The Future of Material Science & Engineering
A Polymer Industry Perspective

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The Industry Forecasting Challenge…

This “telephone” has too many shortcomings to be seriously considered as a means of communication.
This device is inherently of no value to us.
*Western Union, Internal Memo, 1876*

The wireless music box has no imaginable commercial value.
Who would pay for a message sent to nobody in particular?
*Industry response to investment proposal for Radio, 1920s*

I think there is a world market for maybe five computers.
*Thomas Watson, Chairman of IBM, 1943*
The Expert Forecasting Challenge…

Radio has no future.  
Heavier-than-Air Flying machines are impossible.  
X-Rays will prove to be a hoax.  
Lord Kelvin, British Scientist, 1899

The bomb will never go off.  
I speak as an expert in explosives.  
Admiral William Leahy, US Atomic Bomb Project

Dear Colleague,  
leave the concept of large molecules well alone…  
There can be no such thing as a macromolecule.  
Expert advice given to Staudinger circa 1925

Deep Insight can Impair Foresight…
The Industry Mindset…

“I did not come to Schenectady to create a philanthropic asylum for indigent chemists”.
- Willis Whitney, GE R&D
What does Industry Think?
An Industry Insider’s Musings…

• Lessons from the Past
• Extrapolations Into the Future

Equally Dangerous Approaches…
We’re We’ve Been

US Production of Synthetic Polymers (semi-log scale)

The Beginning of the End – or the End of the Beginning?
## The Role of Serendipity
### Anticipated Needs & Unexpected Utility

<table>
<thead>
<tr>
<th>Unmet Need</th>
<th>Result</th>
<th>Primary Utility</th>
<th>~Lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>1860s Ivory Substitute</td>
<td>Celluloid</td>
<td>Film, Fiber, Coatings</td>
<td>~20y</td>
</tr>
<tr>
<td>1900s Electrical Insulation</td>
<td>Phenol-Formaldehyde</td>
<td>Electrical Housings</td>
<td>~10y</td>
</tr>
<tr>
<td>1920s Antifreeze</td>
<td>Polysulfide Rubber</td>
<td>Rocket Fuel</td>
<td>~10y</td>
</tr>
<tr>
<td>1920s Rubber Substitute</td>
<td>IR, SBR, NBR, etc.</td>
<td>Tires &amp; Rubber goods</td>
<td>~5y</td>
</tr>
<tr>
<td>1920s Coatings</td>
<td>PMA, PMMA</td>
<td>Glazing, Adhesives</td>
<td>~10y</td>
</tr>
<tr>
<td>1920s Waste Byproducts</td>
<td>PVC</td>
<td>Ubiquitous</td>
<td>~20y</td>
</tr>
<tr>
<td>1930s Electrical Insulation</td>
<td>Polystyrene</td>
<td>Packaging, Moldings</td>
<td>~15y</td>
</tr>
<tr>
<td>1930s “Directed Play”</td>
<td>Nylon, Polyester</td>
<td>Fibers, Moldings</td>
<td>~15y</td>
</tr>
<tr>
<td>1930s Refrigerants</td>
<td>Fluoropolymers</td>
<td>Surfaces, Heat/ChemRes</td>
<td>~20y</td>
</tr>
<tr>
<td>1930s Electrical Insulation</td>
<td>PE</td>
<td>Ubiquitous</td>
<td>~5y</td>
</tr>
<tr>
<td>1930s Nylon Substitute</td>
<td>Polyurethane</td>
<td>Foams, Fibers, Coatings</td>
<td>~15y</td>
</tr>
<tr>
<td>1950s Electrical Insulation</td>
<td>Polycarbonate</td>
<td>Transparency/Toughness</td>
<td>~15y</td>
</tr>
<tr>
<td>1960s Electrical Insulation</td>
<td>Polyketone</td>
<td>Heat/ChemRes</td>
<td>~20y</td>
</tr>
<tr>
<td>1960s Electrical Insulation</td>
<td>Polysulfone</td>
<td>Heat/ChemRes</td>
<td>~20y</td>
</tr>
</tbody>
</table>

A = accidental discovery

Often find what you’re not looking for... and profits accrue elsewhere
Historical Recipe for Success: 
*New Polymers with Commercial Utility*

