How Chemical Engineering will Drive the 21st Century?

The Mega Possibilities Ahead

AIChE Leadership Forum

October 2006

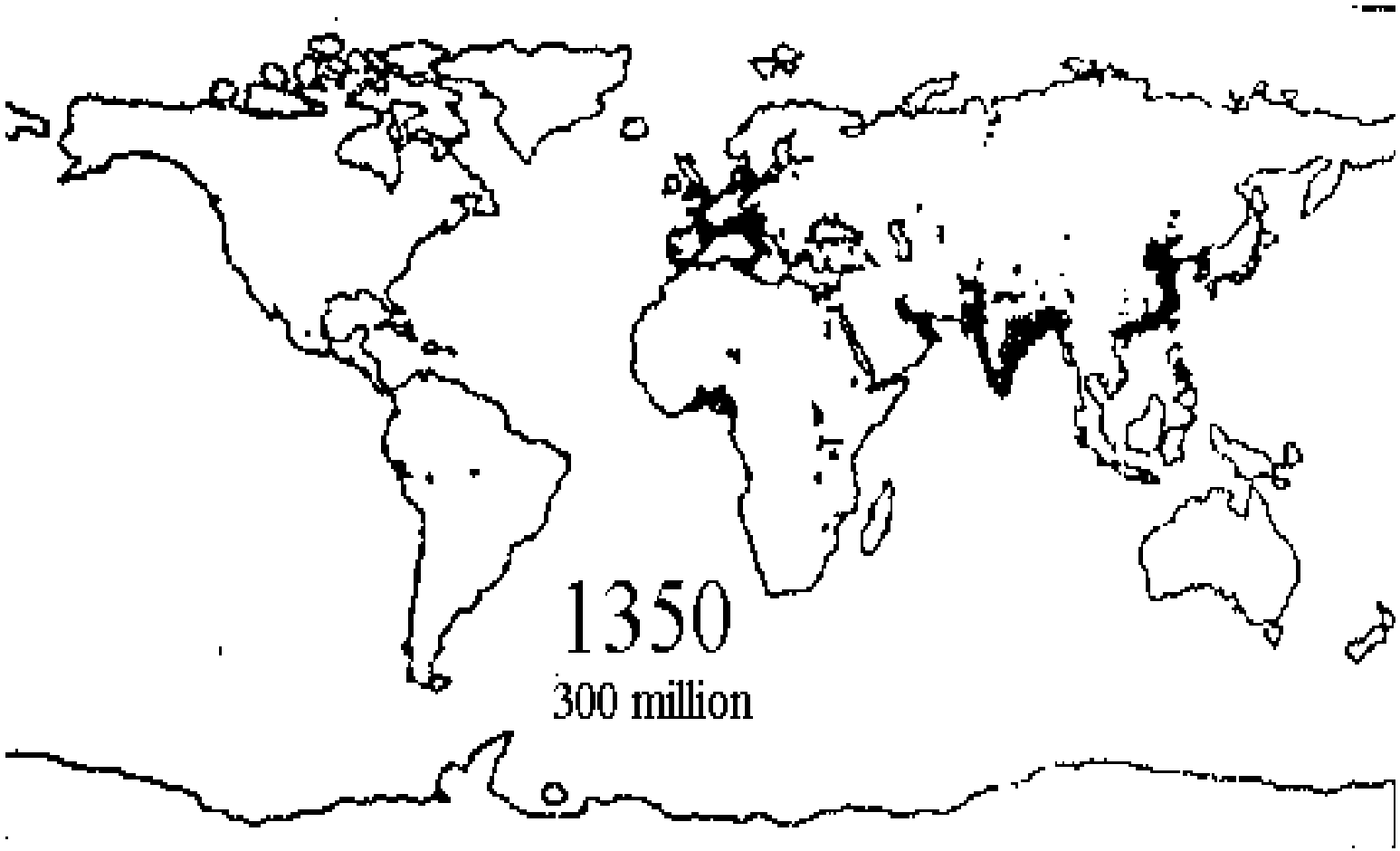
Partha S. Ghosh

How do you sense the "State of Health" of our Planet?

What is the Global GDP?

What percentage of Global GDP is Process Industry?

Global Population 650 Years = US today: *300M*

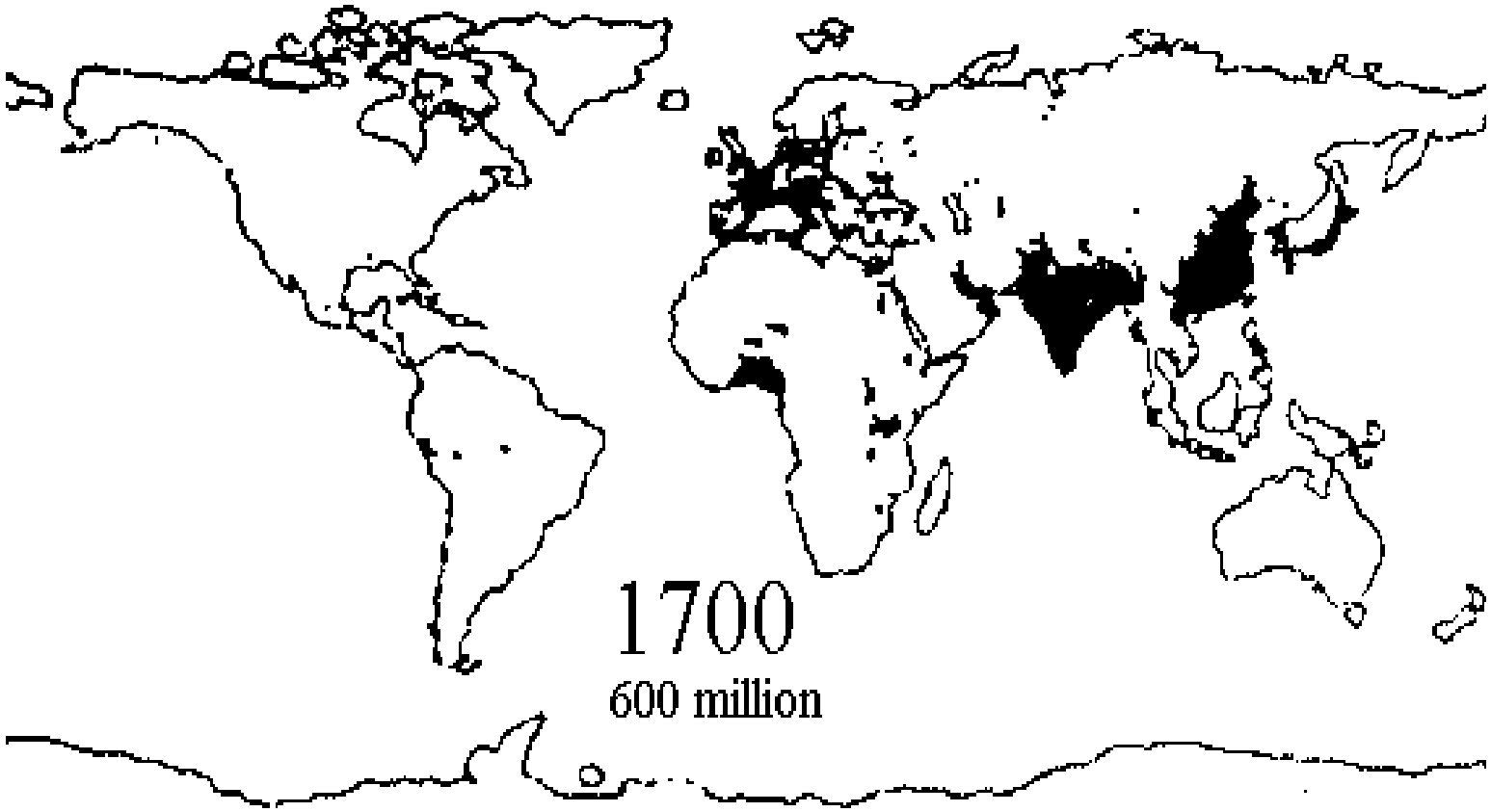


Note : Each dot represents 1 million people

Boston Analytics Research

1. “Energy Consumption and Sources of Renewable Energy”, Amitabh Lath, (www.physics.rutgers.edu/~lath/Piscataway_2003.ppt)

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



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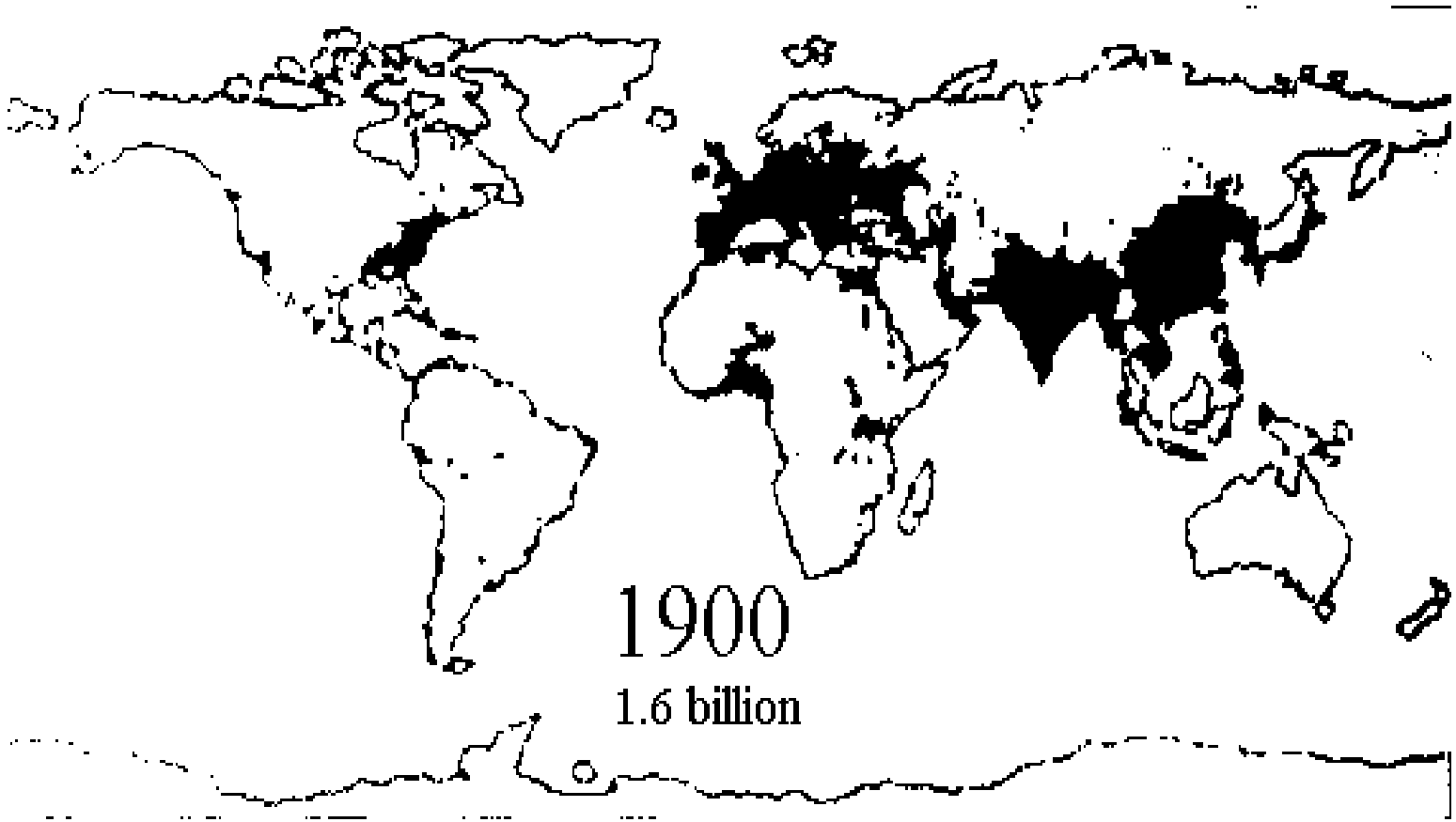
1. “Energy Consumption and Sources of Renewable Energy”, Amitabh Lath, (www.physics.rutgers.edu/~lath/Piscataway_2003.ppt)

Population Hundred Years ago : 1,600 Million



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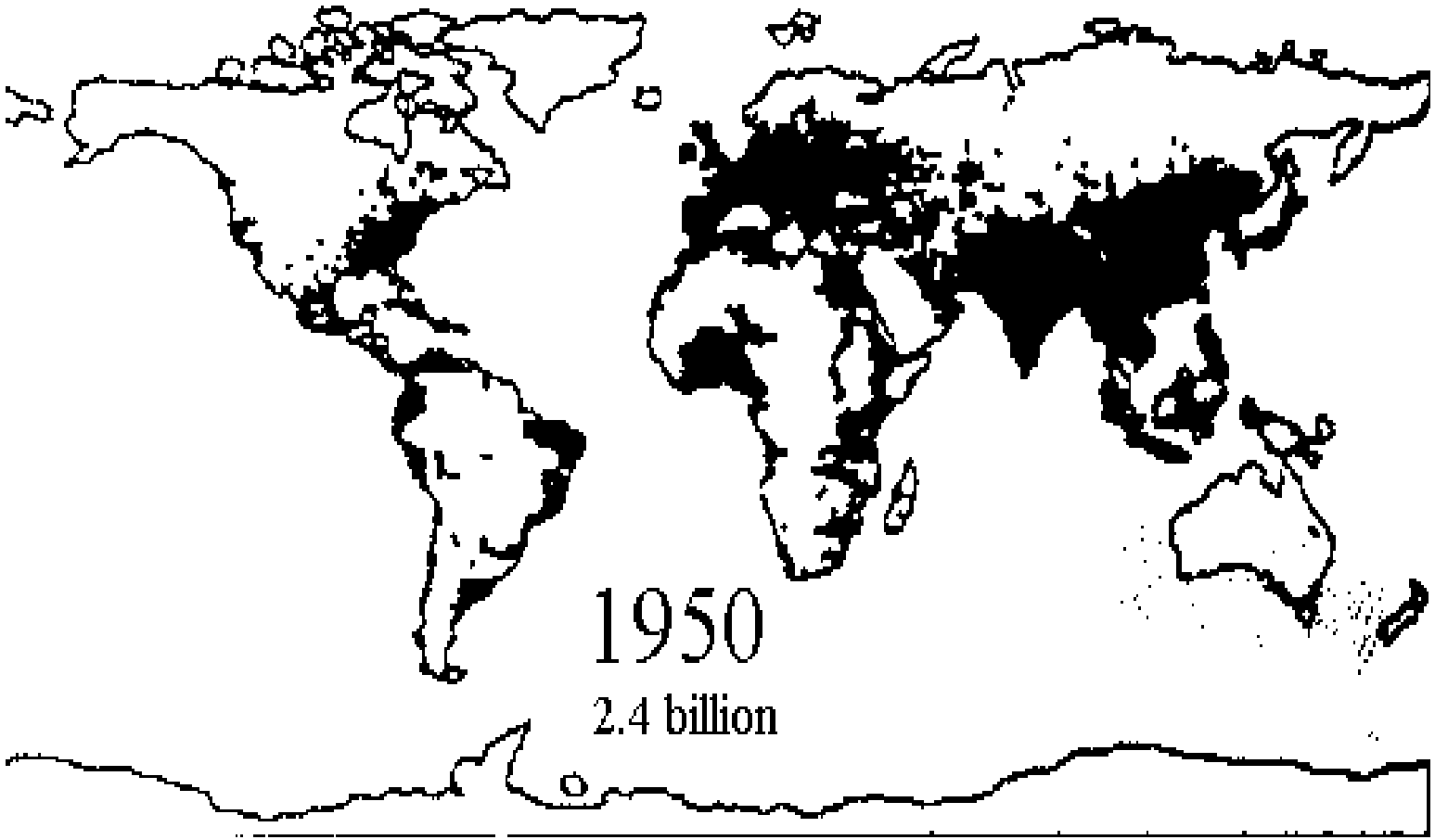
1. "Energy Consumption and Sources of Renewable Energy", Amitabh Lath, (www.physics.rutgers.edu/~lath/Piscataway_2003.ppt)

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



Note : Each dot represents 1 million people

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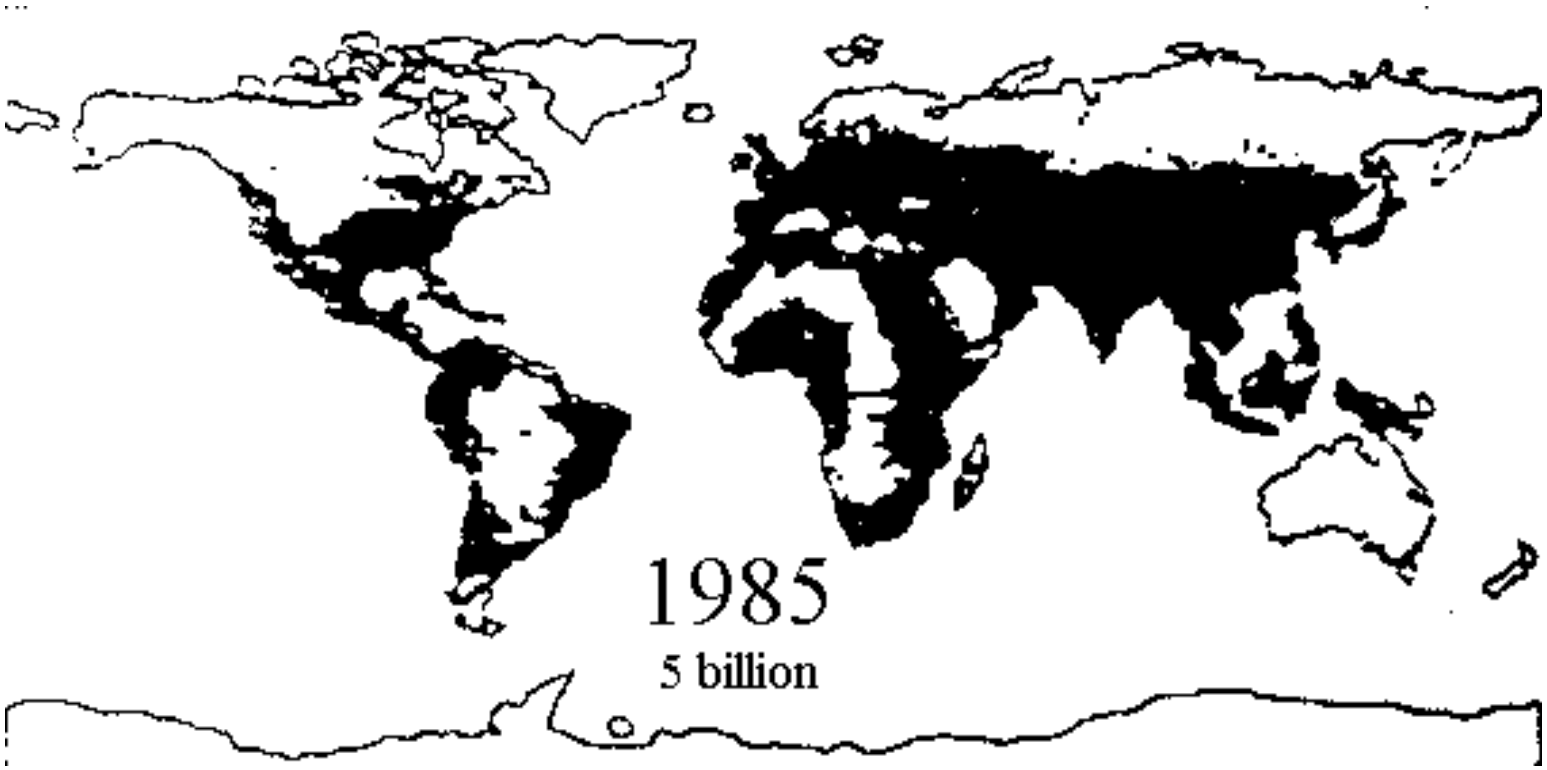
1. "Energy Consumption and Sources of Renewable Energy", Amitabh Lath, (www.physics.rutgers.edu/~lath/Piscataway_2003.ppt)

