How Chemical Engineering will Drive the 21st Century?

The Mega Possibilities Ahead

Partha@ParthaGhosh
How do you sense the “State of Health” of our Planet?

What is the Global GDP?

What percentage of Global GDP is Process Industry?

Partha S Ghosh
Global Population 650 Years = US today: 300M

Note: Each dot represents 1 million people

Boston Analytics Research

Partha S Ghosh
Population 300 Years ago: **600M Pre-industrial revolution**

*Note: Each dot represents 1 million people*

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Population Hundred Years ago : 1,600 Million

Note: Each dot represents 1 million people

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Post World War II, 50 years later 2,400 Million

Note: Each dot represents 1 million people

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The Recent Past, 20 Years back 5,000 Million

Note: Each dot represents 1 million people

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And Near Future 2020: 8000 Million

Note: Each dot represents 1 million people

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Slow Pace of Dangerous Change: CO₂ Emission

World Carbon Dioxide Emission in Million Metric Tons
(1980 to 2050*)

65 Billion Tons by 2050

Boston Analytics Research
1. Energy Information Administration (http://www.eia.doe.gov)

Partha S Ghosh
How Hot will Boston be?

Number of Hot Days in Boston (1961 to 2099)

<table>
<thead>
<tr>
<th>Period</th>
<th>Lower emissions</th>
<th>Higher emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961 to 1990</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>2010 to 2039</td>
<td>15.7</td>
<td>17.7</td>
</tr>
<tr>
<td>2040 to 2069</td>
<td>25.5</td>
<td>39.3</td>
</tr>
<tr>
<td>2070 to 2099</td>
<td>31.5</td>
<td>64.1</td>
</tr>
</tbody>
</table>

Projections

Boston Analytics Research
1. “Union of Concerned Scientists”, Joan McLaughin/Globe Staff

Partha S Ghosh
Global Warming is Lethal?

Causes and Effects of Global Warming

- Greenhouse Gases (GHG e.g. CO₂)
- Chlorofluorocarbons, 17%
- Agricultural practices, 14%
- Changes in land use, 9%
- Other industrial activities, 3%
- Energy use and production, 57%

Effect

- Rise in Sea level
- Reductions in the ozone layer
- Increased intensity and frequency of extreme weather events
- Impacts on agriculture
- Spread of disease

Boston Analytics Research

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Sea level is expected to Rise: How much?

Estimated Sea Level Rise in cm (2000 to 2100)

- **Conservative Scenario**
- **High Scenario**

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Annual loss of Forest land 16.2 Mn Hectares

Annual Change in Forest Area (000 ha per year) 1990 to 2005)

Europe
Asia
Oceania & Australia
North & Central America
South America
Africa
World

Boston Analytics Research
1. “Extent of forest resources”, (http://www.mongabay.com/deforestation.htm)

Partha S Ghosh
In fact the US has lost considerable forest area
Dynamics of Deforestation and Ecology: Require Repurposing our Chemical Engineering Knowledge

- Loss of vegetation
- Decrease in no. of species
- Leads to increasing infestation
- Decrease of pollinators & seed dispersers
- Loss of human diversity

- HYDROSPHERE
  - Increase in Flash Floods
  - Aquatic Habitat Degraded
  - Flow of Water Changes
  - Less Oxygen in the waterways

- ATMOSPHERE
  - Less CO₂ taken in
  - Burning Trees adds even more CO₂
  - Less photosynthesis takes place
  - Increased risk of fire

- GEOSPHERE
  - Soil Erosion

- BIOSPHERE


Partha S Ghosh
The Essential Points:

1. Indeed Challenging & Interesting times ahead
Powerful Forces at Work?

Changing Ecology

- 65 Billion Tons of CO2
- Rising Temperature
- Increasing Sea Level

Finite Resources

- Increasing Population
- Equity
- Deforestation

Partha S Ghosh
Powerful Forces at Work: *Clash of Perspectives?*

**Digitization requirements**
- 65 Billion Tons of CO2
- Rising Temperature
- Increasing Sea Level

**Changing Ecology**
- CO2

**Wall Street Expectations**
- Increasing Population
- Equity
- Deforestation

**Finite Resources**

Partha S Ghosh
Most of the world is still in the early stage of Economic development

