Engineering Thermoplastics

Perspectives for the 21st Century

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Outline

• Introduction
  – GE
  – GE Plastics
• Definition of ETP
• General Trends in ETP
• Outlook for
  • Silicones
  • Polycarbonates
  • Crystalline Resins
  • Polyimides/High Temperature Resins
  • POSS in ETP
• Discussion
General Electric Company

• **1999 Revenues:** $112 Billion
  - **Businesses:**
    - GE Aircraft Engines
    - GE Appliances
    - GE Capital Services
    - GE Global Exchange Services
    - GE Industrial Systems
    - GE Lighting
    - GE Medical Systems
    - GE Plastics
    - GE Power Systems
    - GE Transportation Systems
    - NBC
Global R&D: Speed and New Ideas

- ‘99 RD&E: $1.9B
- RD&E staff:
  - 7300 U.S.
  - 1800 non-U.S.
- Many RD&E approaches
Resin Business

- **Plastics** — Engineering Thermoplastics Worldwide
- **Polymerland** -- Plastics distribution, resource recovery
- **Structured Products** -- Thermoplastic sheet and film
- **Silicones** -- Adhesives, Sealants, Coatings, Elastomers
- **Superabrasives** -- Man-made diamonds
- **Specialty Chemicals** -- Impact modifiers, Stabilizers
- **Petrochemicals** -- Ethylene, Styrene, Phenol
- **Electromaterials** -- Printed Circuit Boards

$6.9 billion in sales for 1999
Engineering Thermoplastics-Definition

- Engineering Plastics defined as materials which can be used structurally, typically replacing metals, wood, glass, or ceramics. Can maintain mechanical and dimensional stability above 100°C and below 0°C.

- About 7% of all Plastics production, but nearly 10% of Plastics Sales Dollars.

- Do not include films, thermosets, phenolics, epoxies, etc.

- For this Discussion we will include Silicones as well typical ETP’s

- Many other types of injection-molded materials (styrenics, acrylics, poly(vinyl chloride), polyolefins and polyurethanes are not typically considered in this category.

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Engineering Thermoplastics (ETP’s) - Definition

Figure 1

GLOBAL THERMOPLASTIC CONSUMPTION
Estimated 1997 Global Consumption
(120 Million tons)

High Performance Polymers: 154,000 tons
- LCP
- PI
- PAI
- PEEK
- PC-HT
- PSU
- PES
- PPA
- PEI
- PAR
- PA11
- PA12

Engineering Polymers: 12 million tons
- PA6
- PA6/6
- PC
- PBT
- POM
- PPE & PA
- PA & ABS
- PBI & PC
- IPU & PC
- PC & ABS
- PC & ASA
- PAN
- ABS
- ASA
- PMMA
- SMA

Commodity Polymers: 107 million tons
- PE-HD
- PET
- PP
- PS
- PE-LD
- PE-LLD
- PVC

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ETP- Sales by Polymer Type

Engineering Plastics Sales In US Dollars

Polyamide 26%
PPO 7%
PES 1%
PEI 1%
Acetal 10%
PC 13%
PPS 4%
Polyester 38%

2000 Sales to Reach $22 Billion Worldwide
ETP-Business Trends

- **Forces Driving Reduced Time to ROI**
  - High investor expectations (Stock Performance)
  - E-commerce (Rapid Information Exchange)
  - Global competition (Cost Pressure/Commoditization)

- **Time Scale for Technology Innovation Static**

- **How does the Industry Accelerate Innovation**
  - Reorganizations, restructuring, mergers
  - Growth Through Acquisition vs Organic Growth
  - Joint Venturing/Resource pooling
  - Tilt to life sciences and/or Core Business
    (DuPont, Hoescht/Ticona) (Shell, BP Amoco)
  - Specialized vs. Diversified Portfolios?
  - Globalization
  - Combi Chem

**Time Scale of Technology Innovation vs Time to ROI**

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**ETP-- Technology Trends**

Squeeze Play on the Traditional Engineering Thermoplastics

High Perf.

Polyimides, Polysulphones, PEEK, LCP’s, etc

Nylons, Polysters, Acetals, Polycarbonates, PPO/PS, Ultem, Polyarylates.

Polyolefins (PE, PP, PS, PMMA, PVC), ABS, etc.

Cost Becomes the Key Driver for Those in the Middle

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1900-1960  *The Age of Discovery*. New theories of polymeric materials developed. Polymers which account for 98% of the engineering thermoplastic market discovered, developed, and commercialized.

1960-1985  *The Research Years*. Advanced material developments in liquid crystalline polymers high heat materials; pushing the envelope. Multitude of high-tech materials invented; only a few niche materials commercialized. Blends get commercialized.