The Recent Past, 20 Years back **5,000 Million**



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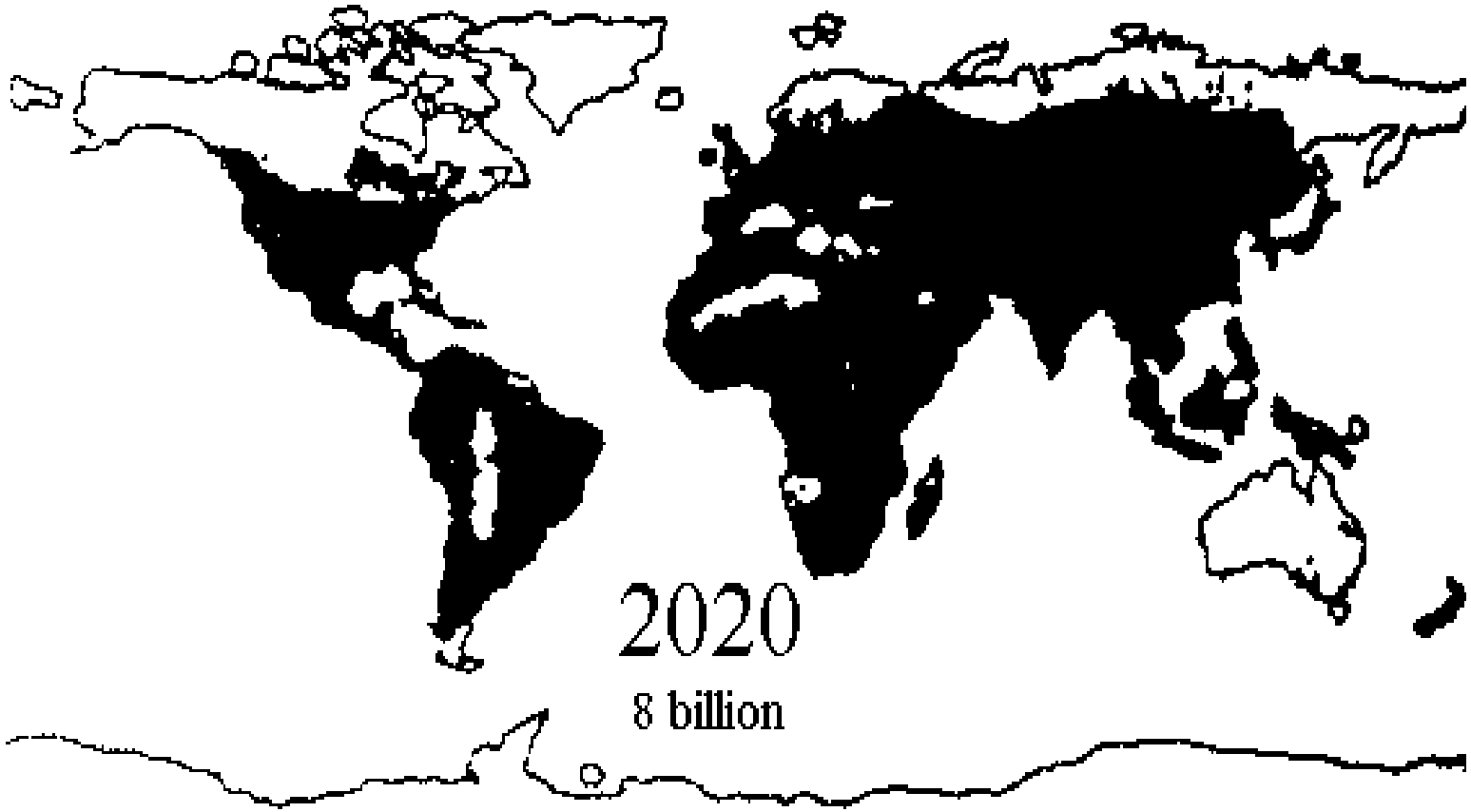
1. "Energy Consumption and Sources of Renewable Energy", Amitabh Lath, (www.physics.rutgers.edu/~lath/Piscataway_2003.ppt)

And Near Future 2020: 8000 Million



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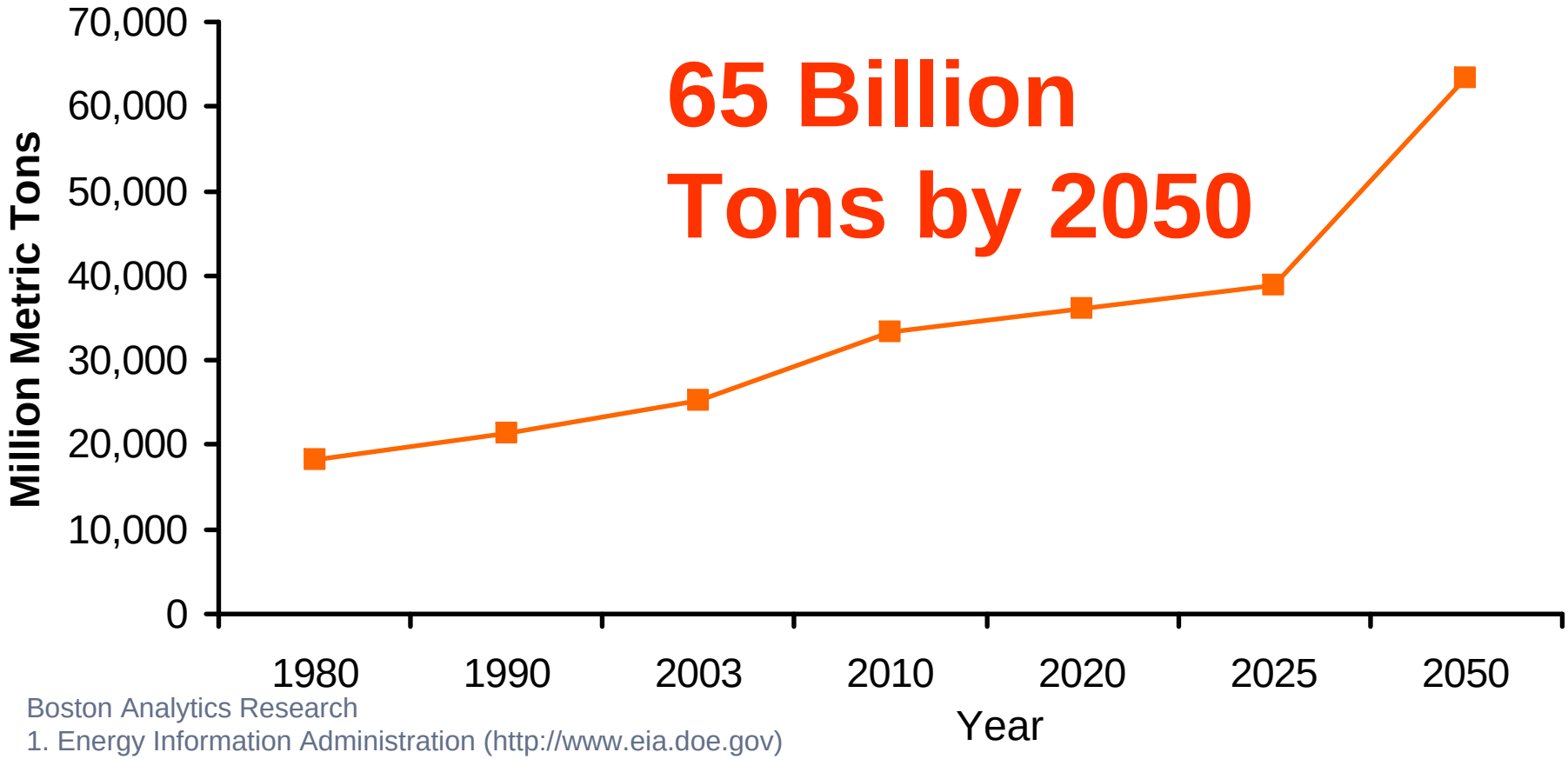
1. "Energy Consumption and Sources of Renewable Energy", Amitabh Lath, (www.physics.rutgers.edu/~lath/Piscataway_2003.ppt)

Slow Pace of Dangerous Change : CO_2 emission

World Carbon Dioxide Emission in Million Metric Tons

(1980 to 2050*)[1]



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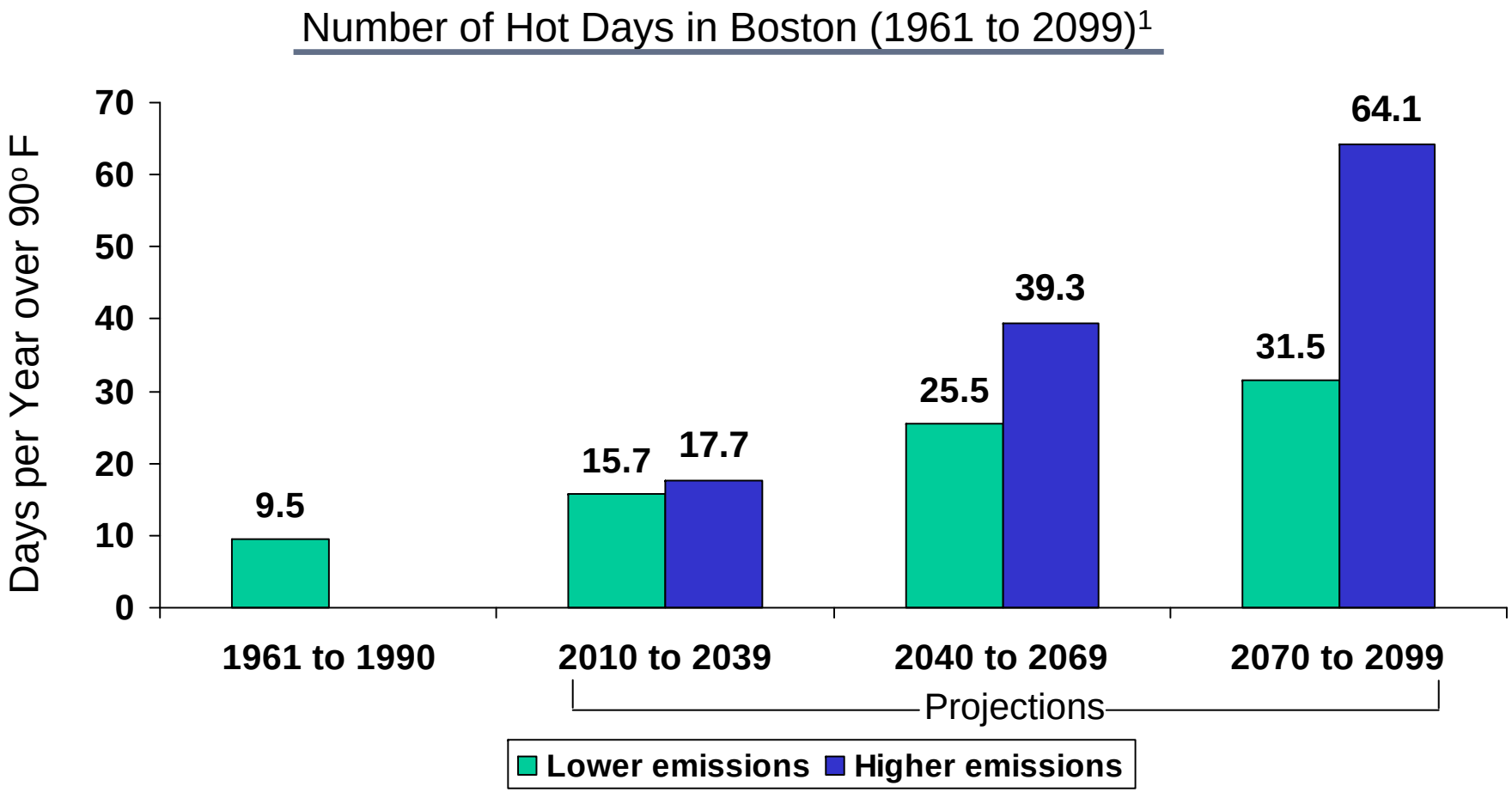
1. Energy Information Administration (http://www.eia.doe.gov)

How Hot will Boston be?



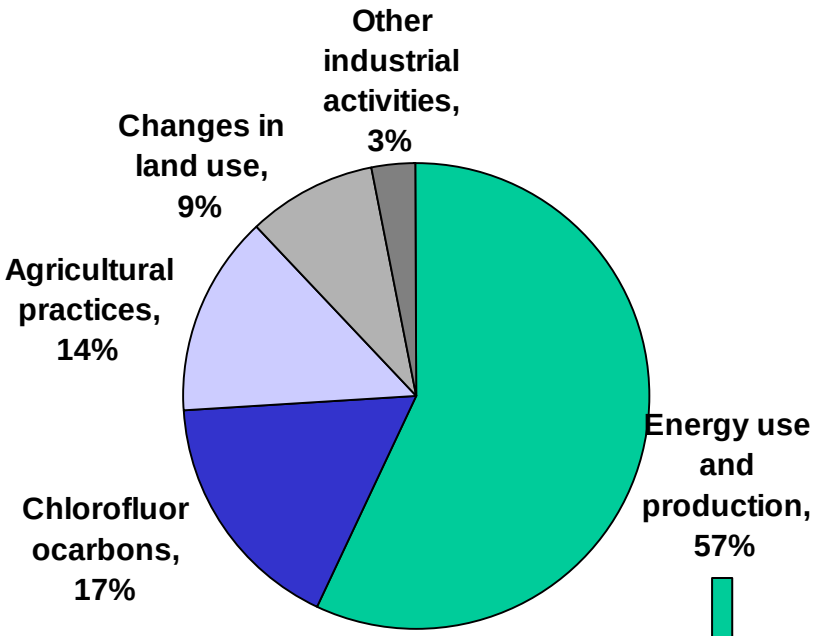
Boston Analytics Research

1. “Union of Concerned Scientists”, Joan Mclaughin/Globe Staff

Global Warming is Lethal?

Causes and Effects of Global Warming[1]

Cause → **Global Warming** → **Effect**



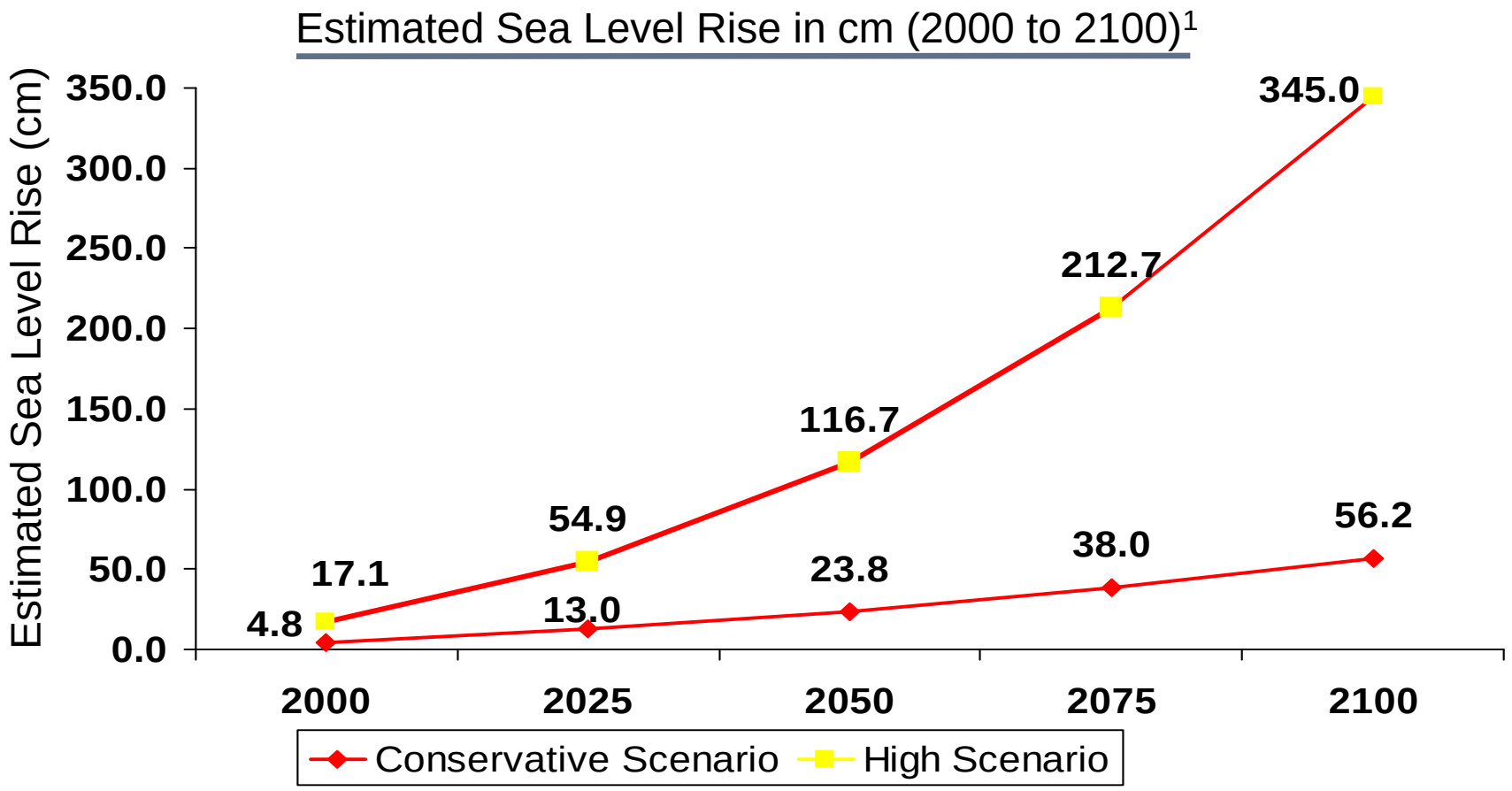
Greenhouse Gases (GHG e.g. CO_2)

- ***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

1. "Causes of Global Warming" (http://library.thinkquest.org/26026/Statistics/causes_of_global_warming.html)