Energy Consumption per Capita vs. GDP per Capita (2004)

80% of Global Population

Boston Analytics Research
1. Energy Information Administration - EIA (http://www.eia.doe.gov/)
## Future Natural Gas requirement of Asia

### Overview of Energy Scenario  
*(In BCM)*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>22</td>
<td>65</td>
<td>90</td>
<td>114</td>
<td>143</td>
</tr>
<tr>
<td>China</td>
<td>28</td>
<td>54</td>
<td>74</td>
<td>102</td>
<td>142</td>
</tr>
<tr>
<td>Japan</td>
<td>79</td>
<td>91</td>
<td>99</td>
<td>108</td>
<td>119</td>
</tr>
<tr>
<td>South Korea</td>
<td>20</td>
<td>28</td>
<td>37</td>
<td>43</td>
<td>51</td>
</tr>
<tr>
<td>Other Asia</td>
<td>139</td>
<td>153</td>
<td>173</td>
<td>198</td>
<td>230</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>288</strong></td>
<td><strong>391</strong></td>
<td><strong>473</strong></td>
<td><strong>565</strong></td>
<td><strong>685</strong></td>
</tr>
</tbody>
</table>
If China & India consumes energy @ 25% of US/capita total energy consumption will increase by 41.6 T KwHr

* Per capita energy consumption of the selected countries is 25% of US per capita energy consumption
Old Path or New Path: *Time to Choose?*

Plastic Consumption per capita in Selected Countries vs. GDP per capita (2003)$^{1,2,3}$

![Graph showing plastic consumption vs. GDP per capita](image)

**Boston Analytics Research**
2. Poland and its investment opportunity – BCG Report

Partha S Ghosh
On the other hand Oil Production Capita has been declining at a rate of 1.2% annually

*Measured in barrels of oil per person per year (b/c/year)

Boston Analytics Research
Cleary we are at the *End of a Long Era?*

Economic Development Curves

- **Industrial Revolution 1** (Steam Engine)
- **Industrial Revolution 2** (Internal Combustion Engine)
- **Information Revolution**

**Time**

2005 ~2010

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The Essential Points:

1. Indeed Challenging & Interesting times ahead

2. The Process Industry will become more dominant & will be the driver
Mega Challenge = Managing a Mega Transition to avoid Mega disruption

- "Unconstrained" Processing of Earth’s resources
- New Relationship of Space & Time
- Supply to Fuel Unidirectional Demand

Next Era Paradigm?

Role of Chemical Engineers?

1. Concentrated Economic Growth
2. Ecological disequilibrium
3. Complex Politics of Supply Chain
Holistic Approach?

PROBLEMS ≈ OPPORTUNITIES

Holistic Approach

Energy

Renewable and Clean Energy Source

Ecology

Equity

Sustainable Economic Developed

Energy, Food and Health for All

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Scope of the Field?

Chemical Industry’s Future (?): Two Strategic Vectors

Balance of Ecology

Conservation driven

Consumption driven

Balance of Economic Advance

Point Solution

Future Chemical Engineer

Holistic/Integrative Solution

Perspective?

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Expanded Field?

Chemical Industry’s Future (?): Two Strategic Vectors

Balance?

Conservation

Balance of Ecology

Carbon Free Energy System

Future Chemical Engineer

Systems Approach to Energy & Transportation Management

Recycling of Waste

Agro based Chemical Industry

Recycling

Improved functionalities

Lighter Products

Process Intensification

New Chemistry for the Car

Today

Point Solution

Balance of Economic Advance

Perspective?

Holistic Solution

Partha S Ghosh
Strategic Direction of Chemical Industry

Balance of Ecological Impact

- Positive
- Negative

Balance of Economic Progress

- Negative
- Positive

Create New Game

Energy/Materials

Investment in Next generation Knowledge Intensive Solutions: “Small is beautiful”

Energy Efficient consumption

Partha S Ghosh
Mega Challenge = Managing a Mega Transition to avoid Mega disruption

- "Unconstrained" Processing of Earth’s resources
- New Relationship of Space & Time
- Supply to Fuel Unidirectional Demand

1. Concentrated Economic Growth
2. Ecological disequilibrium
3. Complex Politics of Supply Chain

Multi vector Multi-tier Renaissance
An unique opportunity for Chemical Engineers

Chemical Industry’s Knowledge Asset

Extraordinary Knowledge base

Rooted in the early Stages of Industrial Revolution

Critical Assets

Thermodynamics

(How far?)