• Patience (τ)
  • “Chasm of Death” up to 20 years (*Profit & Career considerations…*)
  • Development, Industrialization, Market Fit, Regulatory, Stewardship

• Capital
  • >> 100 m$ to Cross Chasm with Success Probability << 1.0

• Serendipity
  • Launch Applications seldom are Profitable
    • Technical “Solutions” looking for the Wrong Market “Problems”
    • Market Agility is Essential

• Unfamiliarity
  • Discontinuities often Emerge from Outside the Industry
    • "Sometimes it is a real advantage .... not to know too much, because too much book knowledge might petrify the mind" – Leo Baekland

**Chance Favoring an Unprepared Mind with $$$, Risk Tolerance, & Time**
Reinvigorating the S-Curve

Value Innovation Levers

• Thousands of Commercially Interesting Polymers Synthesized
  • Relatively Few Commercialized (Patience, Capital, etc)

• Available Innovation Levers:
  • Surgical Chemistry
    • Unique Performance via Precise Control over Microstructure, Morphology, & Functionality
  • Advanced Modeling
    • Cycle-Time Reduction - Predict Performance, Regulatory Profiles, etc
  • Novel Monomer / Polymer Process Technology
    • “Process Intensification” – e.g. Microreactors
    • Lower-Cost Custom Manufacturing of Specialty Monomers & Polymers
  • Clever End-Use Design & Fabrication Processes
    • Hybrid Structures
    • Additive Manufacturing, Out-of-Autoclave (composites), etc
  • Better Marketing???
    • Enduring Value Propositions are difficult to identify a priori

The End of the Beginning… focus on Value vs. Volume
What does Industry Think?
An Industry Insider’s Musings...

• Lessons from the Past
• Extrapolations Into the Future
  • Academic Insights
  • Structure / Properties / Processing
  • Organization & Talent

Opportunities & Challenges
What does Academia Think?
*Logical Extrapolation Point...*

Science in Pursuit of Knowledge – Inspiration for Industry

Nano, Bio, Micro(*structure*), Functional Themes
What Does Naresh Think?

**GT MS&E Vision**

- Design & Develop the Next Generation of Materials for:
  - Structural
  - Electronic
  - Optoelectronic
  - Photonic
  - Bio-enabled
  - Magnetic
  - Energy Storing / Harvesting
  - Other Functionalities & Applications
- With the Goal of overcoming societal challenges…

**MS&E is Broad, Exciting, and Full of Technical Opportunities**

**Industry Agrees… But How do we Make a Profit from this Model?**
Academic Insights

• Precise Control over Molecular Structure & Morphology
• Leverage Inherent & Ultimate Capabilities of Molecules
• Increased Functionality
• Bio Influenced and/or Inspired
• Nano Intense

Large Innovation Space - Profit Recipe TBD…
What does Industry Think?  
An Industry Insider’s Musings…

• Lessons from the Past
• Extrapolations Into the Future
  • Academic Insights
  • Structure / Properties / Processing
    • Custom & Ultimate
    • Nano-Composites
    • Bio-Polymers
    • Process Intensification
    • Advanced Manufacturing
    • Design - Hybrid Structures
  • Organization & Talent

Opportunities & Challenges
Structure / Properties
Custom & Ultimate

- Chemistry to Prepare “Custom” Molecules
  - Novel & Controlled Microstructures
  - Incorporate Multi-Functionality
  - Designer Morphology
  - Approach Ultimate Properties
    - See example…

Industry Relies on Academia for Most Leading Edge Chemistry

Industry has Capabilities to Industrialize Novel Chemistry @ Scale
Superior Specific Strength

Strength of Materials

Approaching Ultimate Property of Polymeric Molecules (Acquisition)

Solvay
asking more from chemistry®
Structure / Properties
Polymer Nano-Composites

• Promise of the “AND”
  • Stiffer AND Tougher
  • Conductive AND Transparent
  • etc.