Sea level is expected to Rise: *How much?*



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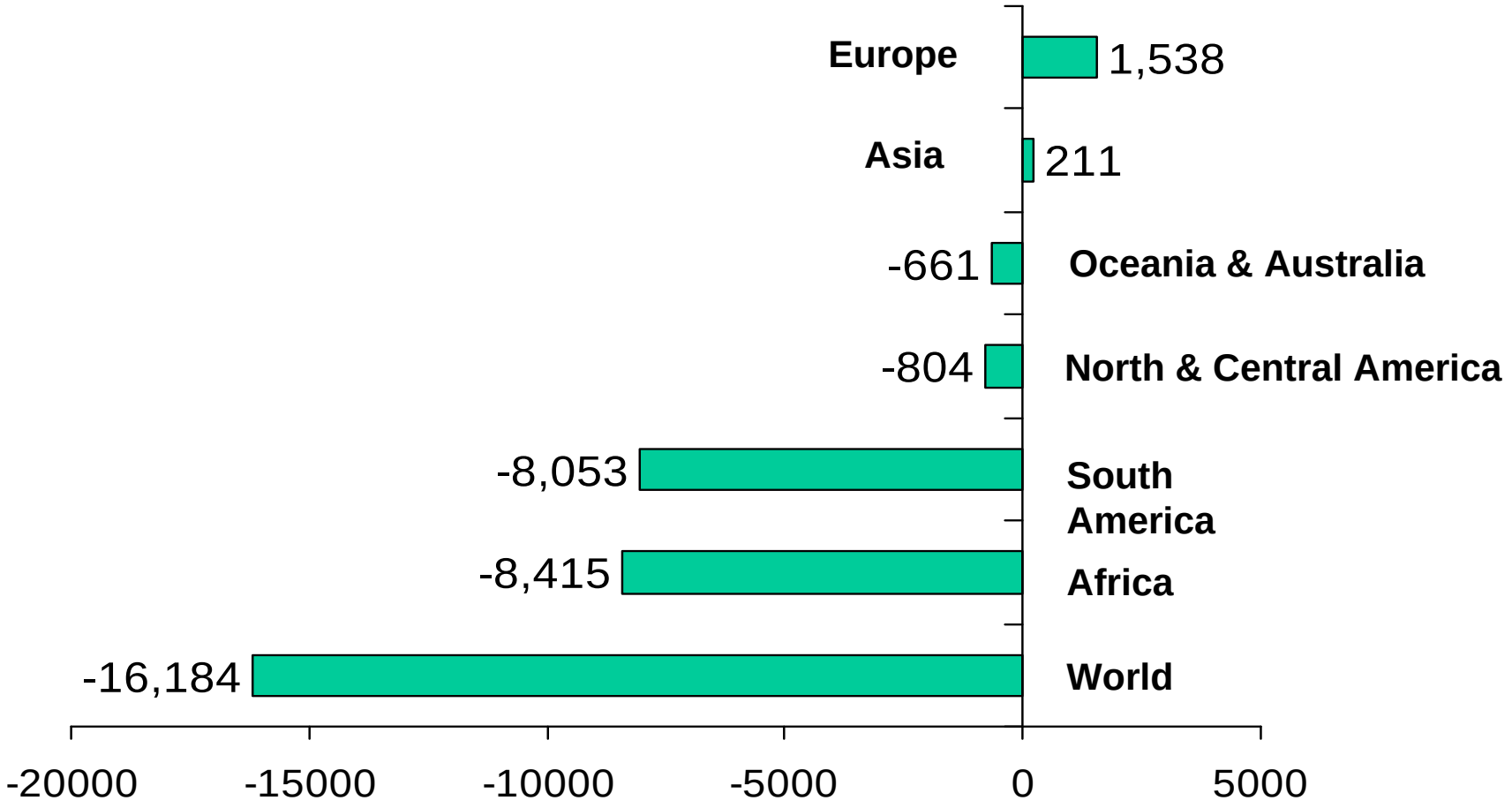
1. “Estimates of Future Sea Level Rise”, John S. Hoffman`

Annual loss of Forest land 16.2 Mn Hectares

Annual Change in Forest Area (000 ha per year) 1990 to 2005)[1]



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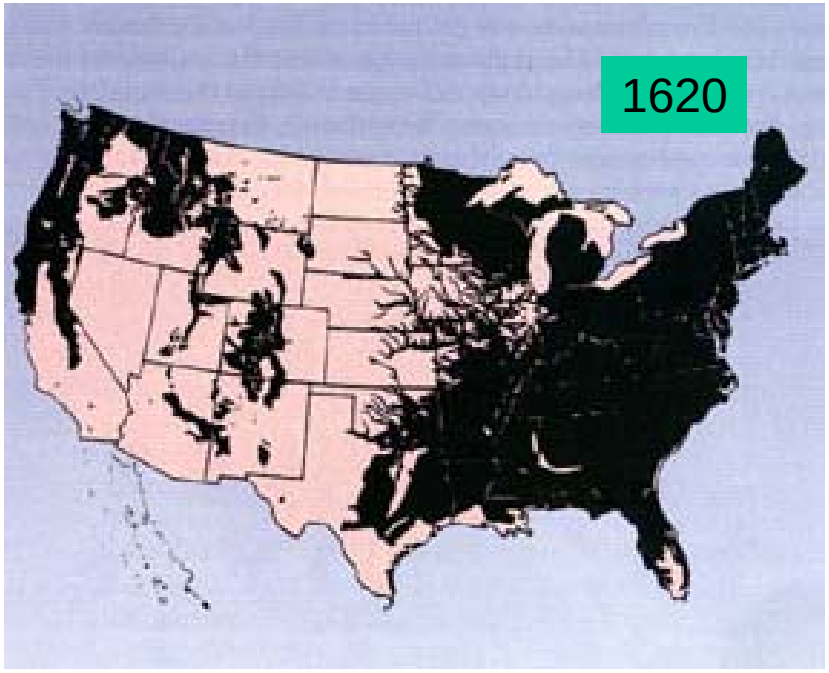
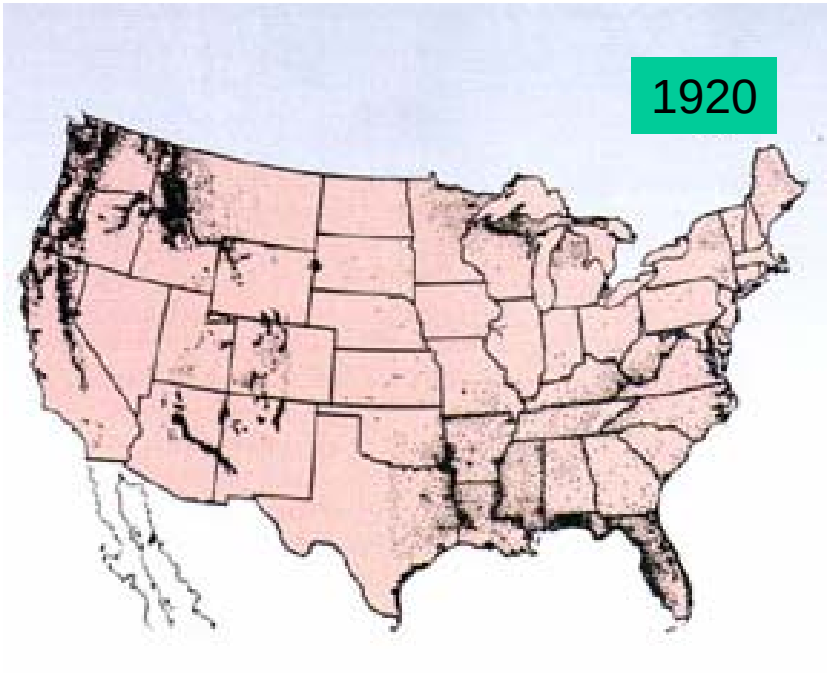
1. “Extent of forest resources”, (http://www.mongabay.com/deforestation.htm)

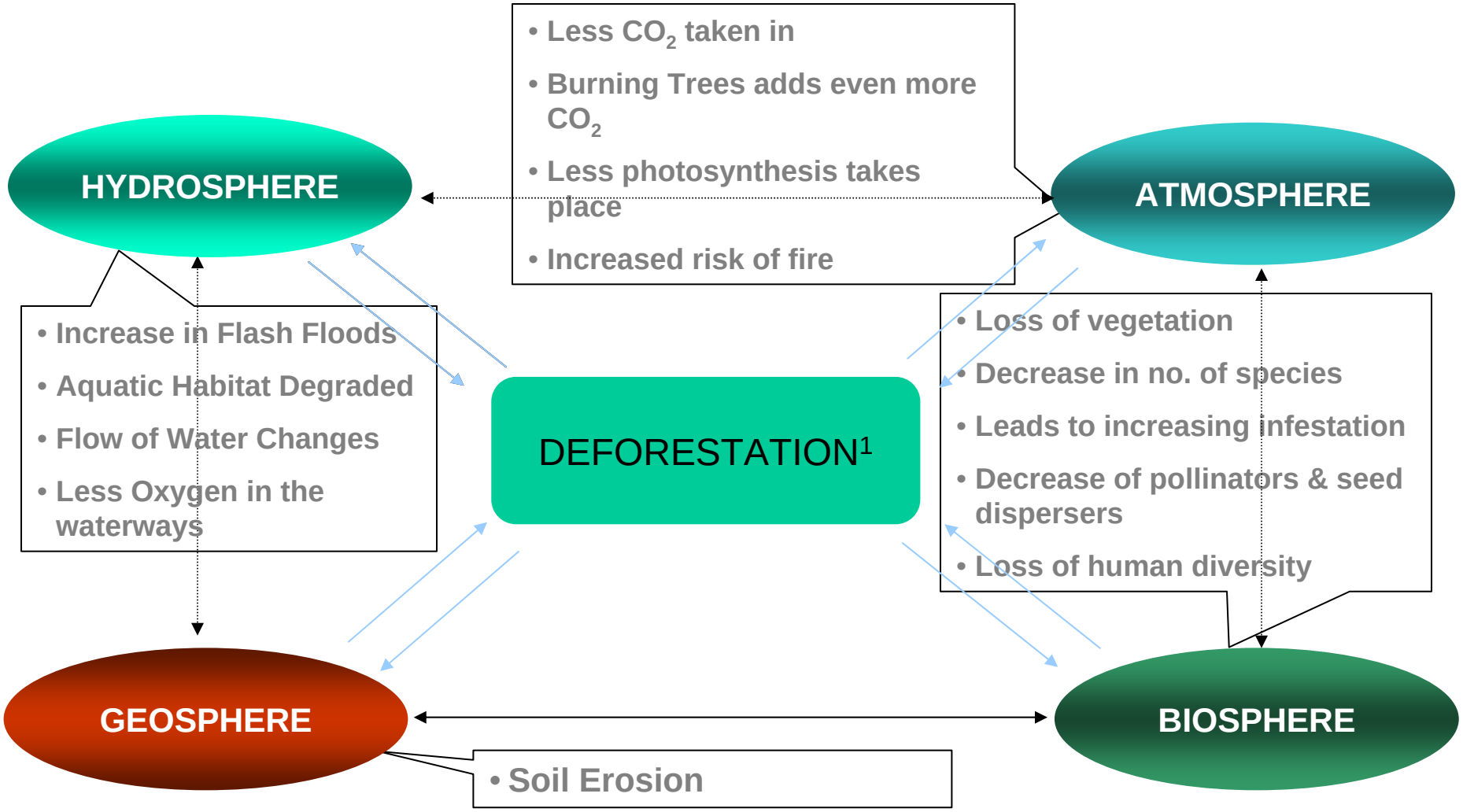
In fact the US has lost considerable forest area

Change in Forest Area in the US (1620 to 1920)[1]





Dynamics of Deforestation and Ecology: *Require Repurposing our Chemical Engineering Knowledge*



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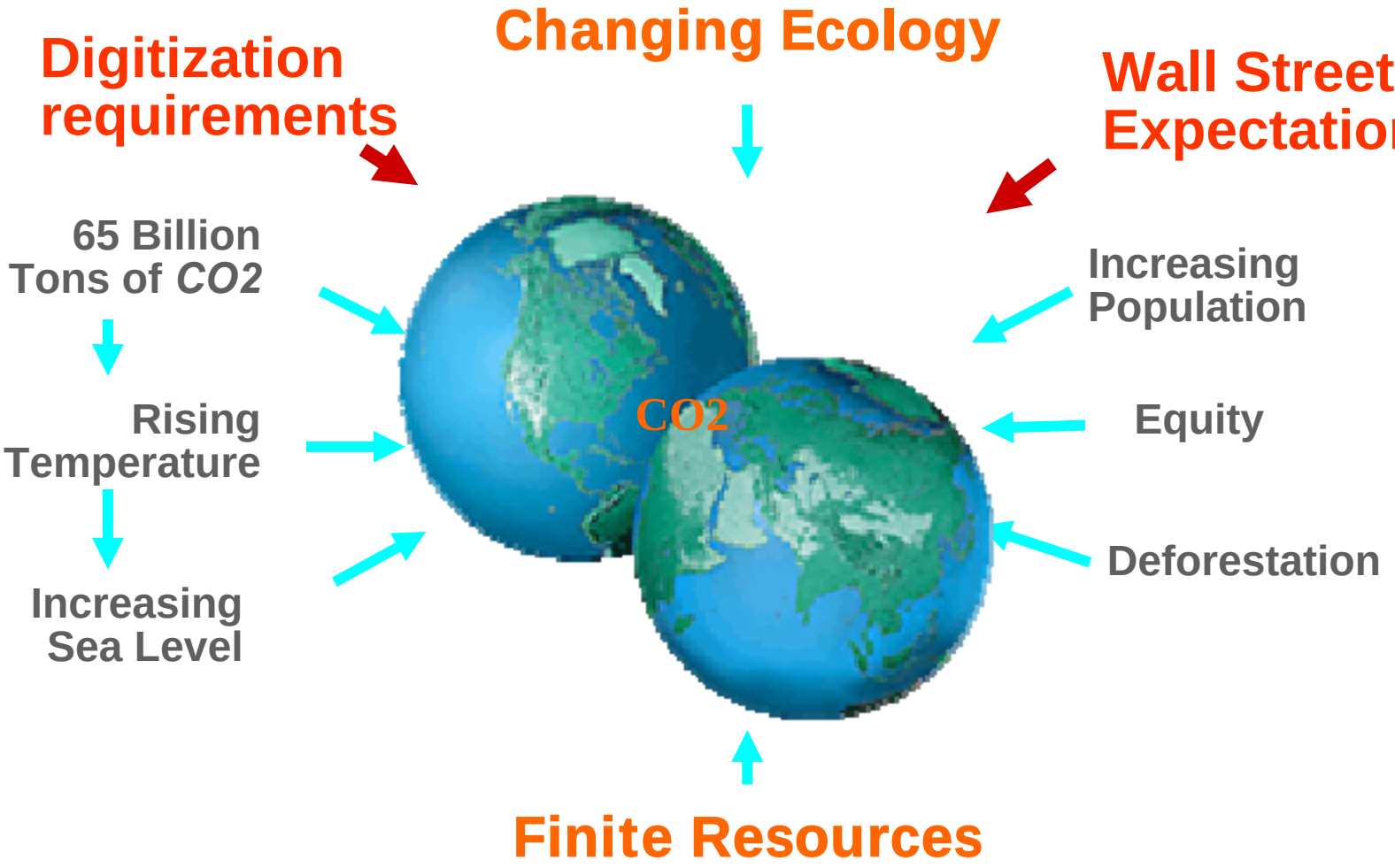
1. "The Choice: Doomsday or Arbor Day", (http://www.umich.edu/~gs265/society/deforestation.htm)

The Essential Points:

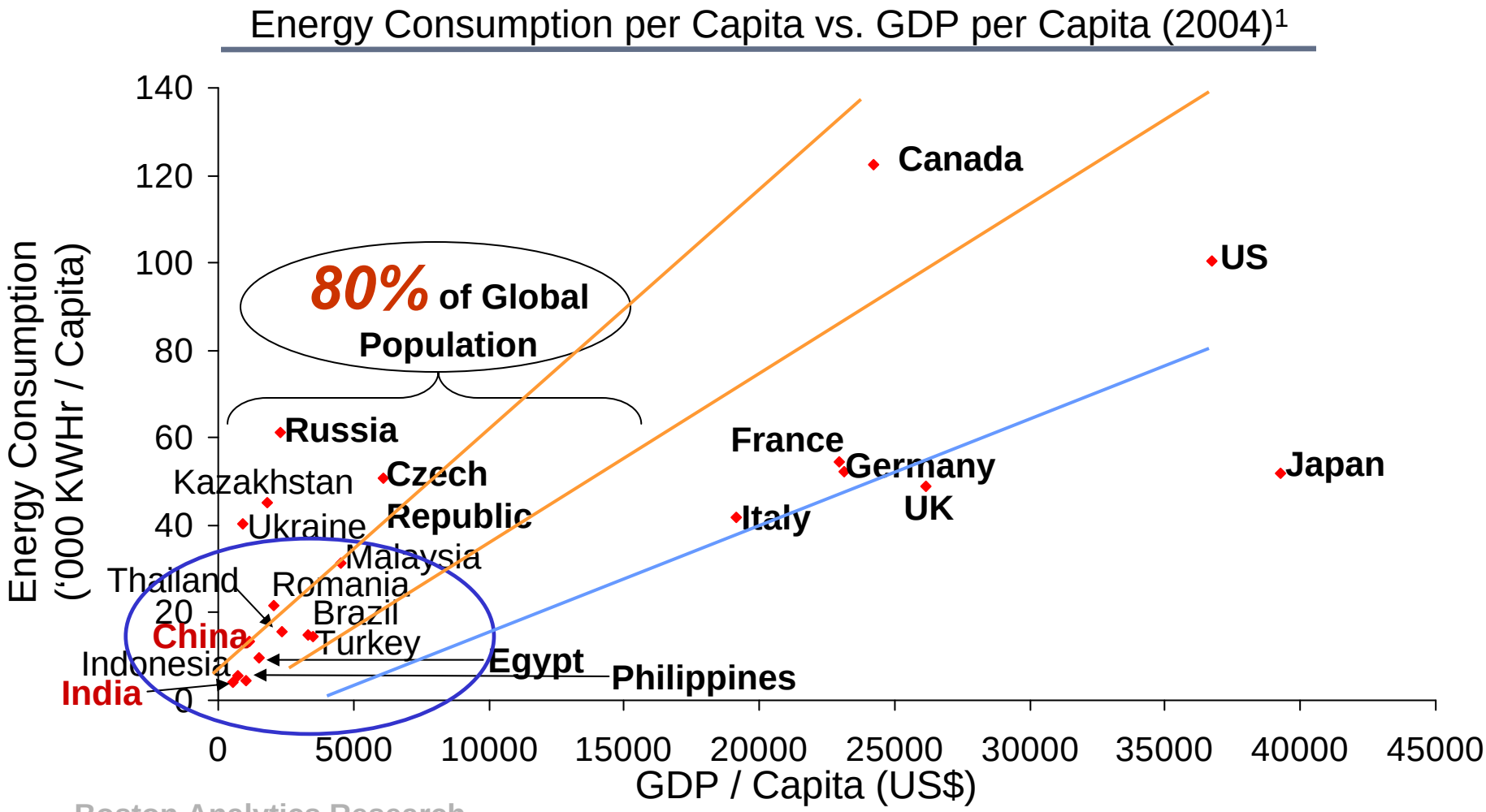
1. Indeed Challenging & Interesting times ahead

Powerful Forces at Work?