Kinetics

(How fast?)

Size Reduction

(Surface Properties ?)

Transport Phenomena

(Flow Mechanisms?)

Partha S Ghosh
And Look for Mega possibilities @ the Intersection of Conventional Engineering & New Technologies

Chemical Fundamentals
- Thermodynamics
- Kinetics
- Transport sciences

Conventional Unit Operations
- Separation processes
- Reactors
- Heat & Mass transfer systems

In flux of New Methodologies
- Genomics
- Proteomics
- Micro fluidics
- Nano technologies

New Convergence Technologies
- Large database tools
- Predictive models
- Increased interactivity
The Promise of Chemical Industry has to be applied in *Multiple Scales*

**Three Scales of Knowledge Application**

1. **Holistic /Tera Scale Perspective**
   - Large Scale Systems Dynamics
   - Issues
   - Global Ecological Balance?
   - Energy Balance?
   - Social Structures?

2. **Current Scale**
   - Raw materials
   - 1. Efficiency
   - 2. Conservation
   - 3. Recycling

3. **Micro Nano Scale**
   - Cellular /Nano Level functionalities

Partha S Ghosh
The Promise of Chemical Industry has to be applied in **Multiple Scales**

**Three Scales of Knowledge Application**

1. **Holistic /Tera Scale Perspective**
   - Large Scale Systems Dynamics Issues
     - Global Ecological Balance?
     - Energy Balance?
     - Social Structures?

2. **Current Scale**
   - Raw materials
   - Cellular /Nano Level functionalities
   - Socialization Process of Multiple disciplines
     - 1. Efficiency
     - 2. Conservation
     - 3. Recycling

3. **Micro Nano Scale**

Partha S Ghosh
New technologies could indeed trigger a New Era

Process Industry Reconfiguration

Nano Technologies
Information Technology

Upstream
Biotechnology
Opto Technologies

Partha S Ghosh
Towards an Agro cell based Economic Revolution?

Development of a More Sustainable Economic Model

Towards improved new socioeconomic structures with a “new agro” based revolution

Symbiosis of Multiple Disciplines
- Genomics / Biosciences
- Unit operations
- Bio Catalyst
- Convergence technologies (4 C’s)†

Partha S Ghosh
For Example: \textit{An Agro Complex?}

<table>
<thead>
<tr>
<th>Resource</th>
<th>Industry</th>
<th>Critical Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal Crops</td>
<td>Food and Beverage</td>
<td>- Increase in yield (kg / hectare)</td>
</tr>
<tr>
<td>Fruits</td>
<td></td>
<td>- Quality and consistency?</td>
</tr>
<tr>
<td>Tea</td>
<td></td>
<td>- Distribution system?</td>
</tr>
<tr>
<td>Vegetables</td>
<td></td>
<td>- Down stream value addition and branding?</td>
</tr>
<tr>
<td>Aqua Products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>Fiber, Fabric and Fashion</td>
<td>- Cost Effectiveness?</td>
</tr>
<tr>
<td>Silk</td>
<td></td>
<td>- Quality consistency?</td>
</tr>
<tr>
<td>Jute</td>
<td></td>
<td>- Familiarity with fashion trends?</td>
</tr>
<tr>
<td>Bio-mass</td>
<td>Energy</td>
<td>- New application on development?</td>
</tr>
<tr>
<td>Wind Farming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Oils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starches</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specialty Chemical Industry</th>
<th>Perfume Personal Care</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbs</td>
<td></td>
<td>- Awareness building?</td>
</tr>
<tr>
<td>Medical Plants</td>
<td></td>
<td>- Involvement of university professionals?</td>
</tr>
<tr>
<td>Algae / Azola</td>
<td></td>
<td>- Incentives for corporate sector?</td>
</tr>
<tr>
<td>Vegetable Oil</td>
<td></td>
<td>- Venture funds “bottom up” development?</td>
</tr>
<tr>
<td>Flowers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Chemical Industry          | Dyes and Pigments                  |                                                                                 |
|----------------------------|                                    | - Knowledge sharing and awareness building?                                      |
| Vegetables                 |                                    | - Development of low cost process equipment and controls?                         |
| Flowers                    |                                    | - Storage and distribution system?                                               |
| Algae                      | Polymers and Epoxy Glues            | - Economics of scale and cost competitiveness?                                    |
| Natural Rubber             |                                    |                                                                                 |
| Starch                     | Solvent and Chemicals               |                                                                                 |
| Lignins                    |                                    |                                                                                 |
| Alcohol                    |                                    |                                                                                 |
| Starches                   |                                    |                                                                                 |
| Jute Stick Board           | Furniture / Constrn.               |                                                                                 |
| Chip Board                 |                                    | - Knowledge sharing application development?                                     |
| Renewable Wood             |                                    | - Machinery development for rural use?                                           |
| Sugar Cane                 | Paper, Paper Board and Packaging   | - Development of hot stamping technology?                                         |
| Straw                      |                                    | - Knowledge Sharing and application?                                             |
| Jute                       |                                    | - Low cost machinery development?                                                |
| Waste Woof Pulp            | Oil and Lubricants                 | - Incentives for corporate sector?                                               |
| Rapeseed                   |                                    | - Promotion of new application based on agro?                                     |
| Lequerella                 |                                    | - Availability of venture funds?                                                 |
| Castor Seed                |                                    | - Creation of down stream pillars?                                               |