• Limited Commercial Success
  • Key Challenge is Achieving Stable Dispersion @ Nano-Level
  • HSE Considerations to Manage
  • Niche Value Propositions
  • High Cost vs. Traditional Materials or Innovative Design Options

Please Help Industry Realize the Promise / Hype…
Structure / Properties

Bio-Polymers

- 2 Dimensional Model:
  - Feedstock Source
  - Biodegradability
- Critical Considerations:
  - Performance?
  - Life Cycle Analysis?
  - Food Chain Competition?
  - Pricing Cyclicality?
  - Advocacy Groups & Misinformation…

Complex Mixture of Science, Marketing, Advocacy, & Value

Develop Viable Non-Food Chemistry with Performance & LCA Benefits

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Processing

Process Intensification

• Process Intensification
  • Strategy for making dramatic reductions in the size of a chemical plant so as to reach a given production objective
  • These reductions can come from shrinking the size of individual pieces of equipment and also from cutting the number of unit operations or apparatuses involved

• Addresses Industrialization Cost / Cycle Time
• Promise yet to be Realized for Macromolecules

Emerging Area of Industrial Interest
Processing

Advanced Manufacturing

- Clever New Conversion Approaches
  - Additive Manufacturing
  - Out-of-Autoclave
  - etc.

Help Industry realize the Promise of our Manufacturing Renaissance
System Level
*Hybrid Structures*

- Clever Forms & Hybrid Designs
  - Leverage Material Properties
  - Mixed-Material Approaches

Macro Offers Promise for Performance Breakthroughs
What does Industry Think?
An Industry Insider’s Musings...

• Lessons from the Past
• Extrapolations Into the Future
  • Academic Insights
  • Structure / Properties / Processing
    • Custom & Ultimate
    • Nano-Composites
    • Bio-Polymers
    • Process Intensification
    • Advanced Manufacturing
    • Design - Hybrid Structures
• Organization & Talent

The Soft Side....
Organization

• How to Compensate for Institutional Myopia?
  • From Not-Invented-Here to Proudly-Found-Elsewhere (P&G)
  • Value Outliers (in Data and People)
  • Open / Collaborative Innovation
  • Awareness & Agility to Change Course

Discontinuities from the Outside (Academia, Start-ups) and the Unusual
Talent

• Rising Above the Gathering Storm…

FOR IMMEDIATE RELEASE

U.S. COMPETITIVE POSITION HAS FURTHER DECLINED IN PAST FIVE YEARS, REPORT SAYS; NATION NEEDS SUSTAINED COMMITMENT TO INVESTMENT IN INNOVATION

Sept. 23, 2010 — The outlook for America's ability to compete for quality jobs in the global economy has continued to deteriorate in the last five years, and the nation needs a sustained investment in education and basic research to keep from slipping further, says a new report requested by the presidents of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, and authored by members of the committee that wrote the influential 2005 report Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.

• Competition for Top Talent from Unconventional Industries
  • Wall Street, Management Consultants, Start-ups, etc.

Probably the Largest Industry Risk Mid-Long Term
What does Industry Think?
An Industry Insider’s Musings...

• Lessons from the Past
• Extrapolations Into the Future
• Closing Thoughts
The Hard Side of Soft Materials
What Does Industry Think?

• Fantastic
  • Custom & Ultimate Properties
  • AND vs OR (promise of nano?)
  • Extreme Environments

• Functional
  • Smart
  • Responsive
  • Multi

• Fabrication
  • New Transformation Technology - Advanced Manufacturing

• Forms
  • Inter-material Structures

• Friendly
  • Sustainable
  • Bio?

• Fast
  • Faster / Less Expensive paths to Industrialization & Profitability

Renaissance in Soft Materials
The Soft Side of Soft Materials
What Does Industry Think?

• Talent is a Strategic Concern
• Organizational Mindset & Behaviors are Critical Success Factors
  • Be Curious
  • Be Responsible / Sustainable
  • Look Inside, Outside, at the interface, & around corners for Ideas/Inspiration
  • Pick a Direction
  • Move Fast & Learn
  • Be Prepared to Change Course
  • Have Fun *(the profit will Follow…)*
What Does Georgia Tech Think?
**Steve Cross’ 3-Prong “Use-Inspired” Research Strategy**

- Transformative / Inter-disciplinary Research
- Collaborative Partnerships – Industry, Government, & Non-Profits
- Maximizing the Economic & Societal Impact

Perfect Alignment with Industry View

MS&E Innovation Space in Polymers is Large, Open, & Vigorous
Solar Impulse
Pioneering Sustainable Chemistry