Powerful Forces at Work: *Clash of Perspectives?*



Most of the world is still in the early stage of Economic development



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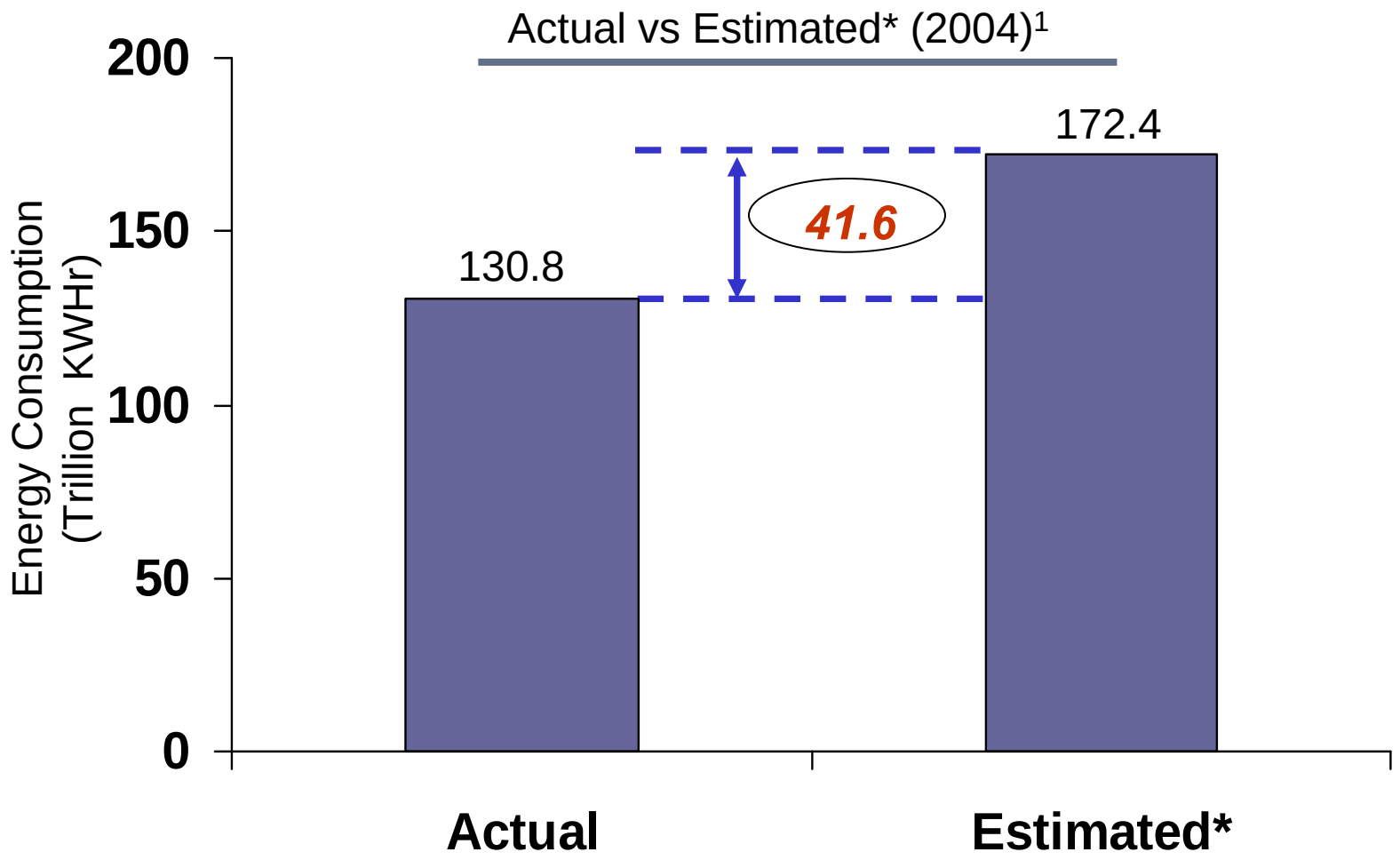
1. Energy Information Administration - EIA (http://www.eia.doe.gov/)

Future Natural Gas requirement of Asia

Overview of Energy Scenario *(In BCM)*

Country	*2001*	*2010*	*2015*	*2020*	*2025*
India	***22***	65	90	114	***143***
China	*28*	54	74	102	***142***
Japan	79	91	99	108	119
South Korea	20	28	37	43	51
Other Asia	139	153	173	198	230
Total	***288***	391	473	565	***685***

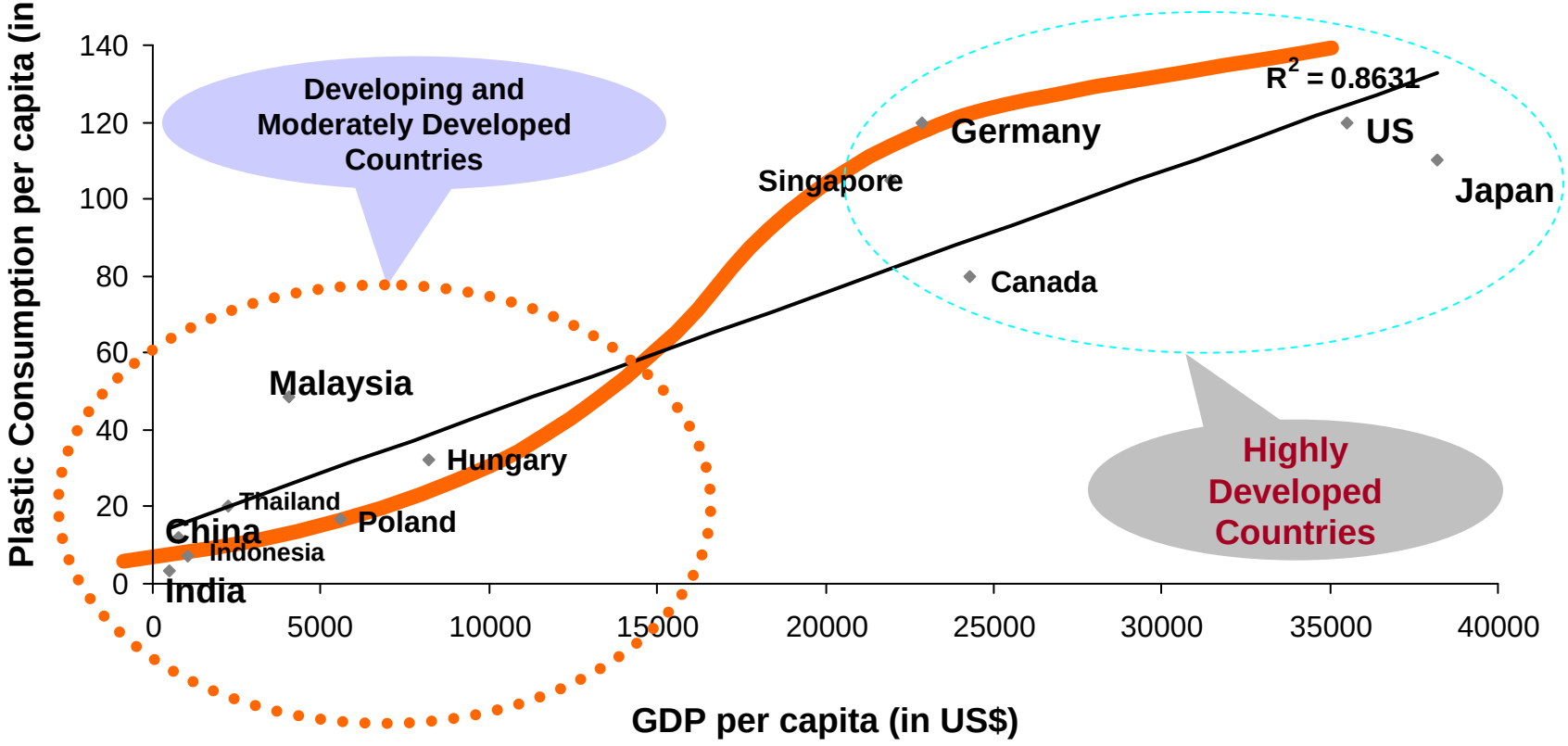
If China & India consumes energy @ 25% of US/capita total energy consumption will increase by *41.6 T KwHr*



* **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]



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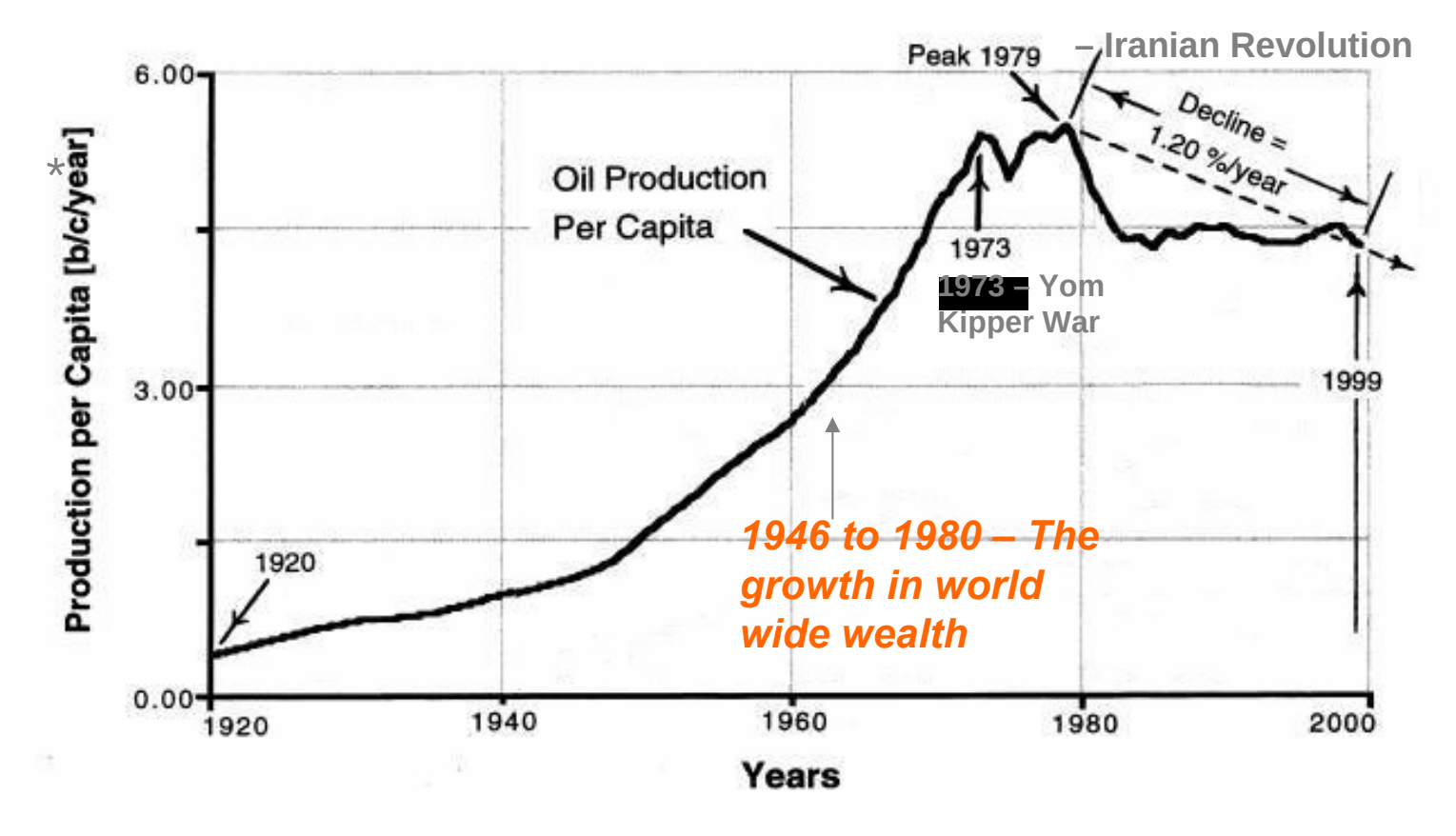
1. http://www.dailytimes.com.pk/default.asp?page=story_11-9-2003_pg5_12
2. Poland and its investment opportunity – BCG Report
3. http://www.eia.doe.gov/

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)**

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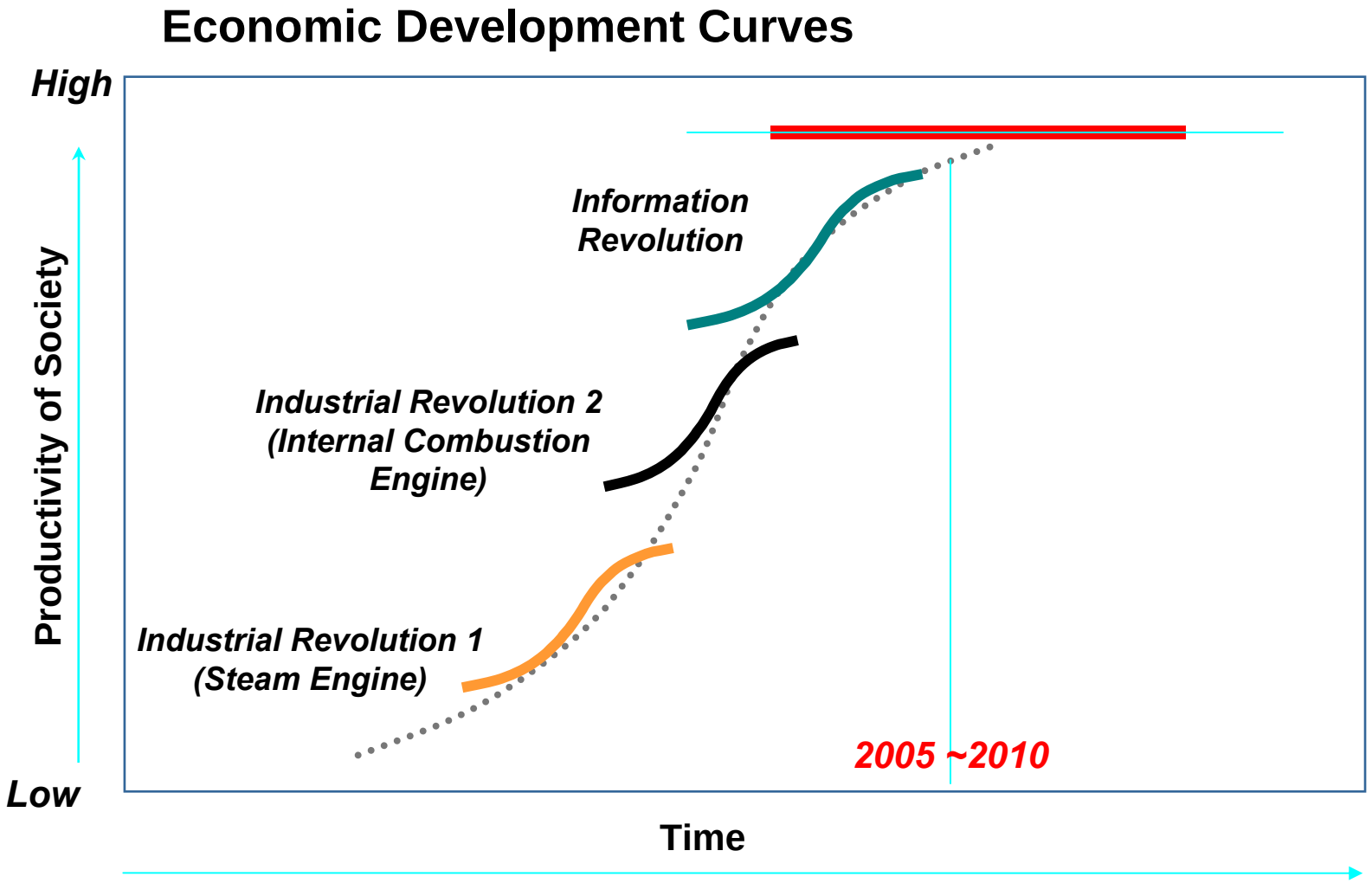
1. "Peak Oil – The Beginning of an End", (http://earthtrends.wri.org/pdf_library/data_tables/ene4_2005.pdf)
2. "BP Statistical Review of World Energy June 2006", BP Plc (http://www.bp.com/statisticalreview)

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



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*

1350 1900 **2005 ~2010** 2050

Era of Extraction & Mono dimensional Value Creation

- "*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

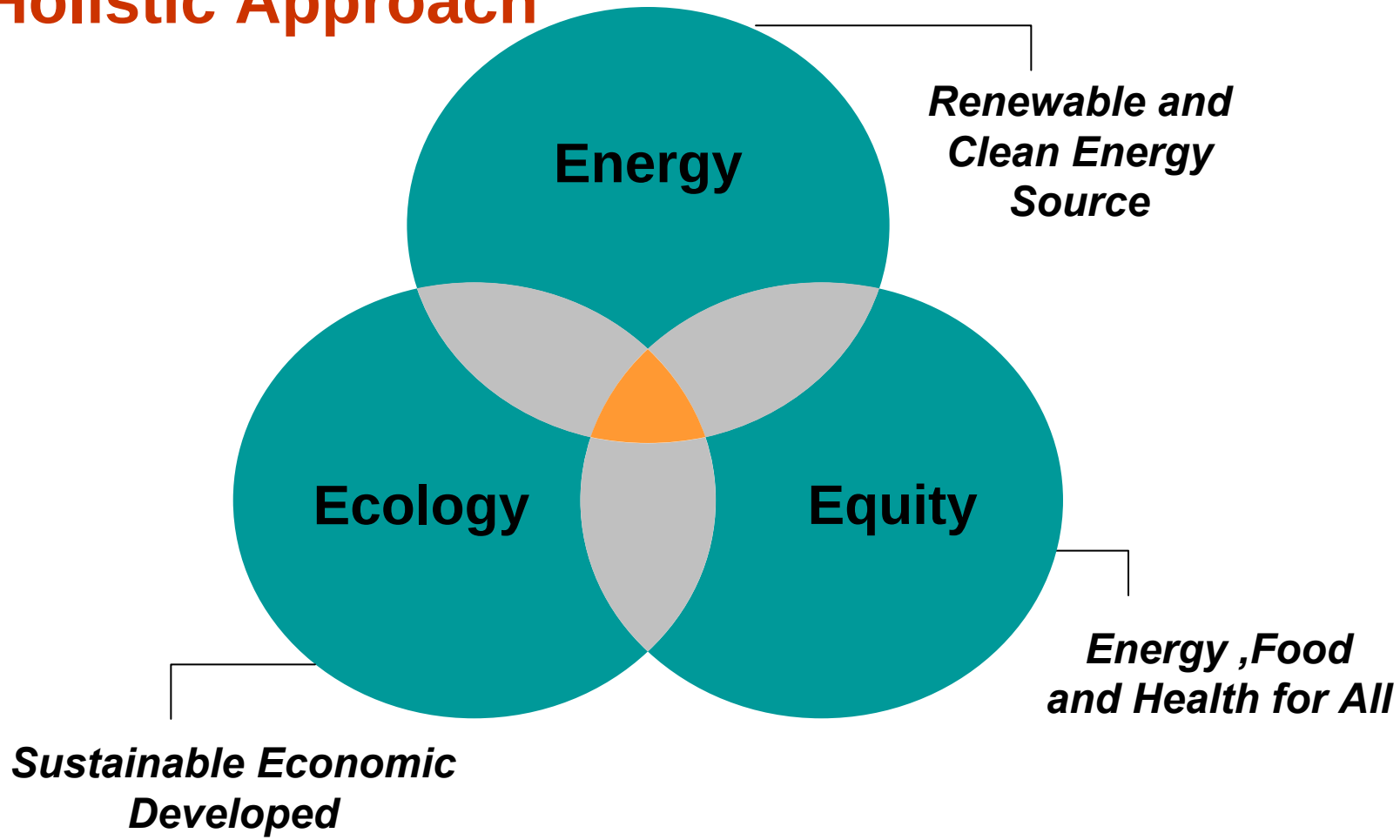
Next Era Paradigm?