1995-??  *Research years Phase 2*. Upper management recognizes the need to develop new markets in order to continue growth. Engineering plastics become commodities and commodity plastics become engineering plastics.
ETP-Market Trends

Cost, Cost, Cost
System Cost Analysis is the Key for New Technology

Performance Differentiation
Aesthetics-Visual, Touch, Smell (personalization)
Weatherability, Modulus/Ductility Balance
Optical Properties-Data Storage/Transmission

ECO Friendly Materials
Processes-Environmental vs. Economic
Products-Biodegradability, FR
Recyclability

Key Technologies Driving Innovation
Combi Chem-Catalysis/Low Cost M
Nanomaterials
Process Innovations-Thin Walls

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ETP-Major Markets

- Automotive-30 to 40 Lbs./car-Mirror Shells, Underhood
- Electrical-Connectors/Switches/Sockets
- Building and Construction-Windows/Glazing/Siding
- Electrical Equipment-Pagers/Cell Phones/PC’s
- Business Equipment-Copiers/Printers
- Appliances
- Data Storage Media-CD’s/DVD’s
**Polycarbonate Chemistry**

**Melt Process**

\[
\text{MeOH} + \text{CO} \xrightarrow{\text{catalyst}} \text{MeO} - \text{OMe}
\]

Advantages: Environmentally acceptable, no solvent or phosgene. Product cleanliness (low lows), MW control for OQ grades.

**Interfacial Process**

\[
\text{PhOH} \quad \xrightarrow{150-320^\circ C} \quad \text{PhO} - \text{OPh} 
\]

Advantages: Simple, fast reactions, ability to make high MW with complete end-capping.

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**Research Areas:**

Catalysis, process engineering, Monomer purification, Activated Carbonates, end-capping, Quenching and stabilization.

**Research Areas:**

New monomers, end-cappers, Process Engineering
ETP’s-Emerging PC Application Needs

Needed-Materials with PC Properties (Ductility/Transparency) With:

- Barrier Properties
- More Flow-Reduced Cycle Time/Thinner Walls
- Better Optical Properties-Reduced Birefrigence/Higher RI/Lower Absorbance
- Better Dimensional Stability-Higher Heat
- Better FR Properties-PC/Silicone hybrids(Idemitsu)
- Improved Weatherability
- Improved Scratch Resistance
- Reduced Surface Static
- Improved Mold Release
- Improved Hydrolytic Stability

Key Issue: Who is Willing to Pay for Improved Performance?
# New Transparent High Temperature Resins

<table>
<thead>
<tr>
<th>Material</th>
<th>Ethyl/phenyl norbornene copolymer</th>
<th>Hydrogen’d Polystyrene</th>
<th>P(cyclo-hexane)</th>
<th>(Substituted) norbornene copolymer</th>
<th>Methyl/norbornyl methacrylate</th>
<th>Ethylene/norbornene copolymer</th>
<th>Norbornyl adduct (polar)</th>
<th>Norbornyl adduct</th>
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</thead>
<tbody>
<tr>
<td>Process</td>
<td>Metalocene</td>
<td>Fr. Radical + H₂</td>
<td>Anionic + H₂</td>
<td>Cationic</td>
<td>Fr. Radical</td>
<td>Metallocene</td>
<td>ROMP + H₂</td>
<td>ROMP + H₂</td>
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<tr>
<td>Producer</td>
<td>OPTATECH</td>
<td>DOW</td>
<td>ASahi</td>
<td>BF GOODRICH</td>
<td>HITACHI</td>
<td>HOECHST</td>
<td>JSR</td>
<td>NIPPON ZEON</td>
</tr>
<tr>
<td>intrinsic birefringence</td>
<td>?</td>
<td>&lt;PC</td>
<td>&lt;PC</td>
<td>&lt;PC</td>
<td>&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
</tr>
<tr>
<td>% Water absorption</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>0.2</td>
<td>&lt;PC</td>
<td>&lt;PC</td>
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<tr>
<td>Tg(°C)</td>
<td>113</td>
<td>145</td>
<td>to 235</td>
<td>to 330(390)</td>
<td>143</td>
<td>to 170</td>
<td>171</td>
<td>140</td>
</tr>
<tr>
<td>Impact</td>
<td>25 kJ/m² Charpy, notch &quot;good&quot;</td>
<td>&lt;&lt;PC</td>
<td>Elongation break = 20%</td>
<td>&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
<td>&lt;&lt;PC</td>
<td></td>
</tr>
</tbody>
</table>

Others: ICI -- acrylate/maleimide copolymer | Tosoh -- isobutene/maleimide copolymer

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Crystalline Resins--New Materials

• “New” Performance Attributes:
  High flow (DuPont, Hoechst)
  Low warp, low density (DuPont --> SAN, SMA ??))
  ASA-containing (BASF, DuPont)
  Lower cost LCPs (eventually)
  ECO-label -- intense development (Toray - - commercial, others)
  Weatherables

