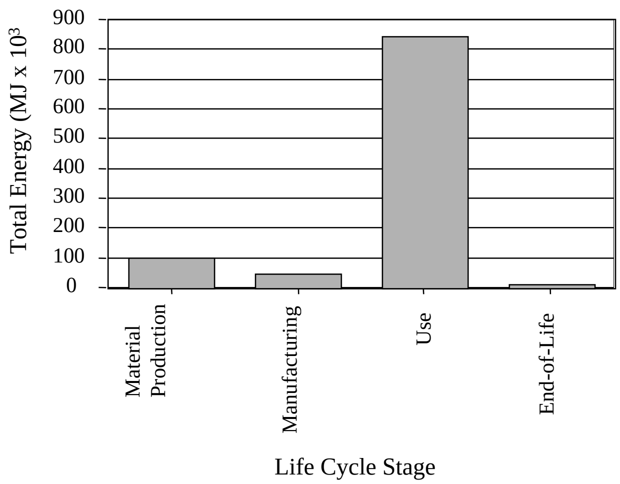
- Reducing agent in blast furnace (Japan)
- Burn for energy (Hoogovens, Chaparral)
- Collection/infrastructure (Fuji Xerox, PVC, PCB, automobiles)
- Sortation technology (IR, floation, surface treatment, proprietary)
- Recycling chemistry (depolymerization, biodegradable, liquid phase thermosets)

Design for End of Life (Polymer Systems)

- Component reuse (Fuji Xerox)
- Minimize materials, design for separation (Toyota, Ford, Interface)
- Use recycled materials in product (Johnson Controls, IBM, PVC window frames, pipes, others)

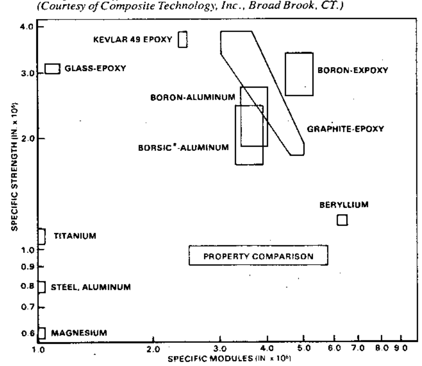
Balance "Use Phase" benefits with "End of Life" Dilemma

Ref. Life Cycle Inventory of a Generic U.S. Family Sedan Overview of Results USCAR AMP Project, by John Sullivan, Ronald Williams, Susan Yester et al SAE TLC Conference 1998



Complex materials provide performance advantages

Typical properties of common fiber composites exhibit significant strength and stiffness characteristics over conventional materials. (Courtesy of Composite Technology, Inc., Broad Brook, CT.)



December 1982 **Manufacturing Engineering**

Critical Needs of Benign Polymer Processing

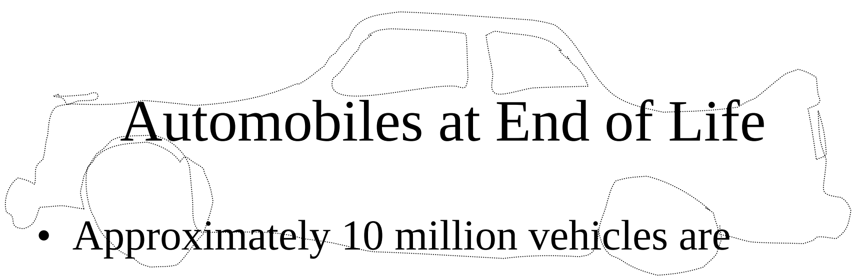
- Infrastructure development (organize and clean up feed stream)
- Standardization for recycled materials
- New technology for cleaning, sorting, recycling
- Material design innovation (zipable, bio, sustainable, etc.)
- Product design methodologies
- Viable recycling scenarios for composites
- Process optimization, control, redesign for improved efficiency

Motivations for Polymer Processing Improvements

- Workers health
- Regulations
- Economics (engergy reduction, new market opportunities PVC)
- Customer/OEM requirements
- Green Purchasing Network
- Public scrutiny

Recycling of Polyester

- DuPont builds 100 million lb./yr. pilot plant in Cape Fear N.C. “Petretec (SM)”
- Methanolysis to original monomer
- Robust to 10% other plastics, **BUT...**
  - Price drops for virgin polymer
  - Collect cost too high
  - Dismantles plant



Automobiles at End of Life

- Approximately 10 million vehicles are scrapped each year
- 75% (wt) is recycled - metals
- 10% (wt) is plastics - goes to landfill
- BUT…… EU directive, Ford buys 25 dismantlers……Chaparral and PCBs

Processing Implications

- Design Implications -DfE, disassembly, “Rotim”,”TSOP”,
- New Chemistries, Materials - water, powder, sustainable,
- End of Life Processes - cleaning, sorting, separation, burning, transport, small-scale recycling
- Process Efficiencies - process control, sensors, robustness, net-shape, melt vs. solvent, closed mold, mechanical toggle vs. hydraulic, tooling, waste water, etc.