Role of Chemical Engineers ?

Holistic Approach?

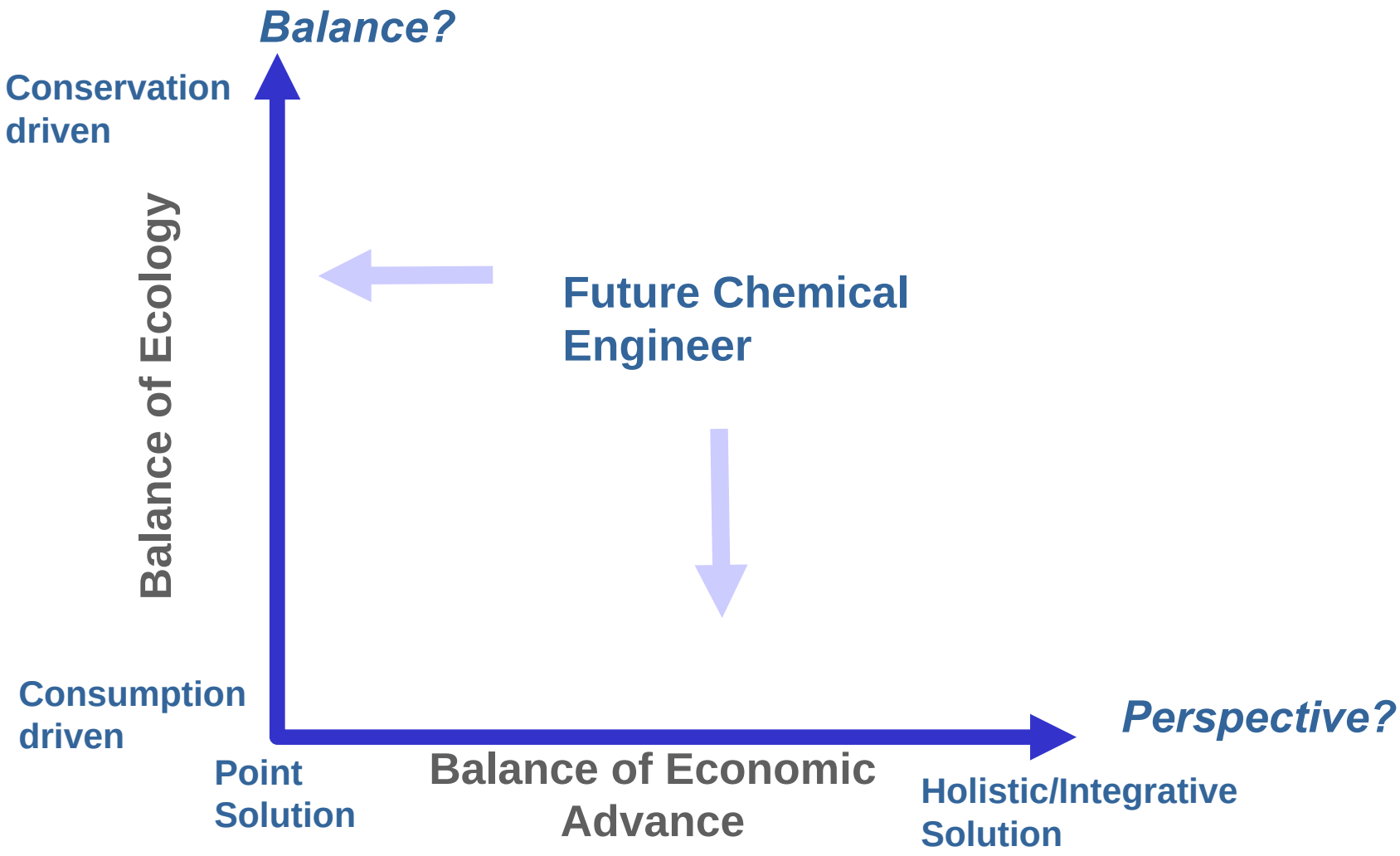
PROBLEMS ≈ OPPORTUNITIES

Holistic Approach



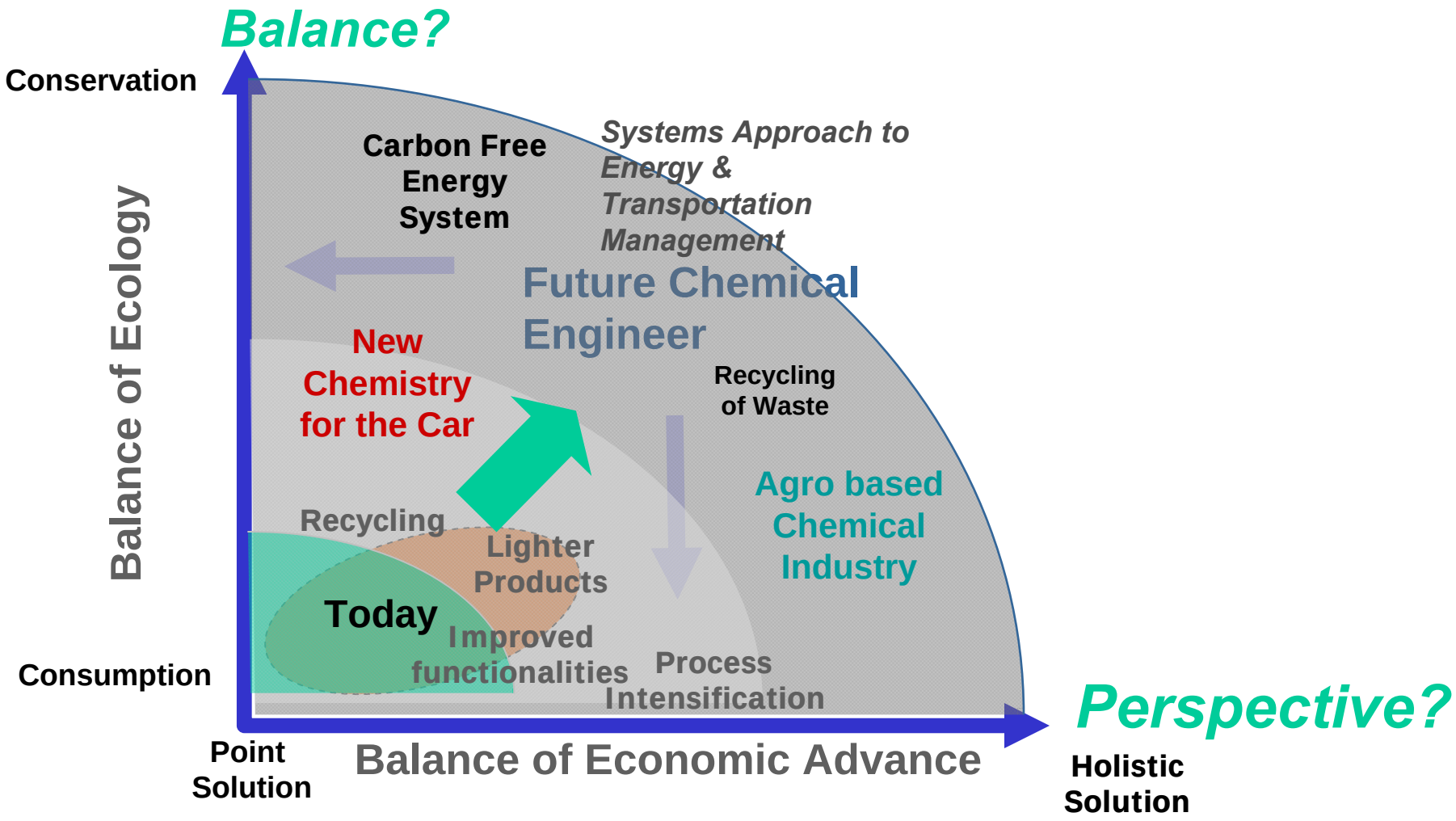
Scope of the Field?

Chemical Industry's Future (?): *Two Strategic Vectors*

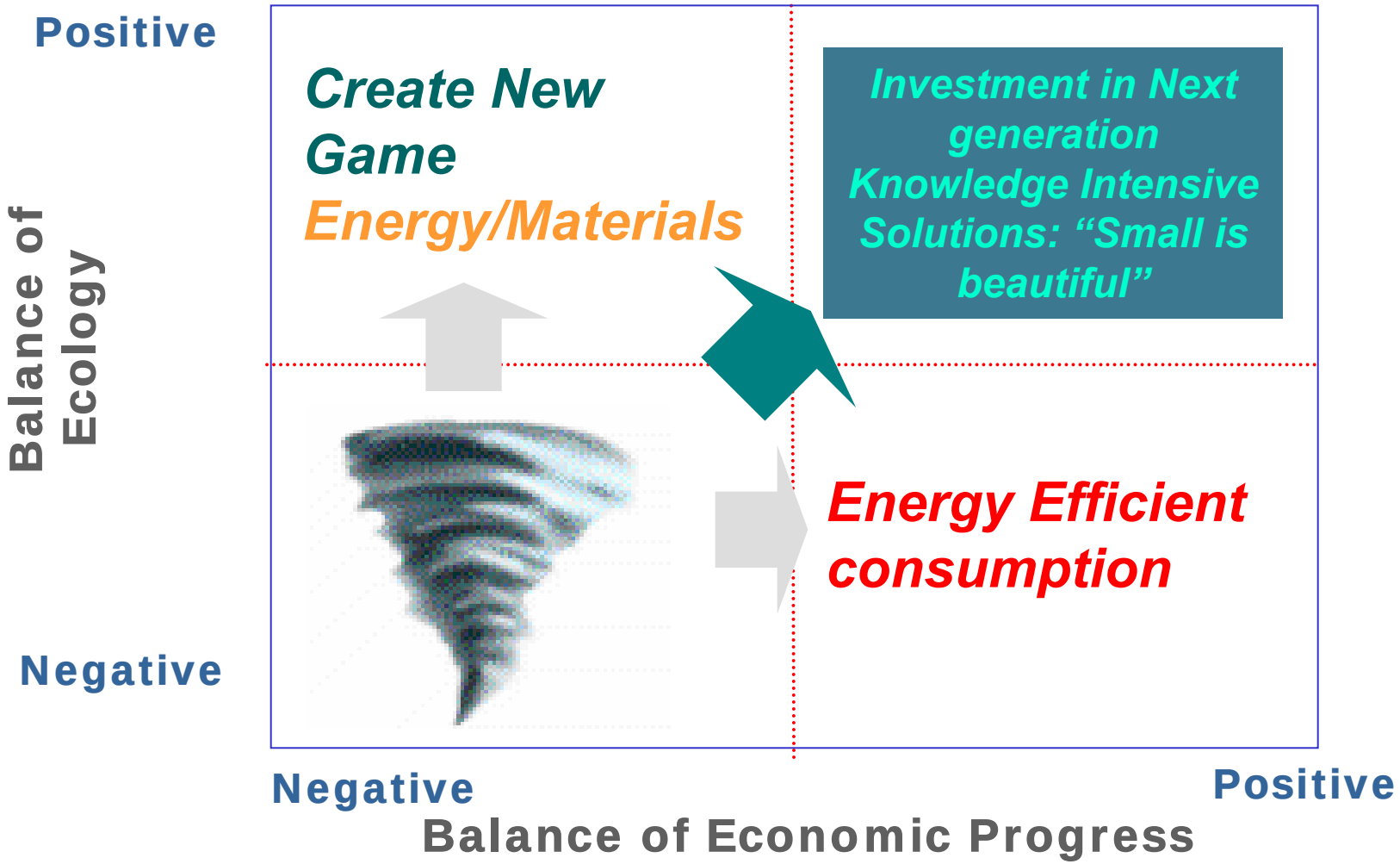


Expanded Field?

Chemical Industry's Future (?): *Two Strategic Vectors*



Strategic Direction of Chemical Industry



Mega Challenge = *Managing a Mega Transition to avoid Mega disruption*

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Era of Extraction & Mono dimensional Value Creation

- "*Unconstrained*" Processing of Earth's resources
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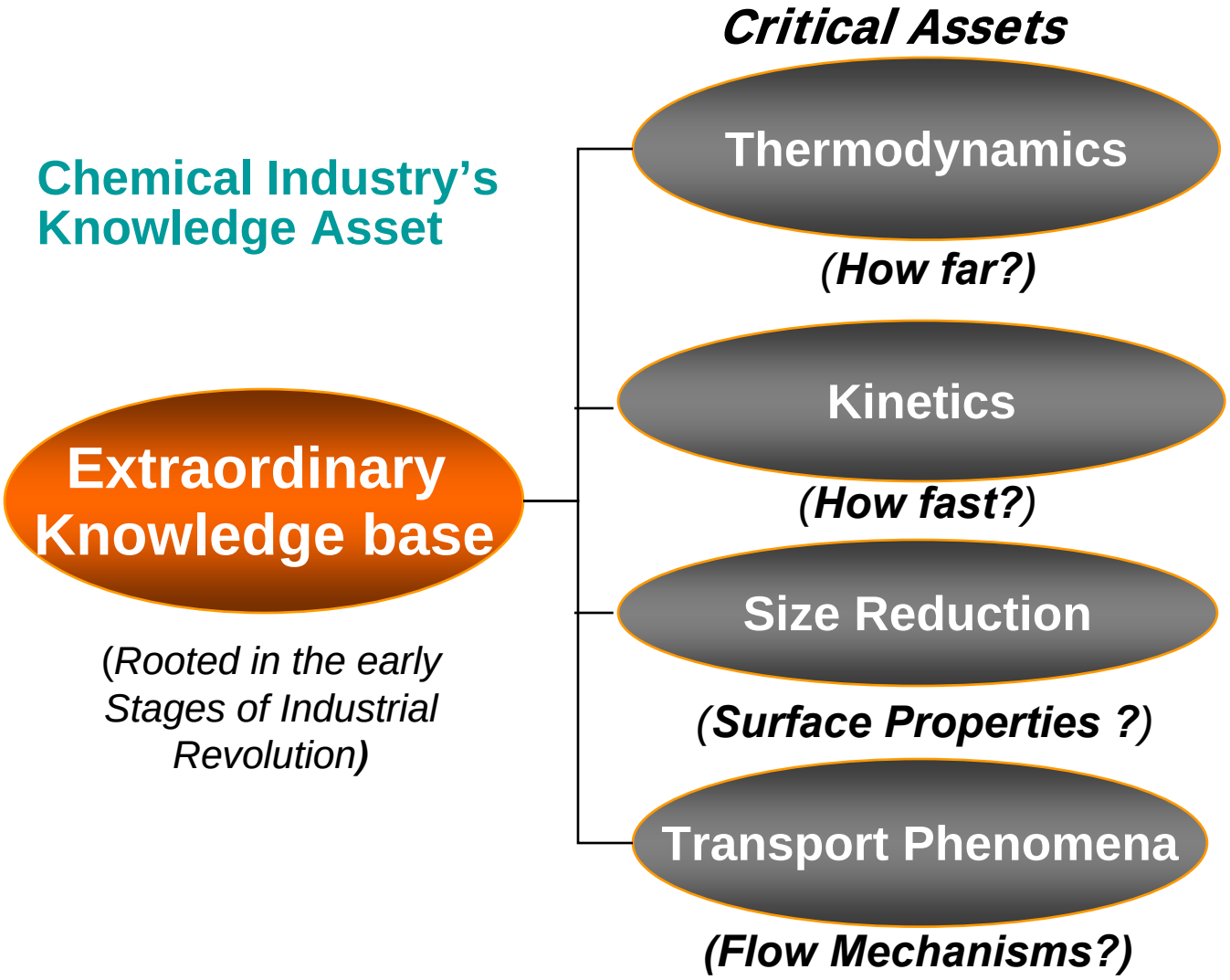
1. Concentrated Economic Growth
2. Ecological disequilibrium
3. Complex Politics of Supply Chain

Multi vector Multi –tier Renaissance

An unique opportunity for Chemical Engineers



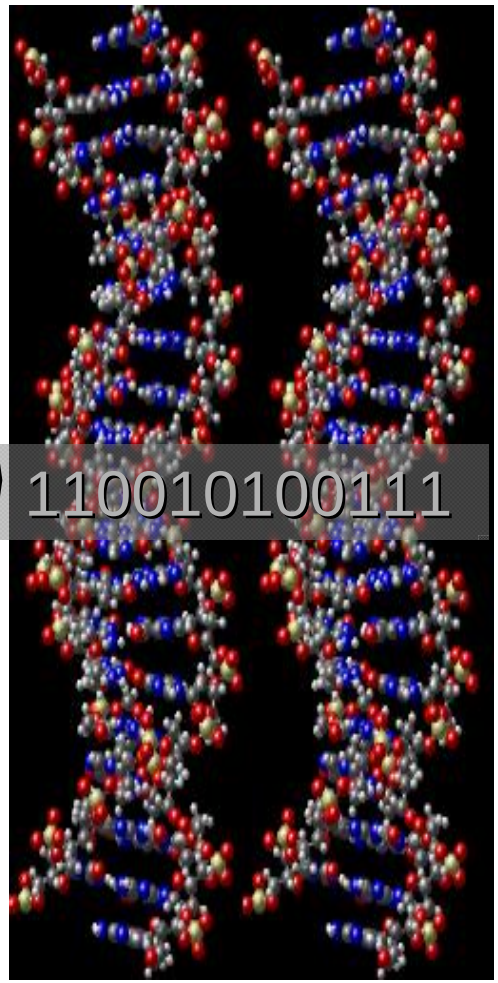
And Look for Mega possibilities @ the Intersection of Conventional Engineering & New Technologies