Partha S Ghosh
Biotechnology could enable production of better breeds of trees enabling fast and healthy reforestation

**Tree Breeding and Seed Production Processes**

1. **Selection:** The selection process involves the finding wild trees which possess the desired traits (e.g. pest resistance, superior growth or form etc).

2. **Testing:** In the testing phase, researchers try to find those parent trees that carry the best genes for the desired characteristics.

3. **Breeding:** After testing, better wild parent trees are selected for the breeding program. The aim is to increase the extent to which the desired characteristics are shown in every subsequent generation.

4. **Production:** Cuttings from the wild parent trees are grafted in the orchard in a random pattern and allowed to cross-pollinate.
Biocatalysts: Using enzymes as catalysts for synthesis in mild conditions?

Biocatalysis in the Manufacture of Polymers

Enzymes act as biocatalysts enabling precision polymer synthesis.

Polymer is obtained under mild process conditions and is environmentally friendly.
Development and fine tuning of Biofuels Technologies could open up new vistas

Feedstocks
- Consumer Residues
- Agricultural Residues
- Fiber Residues
- Cellulosic Peren. Crops
- Energy Crops
- Oil Crops

Conversion
- Thermochemical Conv.
  - Gasification
  - Pyrolysis
    - Liquif & HTU
- Biochemical Conv.
  - Anaerobic Digestion
  - Fermentation & Distillation
  - Microbial Digestion
  - Extraction

Fuel
- Hydrogen
- Methanol
- Bio-Oil (Fischer-Tropsch)
- Biogas
- Ethanol
- Biodiesel (Veg. Oil Methyl Esters)

End-Use
- Fuel Cell Vehicles
- Gasoline Vehicles
- Diesel Vehicles

Partha S Ghosh
## Cellulosic ethanol is on the horizon

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
<th>Pilot plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermentation</td>
<td>Conventional ethanol from sugars (corn, sugarcane) are marginally energy positive. 100-110 gal/ton</td>
<td>2% of U.S. gasoline demand currently comes from ethanol made this way from 7% of corn</td>
</tr>
<tr>
<td>Acid hydrolysis</td>
<td>Strong acids are used to break down cellulose into sugars.</td>
<td>Commercial plants in operation. Used mainly in niche markets for waste disposal.</td>
</tr>
<tr>
<td>Thermal gasification</td>
<td>High temperatures convert biomass into synthesis gas of carbon oxides and hydrogen. In the presence of a catalyst, these gases are converted to ethanol.</td>
<td>Arkansas and Colorado</td>
</tr>
<tr>
<td>Enzymatic reduction</td>
<td>Enzymes turn woody biomass into sugars.</td>
<td>Ontario</td>
</tr>
</tbody>
</table>
### Biomass Energy development will require a full range of conventional Chemical Technologies