July 13, 2000 Wash. D.C. T. Gutowski / Polymers 17

Energy Consumption

MATERIAL	ENERGY Q (MJ/kg)	ENERGY ρq(GJ/m3)
METALS		
	555-565	2400-2880
Magnesium and alloys	410-420	717-756
Cast Irons	60-260	468-1500
Aluminum and alloys	290-305	754-884
Stainless Steels	110-120	825-972
Copper and alloys	95-115	712-1035
Zinc and alloys	67-73	348-525
Carbon steels	50-60	390-468
Lead and alloys	28-32	300-360
POLYMERS		
Nylon 66	170-180	187-216
Polypropylene	108-113	95-102
H.D. Polyethylene	103-120	97-116
L.D. Polyethylene	80-104	73-94
Polystyrene	96-140	96-154
PVC	67-92	87-147
Synthetic Rubber	120-140	108-126
Natural Rubber	5.5-6.5	5-6

MATERIAL	ENERGY Q (MJ/kg)	ENERGY ρq(GJ/m3)
CERAMICS GLASSES		
Glasses	13-23	32-57
Glass fibers	38-64	95-160
Bone china	270	540-580
Bricks	3.4-6.0	6.8-12
Refractories	1-50	3-100
Pottery	6-15	12-30
Cement	4.5-8.0	9-18
Concrete	3-6	7-15
Stone	1.8-4.0	4-8.8
COMPOSITES (estimates)		
GFRP	90-120	160-220
CFRP	130-300	230-540
OTHER		
Hard and soft woods	1.8-4.0	1.2-3.6
Reinforced concrete	8-20	20-50
Gravel/stone	0.1	0.2-0.4
Oil	44	38-40
Coal	29	27-30

Source: Ashby, 1992

July 13, 2000 Wash. D.C. T. Gutowski / Polymers 18

Energy Consumption

MATERIAL	ENERGY Q (MJ/kg)	ENERGY ρq(GJ/m3)
METALS		
	555-565	2400-2880
Magnesium and alloys	410-420	717-756
Cast Irons	60-260	468-1500
Aluminum and alloys	290-305	754-884
Stainless Steels	110-120	825-972
Copper and alloys	95-115	712-1035
Zinc and alloys	67-73	348-525
Carbon steels	50-60	390-468
Lead and alloys	28-32	300-360
POLYMERS		
Nylon 66	170-180	187-216
Polypropylene	108-113	95-102
H.D. Polyethylene	103-120	97-116
L.D. Polyethylene	80-104	73-94
Polystyrene	96-140	96-154
PVC	67-92	87-147
Synthetic Rubber	120-140	108-126
Natural Rubber	5.5-6.5	5-6

MATERIAL	ENERGY Q (MJ/kg)	ENERGY ρq(GJ/m3)
CERAMICS GLASSES		
Glasses	13-23	32-57
Glass fibers	38-64	95-160
Bone china	270	540-580
Bricks	3.4-6.0	6.8-12
Refractories	1-50	3-100
Pottery	6-15	12-30
Cement	4.5-8.0	9-18
Concrete	3-6	7-15
Stone	1.8-4.0	4-8.8
COMPOSITES (estimates)		
GFRP	90-120	160-220
CFRP	130-300	230-540
OTHER		
Hard and soft woods	1.8-4.0	1.2-3.6
Reinforced concrete	8-20	20-50
Gravel/stone	0.1	0.2-0.4
Oil	44	38-40
Coal	29	27-30

Source: Ashby, 1992

Process Level Improvements

- **Issues**:reduce,recycle, reuse: raw mat’ls, aux. mat’ls, minimize wastes, pollutant, toxins,(solvents, out gassing, unreacted monomer) reduce energy, consider product design, use and end of life, materials selection, eliminate secondary operations etc.

Material Use Trends

Ref. “Material Selection in Mechanical Design”
M.F. Ashby, Pergamon Press 1992