Chemical Fundamentals

- **Thermodynamics**
- **Kinetics**
- **Transport sciences**
-

Conventional Unit Operations

- Separation processes
- Reactors
- Heat & Mass transfer systems



In flux of New Methodologies

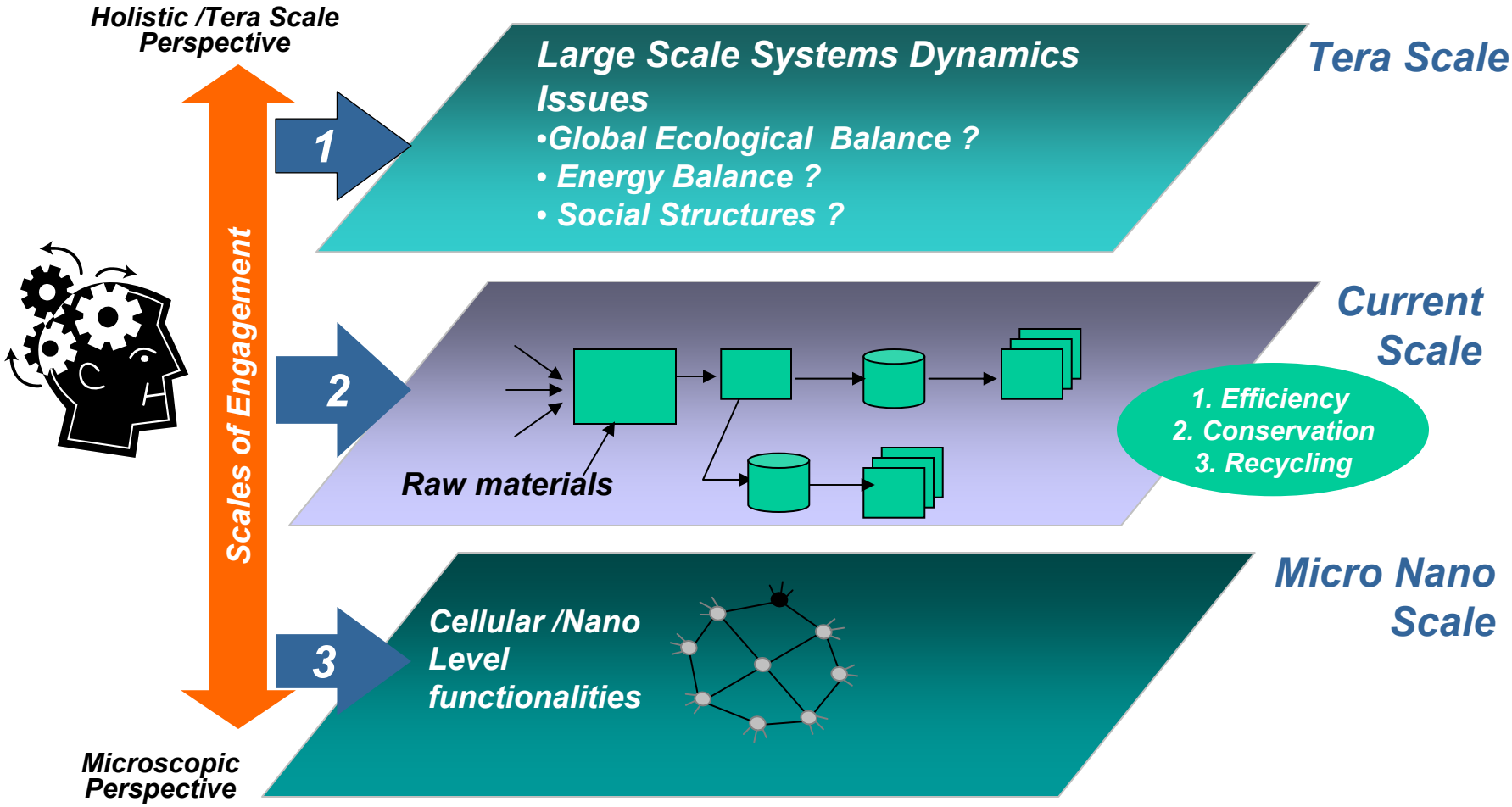
- **Genomics**
- **Proteomics**
- **Micro fluidics**
- **Nano technologies**

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



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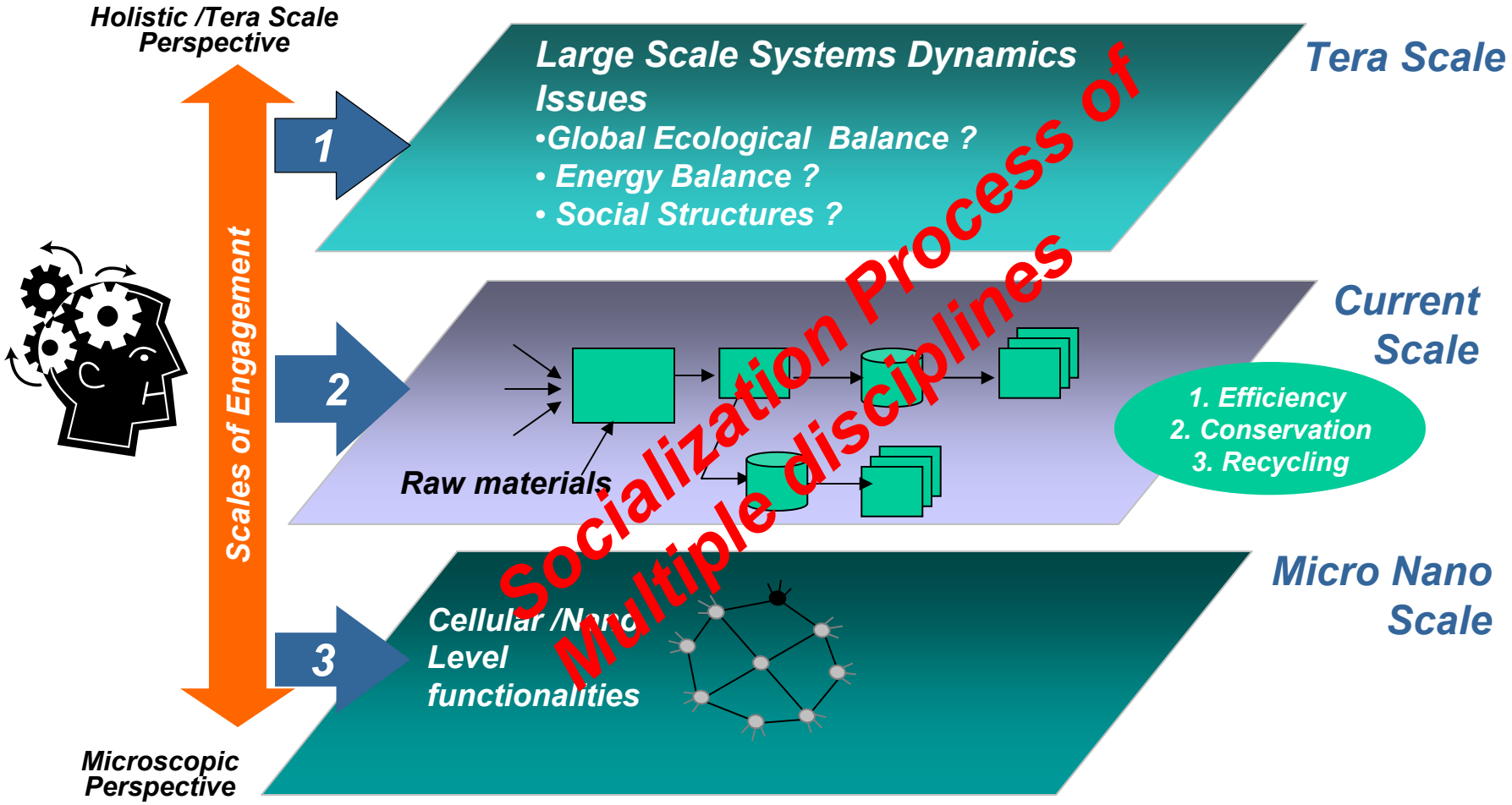
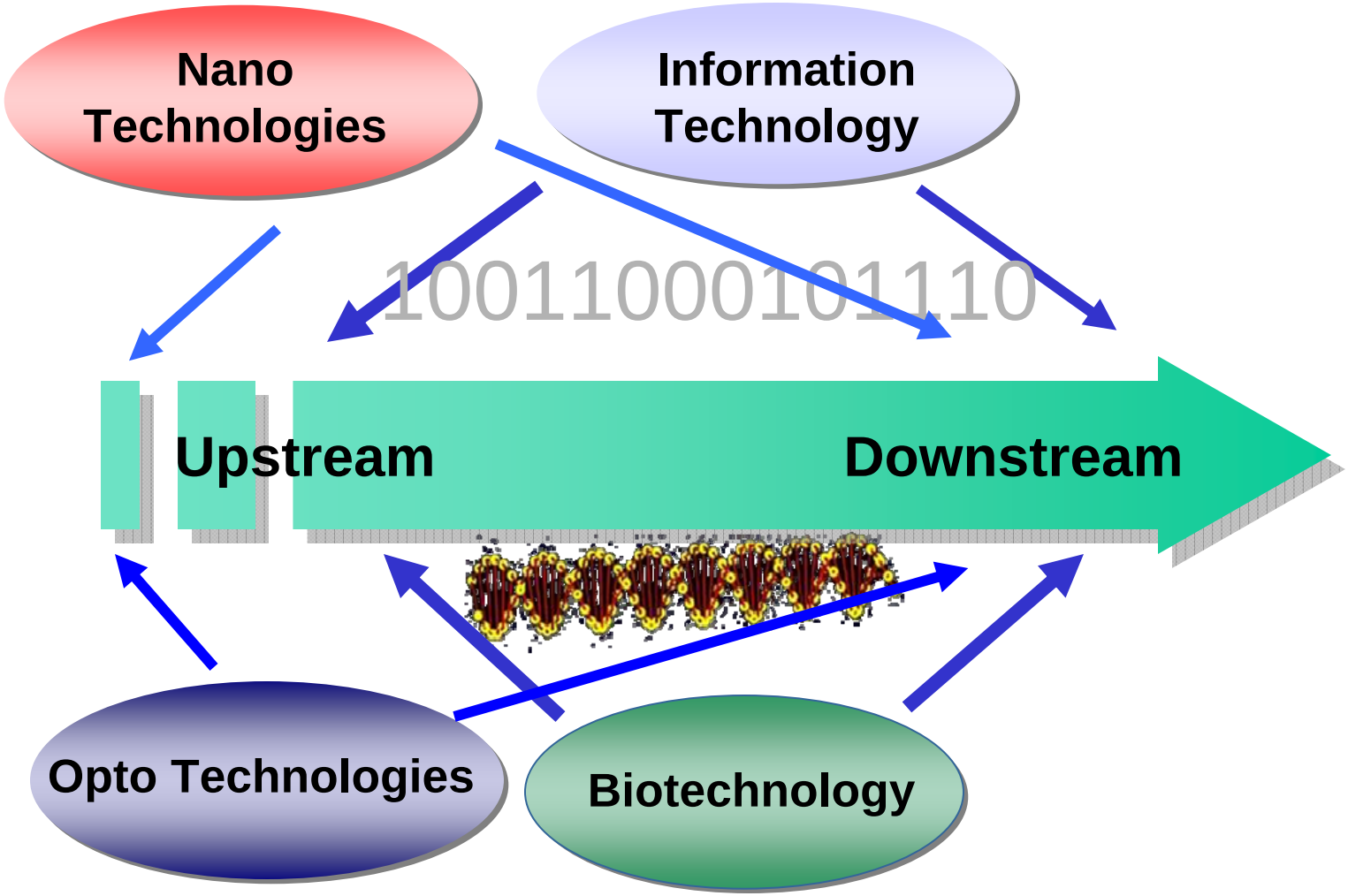
Three Scales of Knowledge Application

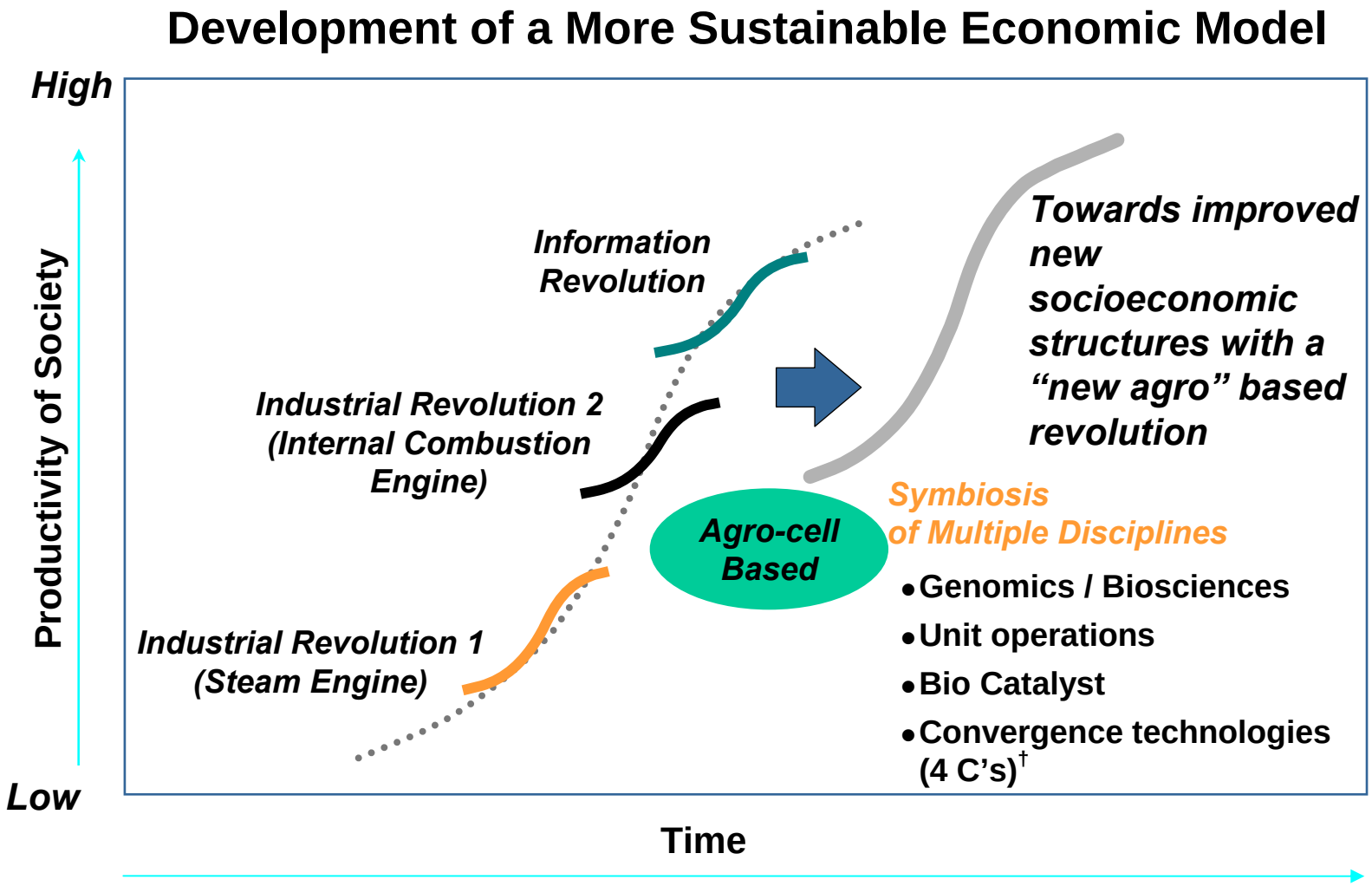


New technologies could indeed trigger a New Era

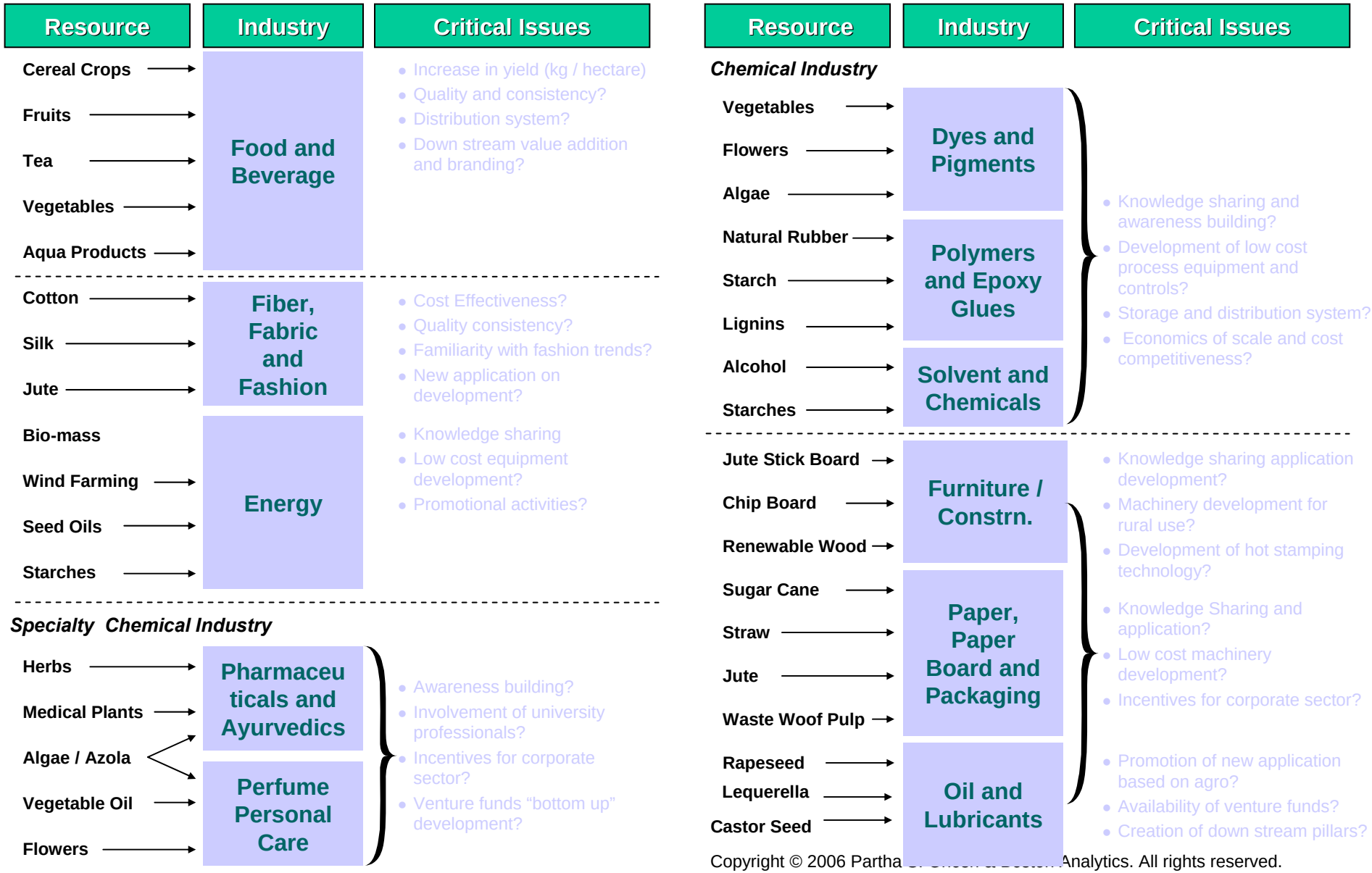
Process Industry Reconfiguration



Towards an Agro cell based Economic Revolution?