#### Different Technologies to Harness Biomass Energy

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Combustion</td>
<td>Combustion of biomass to produce electricity</td>
</tr>
<tr>
<td>Biomass Gasification</td>
<td>Gasification is meant to convert solid carbon fuels into gaseous fuels</td>
</tr>
<tr>
<td>Biomass Carbonization</td>
<td>Carbonization converts biomass into biofuels / biocarbons (charcoal and carbonized charcoal)</td>
</tr>
<tr>
<td>Biomass Densification</td>
<td>Biomass densification converts the loose biomass (agricultural and agro – industrial wastes) into a densified fuel called briquettes</td>
</tr>
<tr>
<td>Biogas Production</td>
<td>Biogas production involves the fermentation of cowdung, crop residue and kitchen waste in the absence of oxygen to produce biogas (mainly CH₄, CO₂ and other gases)</td>
</tr>
</tbody>
</table>
Power & Energy: Large Scale Engineering systems thinking is essential

The Virtual Power Plant
- Aggregates the output of thousands of micropower technologies
- Peak shaving becomes power trading on the wholesale market
- Coordination and control through a new communications infrastructure

Partha S Ghosh
Solar Energy has the potential to address our growing energy needs in an environmentally-friendly way

**Basic Mechanisms of Solar Energy Conversion**

Solar Energy

- Light
- Fuel
- Electricity

Semiconductor/Liquid Junctions

CO₂

Sugar

H₂O

O₂

H₂O

H₂

O₂

Electrons (e⁻)

Boston Analytics Research

1."Global Energy Perspective", Nathan S. Lewis, California Institute of Technology, Pasadena, CA

Partha S Ghosh
Poor efficiency and intricate material processing techniques are major issues with the solar cell.

**Major Issues with a Photovoltaic (PV) Cell**

- Photovoltaic (PV) cells provide efficiencies as low as 25%.
  - Require: New electrolytes and catalysts to improve efficiency of the PV cell.
- Polycrystalline Si technology in semiconductors is relatively complex.
  - Flat Plate Si crystalline is better but yet significant development will be required.

**Boston Analytics Research**
1. “Global Energy Perspective”, Nathan S. Lewis, California Institute of Technology, Pasadena, CA

Partha S Ghosh
Reducing cost of production of electricity by wind turbines could be a significant challenge

Challenges in Using Wind as a Source of Power

Varying wind supply require innovative storage solutions

Aerodynamic characteristics of the blade: Knowledge of fluid dynamics and lubrication to improve efficiencies

Boston Analytics Research
1. www1.eere.energy.gov/windandhydro/wind_how.html
3. “Generic Wind Turbine- generator Models”, Western electricity Coordinating Council, Abraham E

Partha S Ghosh
Next Generation Nuclear plant design will require significant Chemical Engineering Knowledge.

Production of Nuclear Energy in a Pressurized Water Reactor:

- **Fission zone in the reactor**
- **Heat Exchangers**
- **Recycling of steam**
- **Steam gives energy to the turbine**

Partha S Ghosh
... Particularly in recycling of Spent Fuel

Challenges in Nuclear Fission\textsuperscript{1,2}

The lighter elements in Spent Fuel are radioactive. Need new forms reuse of fuel and chemical treatment processes before disposal.

Partha S Ghosh
Not Either Or, it is all about Unification

A. Electrolizer

B. Sun’s Rays

C. H₂ Cylinder

D. 

E. 

F. 

Partha S’Ghosh
Fuel Cells works by converting chemical energy to electrical energy **On Demand**

Basic Mechanism of a Fuel Cell

---

Partha S Ghosh
Fuel Cells have been around since the 19th century: Could we take on the Challenge of commercialization?