• “New” Polyester Polymers:
  PTT (Shell, DuPont, Asahi --> fiber strategy )
  Thermx PCT (Eastman, new nucleation package)

• “New” Materials with Similar Performance:
  sPS (Dow Questra, Idemitsu Xarec)
    Dow: sPS/nylon blends, p-methyl styrene
Crystalline--New Developments

**Monomers:**
- Functional cycloolefins -- diacids and diols (Teijin, Mitsubishi Rayon)
- Cyclobutane diols (Shell)
- Crystalline to Amorphous polyesters
- Alkane diols from ethylene oxide (new catalysts Shell)

**Process:**
- DuPont developments:
  - Polymerization under Nitrogen sweep -- no vacuum
  - Solid state -- micropellets

**Additives**
- Nanocomposites-Commercially used in Nylon for HDT

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High Temperature ETP’s-Market View

High Temperature Thermoplastics
1997 & 2002 Global Market Volume vs Price

High Temperature Resins: Volume is Controlled by Price.

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Polyetherimides-Market Breakdown

1998 Sales: 26MM lbs.
- Packaging: 31%
- Houseware: 18%
- Medical: 14%
- Other: 14%
- Automotive: 16%
- E/E: 16%

2005 Sales: 70MM lbs.
- Houseware: 25%
- CEIS: 7%
- Automotive: 43%
- Other: 13%
- E/E: 13%

Growth Platforms
- Metallizing: 40%
- Cookware: 10%
- All Other: 10%
- Dimensional Stability: 40%
**ETP’s- Perspectives for POSS**

Higher Performance Standards Create Opportunity for POSS

- ECO FR-PWB’s
- Higher Heat/Modulus/ Nanotechnology
- Control of Surface Architecture-Nanopatterning
- High Performance Silicone Resins-PSA/Controlled Release
- Nanostructured Composites-Fillers
- Catalyst Supports

Current Themes/Opportunities

**ECO**

Biodegradable
Recyclable
Weatherable

**But Who Will Pay More for it??**

Breakthrough In Cost Needed to Fuel Application Growth

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Parting Thoughts

• Search for new ideas, new products, new markets
  . . . *mutual interaction between technology & commercial*
  . . . Don’t underestimate unknown markets for new materials

  . . . *Keenly aware of competition at our doors; must differentiate*

• The future will not reflect the past
  . . . *willingness to think and operate outside our comfort zone . . .*

  **Metals have been around for 5000 years**
  • **Polymers have only been around for 70 years**
  • **The 21st century will bring many new things; expect surprises**

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Resin Types

Polyphenylene ether alloys

High temperature amorphous material. PPO with Tg ~260°C blends with PS to lower HDT and processing temperature. Must be impact modified to obtain high strength. Excellent dimensional and hydrolytic stability, but no solvent resistance. Blends with nylons give materials for large parts for automotive applications. Markets of 100-160,000 t/yr with growth ~9%/yr.

Polysulfones

Several types of polysulfones (PSO, PES, PPSO) are sold as amorphous materials with low flammability and good electric properties. Excellent hydrolytic stability and high HDT for high temperature use. Markets include electrical, electronic, and medical, with sales of 13,000 t/yr. Relatively high prices.
Resin Types

Acetals \(-(\text{CH}_2\text{O})_n\)-, copolymers with ethylene oxide
fast crystallizing, solvent resistant; use temperature up to 135°C, brittle, self-lubricating, low moisture absorption, but high shrinkage (25%). Used for small parts. Processibility and thermal stability main advantages. Worldwide capacity ~ 250,000 t/yr; Growth 2-10%/yr.

Nylons

Nylon 6 and Nylon 6,6 largest volumes (~600,000 t/yr non-fiber), with modest growth (5-8%/yr). Amorphous nylons only ~1000 t/yr, but with higher growth. Fast-crystallizing polymer with HDT 194°C (6,6) and 129°C (6). from mp of 270°C and 228°C, respectively. Poor impact strength. Good hydrolytic stability but high water absorption (10%) and mold shrinkage. Small parts, electrical, building construction applications, under-the-hood automotive.

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**Resin types**

**Polyesters**

Both crystalline and amorphous products. Melt processing and solid-state polymerization are used. Largest applications are blow-molded bottles, films, and extrusions. PBT crystallizes fast, PET slower. PBT has $T_m$ 225°C, PET 265°C. Both have low moisture absorption, poor impact strength. Glass-filled products are common. Market about 800,000 t/yr with a growth rate of 7-12%. Aromatic polyesters have much smaller niche in high temp materials which have high impact and are photostable.

**Polycarbonates**

Transparent, very high impact strength, amorphous material with low moisture absorption, $T_g$ of about 150°C. Made interfacially via phosgene and by melt process. Poor solvent resistance. Markets include sheet products, optical applications, consoles and cabinets, power tools, automotive, etc. Market about 300,000t/yr with growth ~ 10%/yr