For Example: *An Agro Complex?*

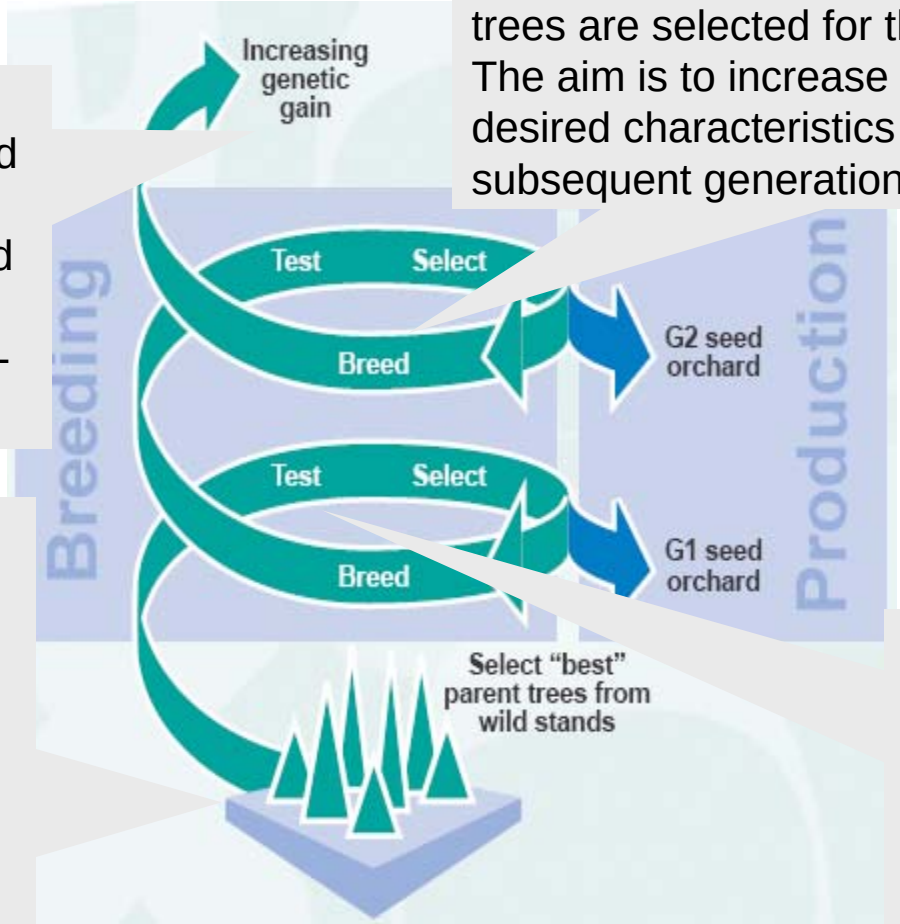


Biotechnology could enable production of better breeds of trees enabling fast and healthy reforestation

Tree Breeding and Seed Production Processes[1]

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

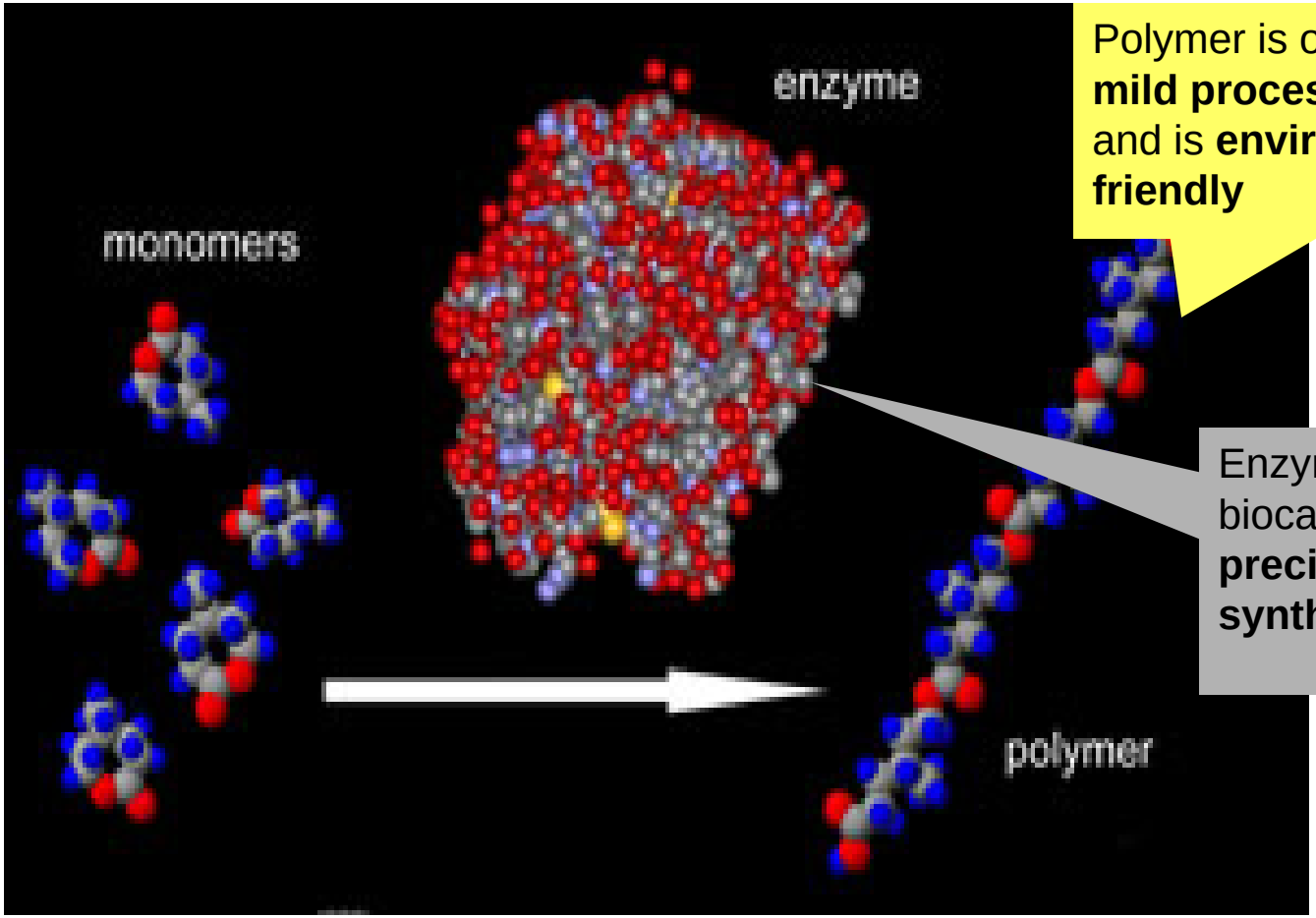


1. Selection: The selection process involves the finding wild trees which possess the desired traits (e.g. pest resistance, superior growth or form etc)

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

Biocatalysts: Using enzymes as catalysts for synthesis in mild conditions?

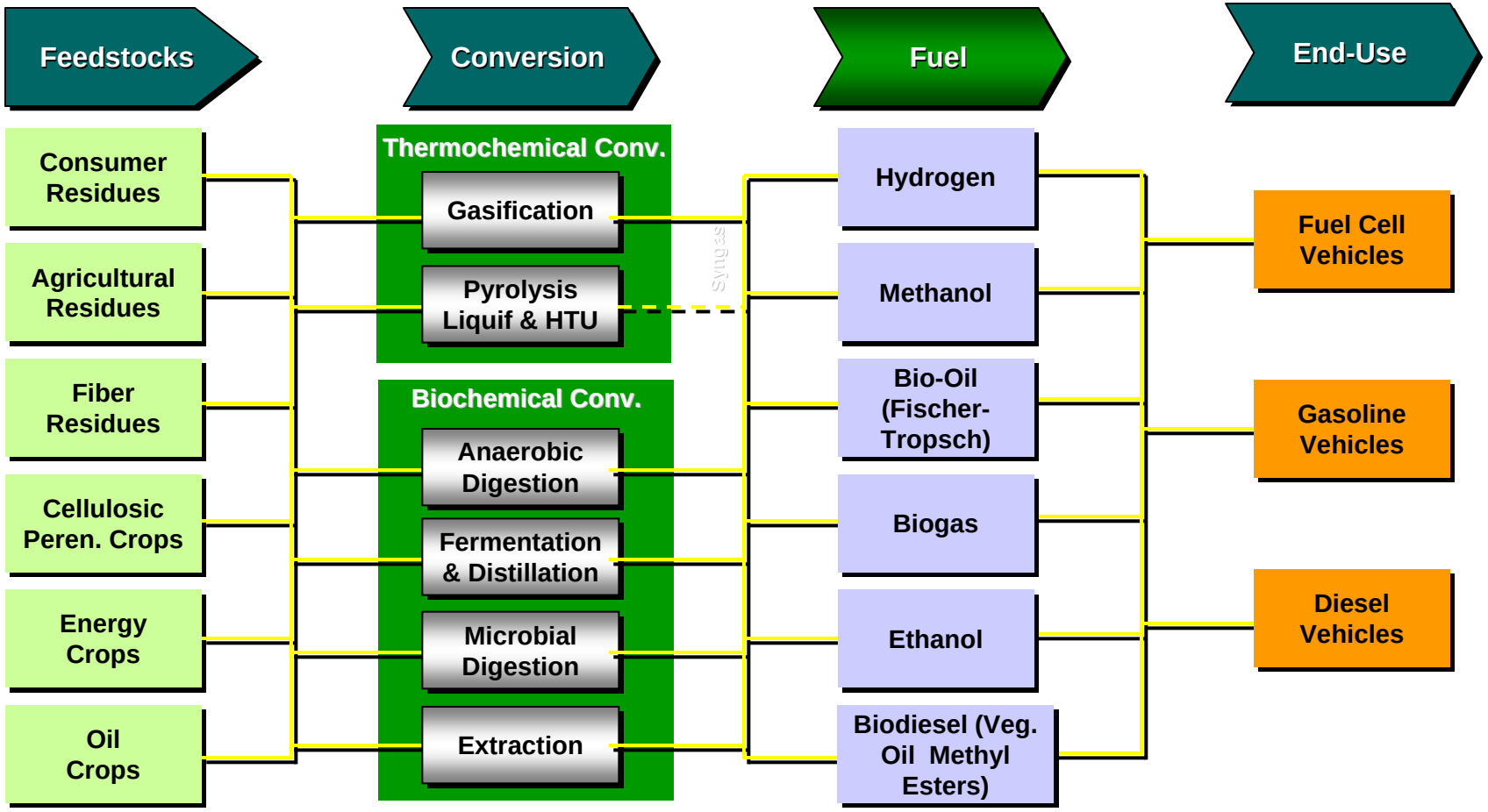
Biocatalysis in the Manufacture of Polymers[1]



Polymer is obtained under **mild process conditions** and is **environmentally friendly**

Enzymes act as biocatalysts enabling **precision polymer synthesis**

Development and fine tuning of Biofuels Technologies could open up new vistas



Cellulosic ethanol is on the horizon

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

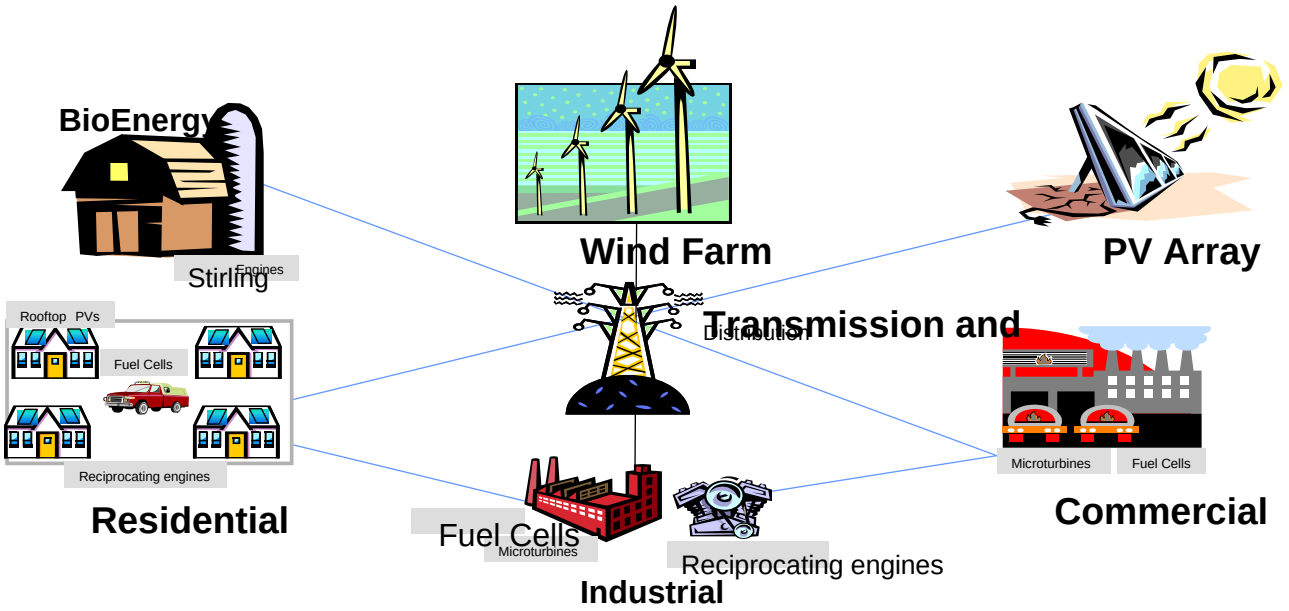
cellulose

Biomass Energy development will require a full range of conventional Chemical Technologies

Different Technologies to Harness Biomass Energy[1,2]

Biomass Combustion	Combustion of biomass to produce electricity
Biomass Gasification	Gasification is meant to convert solid carbon fuels into gaseous fuels
Biomass Carbonization	Carbonization converts biomass into biofuels / biocarbons (charcoal and carbonized charcoal)
Biomass Densification	Biomass densification converts the loose biomass (agricultural and agro – industrial wastes) into a densified fuel called briquettes
Biogas Production	Biogas production involves the fermentation of cowdung, crop residue and kitchen waste in the absence of oxygen to produce biogas (mainly CH_4, CO_2 and other gases)

Power & Energy: *Large Scale Engineering systems thinking is essential*

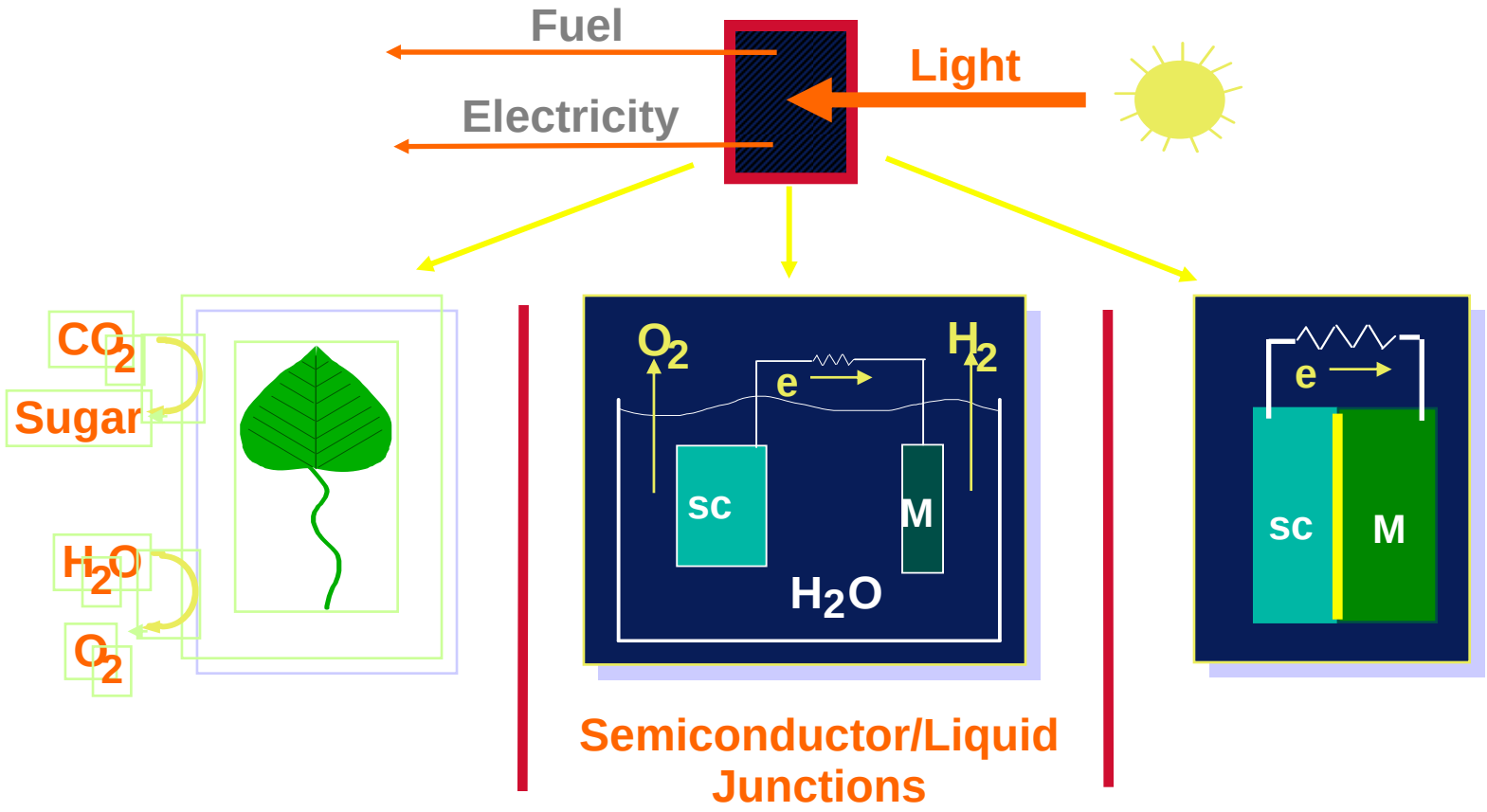


The Virtual Power Plant

- ***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***

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

Basic Mechanisms of Solar Energy Conversion[1]



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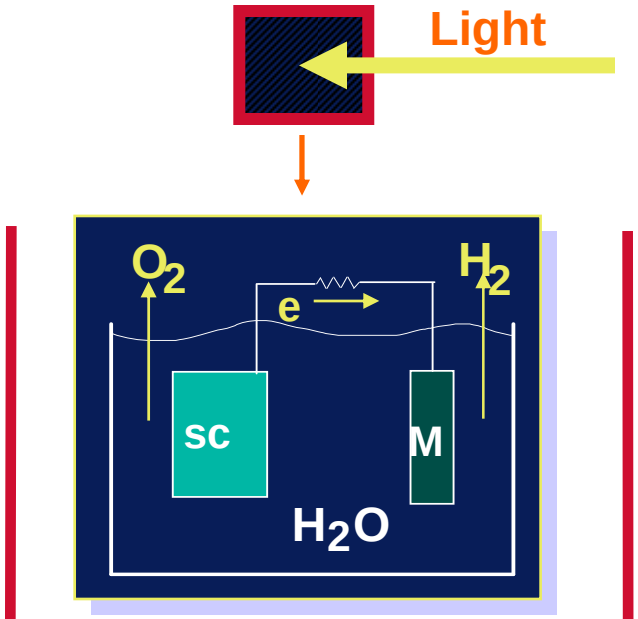
1."Global Energy Perspective", Nathan S. Lewis, California Institute of Technology, Pasadena, CA

Poor efficiency and intricate material processing techniques are major issues with the solar cell

Major Issues with a Photovoltaic (PV) Cell [1,2,3]

Photovoltaic (PV) cells provide efficiencies as low as 25%
Require: *New electrolytes and catalysts to improve efficiency of the PV cell*



Semiconductor/Liquid Junctions/Photovoltaic

Polycrystalline Si technology in semiconductors is relatively complex.