Major Challenges in Using a Fuel Cell\(^1,2,3\)

Fuel cell’s performance function of Electrolytes and Catalysts
Knowledge of Fluid flow
Material science for advanced catalysts and electrolyte systems

Size and weight of fuel cells
Process Intensification to reduce size and weight of cell

Overall efficiency of the cell is just 24-30% due to poor conversion of CH\(_3\)OH to H\(_2\)
Systems design and catalysts

Chemical engineers can experiment with different materials and electrode systems to come up with cost-effective solutions

---

Boston Analytics Research
1. www.howstuffworks.com
2. “Changing the way America drives: WPI chemical engineer works on fuel-cell power”, WPI News & Events

Partha S Ghosh
Heat Mining: Health & safety concerns due to materials ejecting from the Earth are issues that will need attention

Challenges in Harnessing Geothermal Energy\(^1,2,3,4\)

The steam coming out needs to be purified before it drives the turbine
Chemical engineers can design a steam purification plant

Many-a-times, hazardous gases and minerals may be released during heat extraction
Engineers can develop a safety systems by which the toxic substances would not harm the surroundings – just like SHE mechanisms are evolved for chemical plants

Boston Analytics Research
1. www.darvill.clara.net/altenerg/geothermal.htm#more ,2. www1.eere.energy.gov/geothermal/egs_animation_text.html

Partha S Ghosh
An Opportunity in search of Creativity: Nano manufacturing will need committed work

Deep understanding of molecular behavior required for accurate positioning and attack of molecules. Knowledge in **Quantum chemistry** is essential.

**Challenges of Nano-Manufacturing**

- Scale-up of processes for cost-effective methods of manufacturing.

Partha S Ghosh
Shape Memory Alloys (SMAs) are materials that can recover from strain when they are heated above a certain temperature.

### Basic Mechanism of SMAs

<table>
<thead>
<tr>
<th>Phase</th>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austenite</td>
<td>( A^{of} )</td>
<td>High-temperature phase, hard, inelastic, simple FCC structure</td>
</tr>
<tr>
<td>Martensite</td>
<td>( M^{of} )</td>
<td>Low-temperature phase, soft, elastic, complex structure</td>
</tr>
</tbody>
</table>

The SMAs have two phases - the high-temperature phase, **austenite** (hard, inelastic, simple FCC structure) and the low-temperature phase, **martensite** (soft, elastic, complex structure). Transformation between these two phases at different temperatures leads to shape memory.

- Example: NiTiNol, CuZnAl etc.
Current Research is directed towards improving the data quality and biodegradability of optical fibers

Research is on to enhance the size and quality of data transfer through a fiber. For example, tiny drops of fluid inside the fiber in order to improve the flow of data carrying photons resulting in fast transmission and improvement in quality.

Issues in Transmission

As micro technologies develop macro systems solutions will become more affordable.

Comparison of Average Electricity Generation Cost* ($cents/KWh)\(^{1,2,3}\)

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>41.1</td>
</tr>
<tr>
<td>Hydro</td>
<td>24.4</td>
</tr>
<tr>
<td>Biomass</td>
<td>12.5</td>
</tr>
<tr>
<td>Oil</td>
<td>11.0</td>
</tr>
<tr>
<td>Wind</td>
<td>9.9</td>
</tr>
<tr>
<td>Coal IGCC</td>
<td>7.1</td>
</tr>
<tr>
<td>Coal CFB</td>
<td>6.3</td>
</tr>
<tr>
<td>Coal PF</td>
<td>6.1</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Capital Cost* ($/KW)\(^{1,2,3}\)

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>5,544</td>
</tr>
<tr>
<td>Hydro</td>
<td>4,053</td>
</tr>
<tr>
<td>Biomass</td>
<td>3,390</td>
</tr>
<tr>
<td>Oil</td>
<td>910</td>
</tr>
<tr>
<td>Wind</td>
<td>1,363</td>
</tr>
<tr>
<td>Coal IGCC</td>
<td>1,842</td>
</tr>
<tr>
<td>Coal CFB</td>
<td>1,345</td>
</tr>
<tr>
<td>Coal PF</td>
<td>1,511</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2,118</td>
</tr>
</tbody>
</table>

Note: *These are only indicative figures. Actually, electricity generation cost varies across different territories as per the environmental and technological scenario.

Boston Analytics Research
The Essential Points:

1. Indeed Challenging & Interesting times ahead
2. The Process Industry will become more dominant & will be the driver
3. 21st Century Chemical Engineer: Three in One Strategic Problem Solver
We have the tools: We need the commitment to link Supply and Demand

Supply
- New Materials
- Precision Controls
- Nanotechnology
- Life Sciences
- Miniaturization/Process Intensification
- Convergence / Broadband infrastructure

Demand
- Clean Energy
- Six Sigma Power
- Efficiency of Consumption
- Ecological balance
- More advanced living and work spaces
- Global Equity

Supply-Demand Dynamics
The Chemical Engineer is a multi-disciplinary engineer a Strategic Problem Solver

Transport Phenomenon
Thermodynamics Kinetics

Biology/Genetics
Computer Science

Materials Science
Management/Economics

The Chemical Engineer as $\Sigma, O, H$


Boston Analytics Research
1. http://www.ecs.umass.edu/che/

Partha S Ghosh
Equipment efficiency?

Equipment Efficiency vs. Equipment (2004)^1,2,3,4,5

- Thermodynamic Efficiency = 100%
- 20% improvement
- 35% improvement
- 10% improvement

Equipments:
- Lighting Devices
- IC Engines
- Air Conditioners
- Heaters
- Boilers

Boston Analytics Research
Partha S Ghosh
Where a long-haul Class 8 truck’s diesel fuel goes?

Focus: End of Chain [Fuel] → [Engine] → [Drivetrain] → [Ttractive Loads]

- ~38% efficient today: Engine & drivetrain
- Represents >100 years’ R&D: Engine efficiency is more difficult to improve further than is end-use efficiency

End-use: Consider what would happen if we halved aerodynamic drag and mass

Source: Technology Roadmap for the 21st Century Truck Program (DOE 2000), RMI analysis

Partha S Ghosh
Reduction in energy intensity could reduce world energy demand by 14% to 20% in 2025

World Energy Demand in Quadrillion Btu (2025): If Energy Intensity is Reduced in Selected Regions

Assumptions:
• Energy intensity is reduced by 35% for India and China
• Energy intensity is reduced by 20% for Western Europe (WE) and US

Partha S Ghosh
The Essential Points:

1. Indeed Challenging & Interesting times ahead

2. The Process Industry will become more dominant & will be the driver

3. The 21st Century Chemical Engineer

4. A Vision of the Future
### The New horizons...

<table>
<thead>
<tr>
<th>Frontier Areas</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative Energy</td>
<td>Ecology friendly, Sustainable and Safe Energy for all</td>
</tr>
<tr>
<td>Nano-Manufacturing</td>
<td>Taking a bottom-up approach to manufacturing mechanisms at nanoscale to yield products of high quality with zero wastage</td>
</tr>
<tr>
<td>Novel Materials</td>
<td>Efficiency of Usage of Materials e.g. Shape memory alloys, new fibers etc.</td>
</tr>
</tbody>
</table>
… beyond current framework of plant design and engineering

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<tr>
<td><strong>Biocatalysis</strong></td>
<td>Microorganisms and enzymes to catalyze reactions such as polymerization – without any harmful or toxic releases and at normal conditions</td>
</tr>
<tr>
<td><strong>Genetic Reforestation</strong></td>
<td>Production of healthier and fast-growing trees using principles of genetics and biotechnology</td>
</tr>
<tr>
<td><strong>Waste Recycling</strong></td>
<td>Making optimum use of recycling to productively utilize waste materials</td>
</tr>
</tbody>
</table>
Last 5,000 Years...

**Economics of Linear Mechanics:** Extraction, Exploitation & Experimentation

......Future Possibilities...

**Economics of Closed Loop Harmony**

- Agro
- Bio Mass
- Clean Water
- New Technologies
- Energy and Power
- Clean Energy
- Knowledge for Recovery/Recycle

Partha S Ghosh
Chemical Engineering Education & Industry has to **Rekindle the Spirit of Enquiry**

- "The Spirit of Enquiry?"
- "Renewability" intensity
- "Reconfigure" Current processes
- Conservation intensity

..
The Journey forward . . .

Toward a New Integrated Vision for Intelligent Holistic “Mass & Energy Balance” Plays

Partha S Ghosh
It is not in the Seeming, it is in the being,
....but even more in the Becoming . . .
Lets wish for the best
Questions ???