Flat Plate Si crystalline is better but yet significant development will be required

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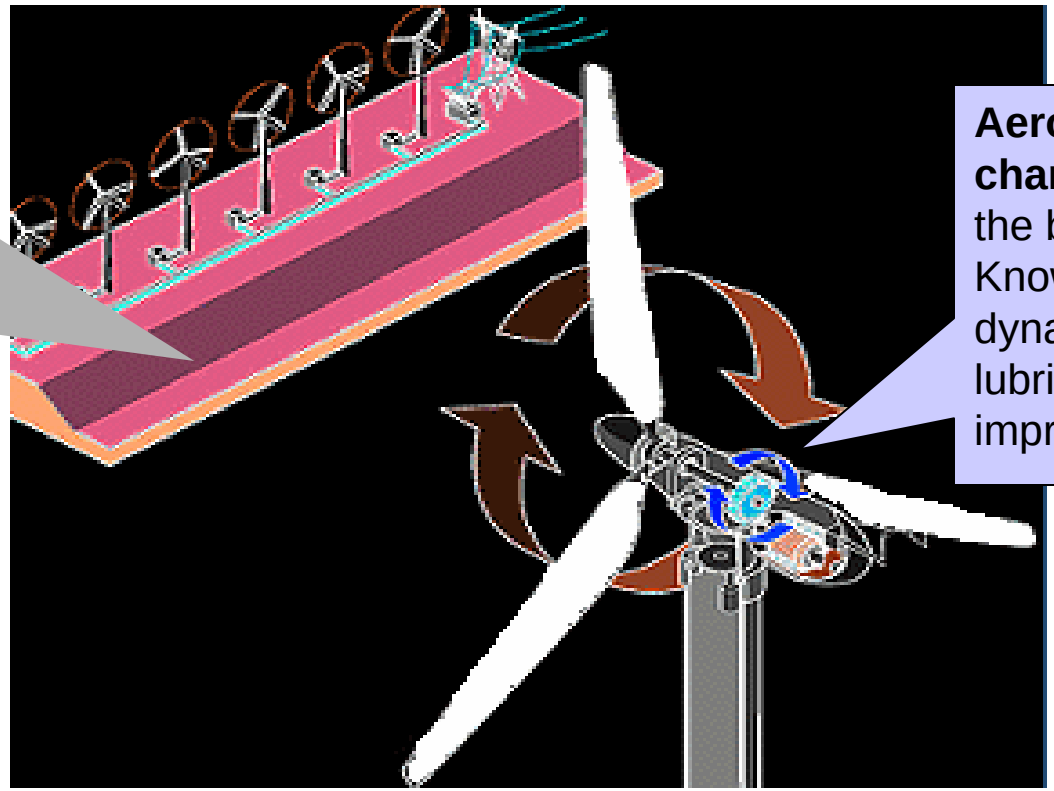
1."Global Energy Perspective", Nathan S. Lewis, California Institute of Technology, Pasadena, CA
2. "Solar Energy: The Ultimate Renewable Resource", Bhavik Shah – www.physics.rutgers.edu
3. "Solar Energy Research at the Department of Energy. Big Deal!", Dan Preston, John Stechschulte, Alok Tayi and Dave Zahora - www.mse.cornell.edu

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

Challenges in Using Wind as a Source of Power[1,2,3,4]

Varying wind supply require **innovative storage solutions**



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

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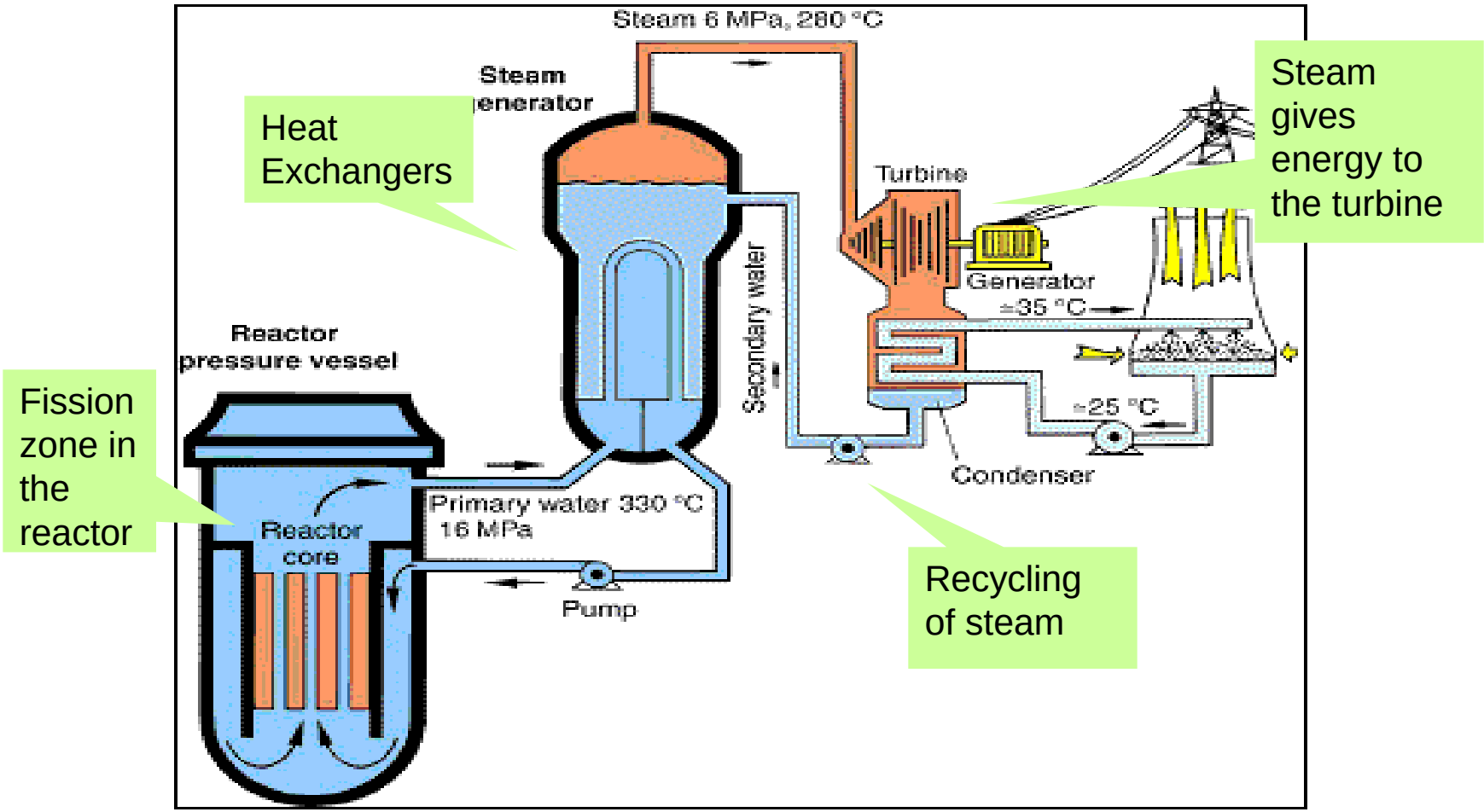
1. www1.eere.energy.gov/windandhydro/wind_how.html
2. http://www.hawaii.gov/dbedt/ert/wwg/issues.html#intermittency
3. “Generic Wind Turbine- generator Models”, Western electricity Coordinating Council, Abraham E

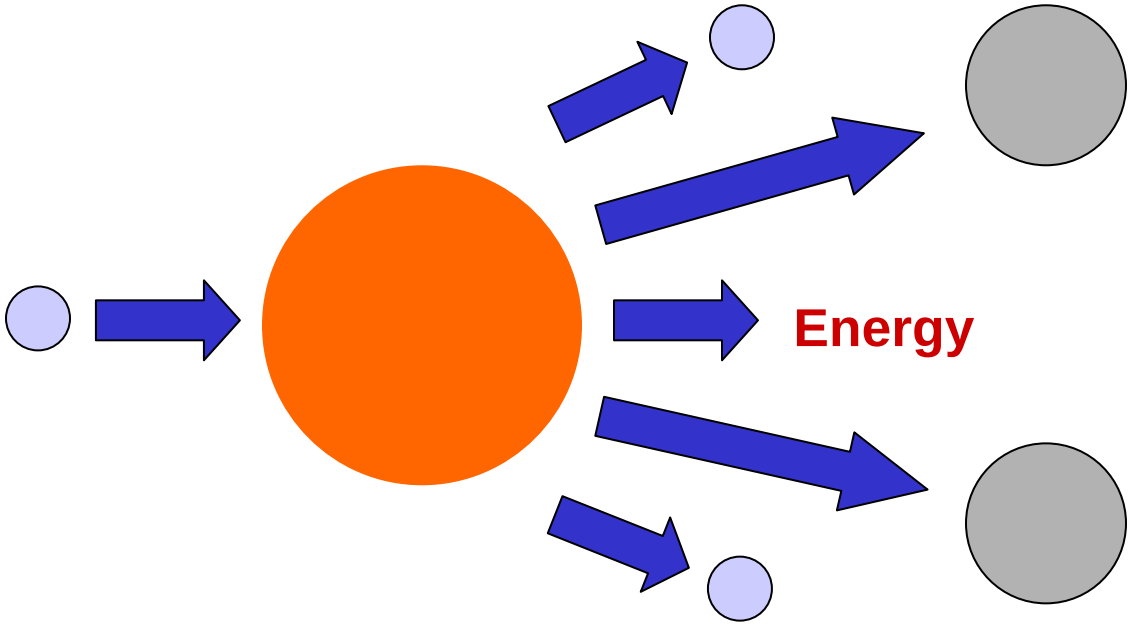
Next Generation Nuclear plant design will require significant Chemical Engineering Knowledge

Production of Nuclear Energy in a Pressurized Water Reactor[1]



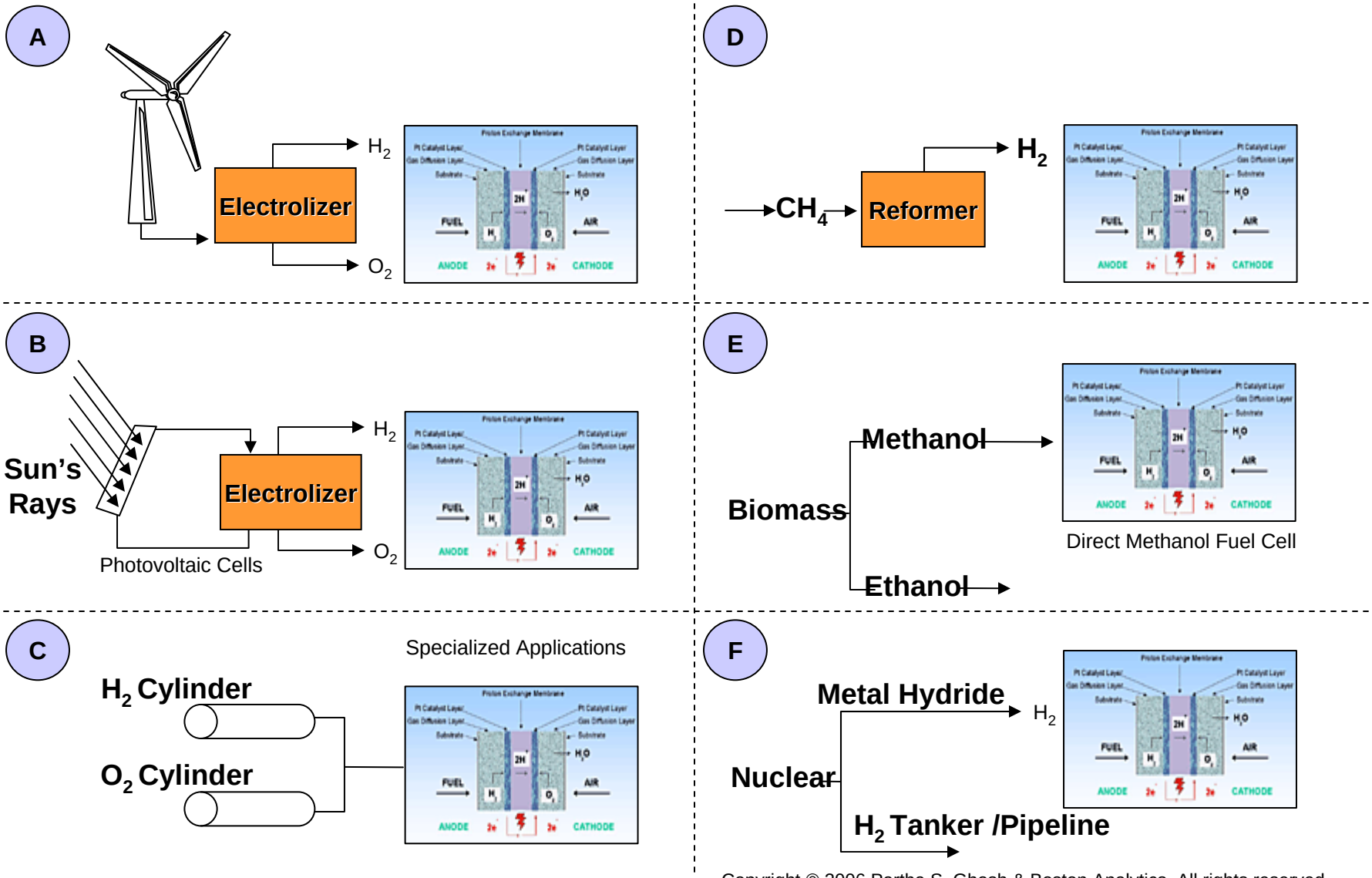
… Particularly in recycling of Spent Fuel

Challenges in Nuclear Fission[1,2]



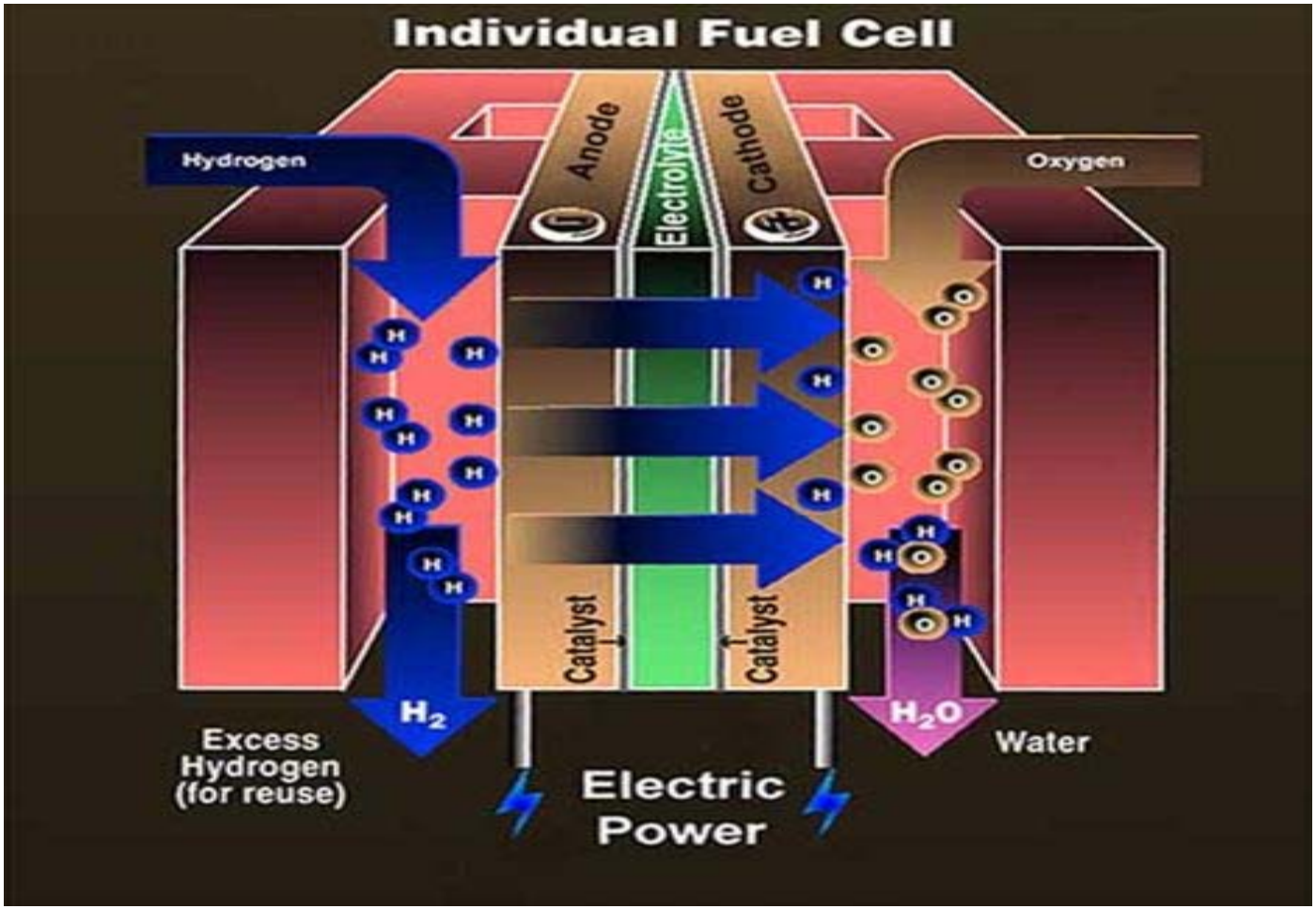
The lighter elements in **Spent Fuel** are radioactive
Need new forms reuse of fuel and chemical treatment processes before disposal

Not Either Or, it is all about Unification



Fuel Cells works by converting chemical energy to electrical energy **On Demand**

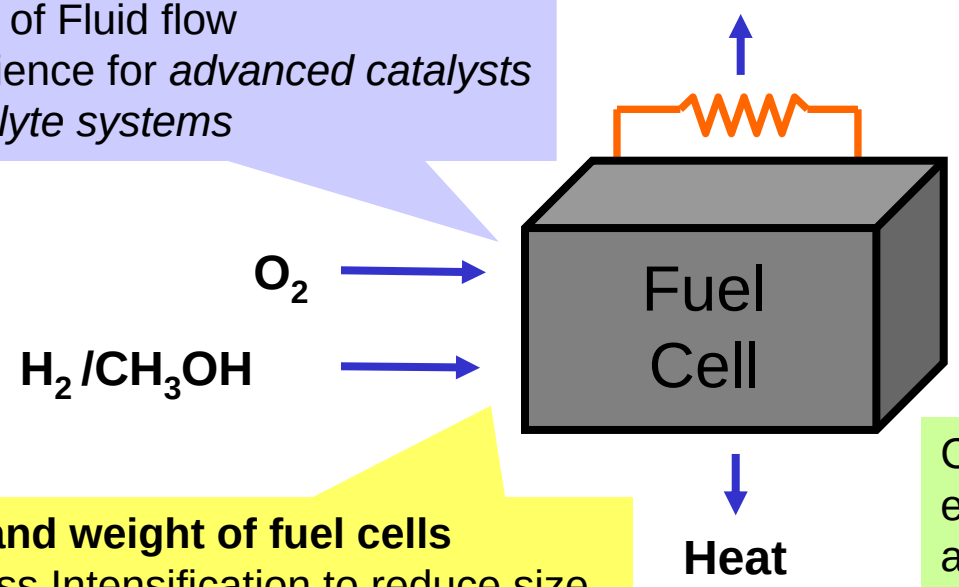
Basic Mechanism of a Fuel Cell[1]



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*



Overall efficiency of the cell is just 24-30% due to poor conversion of CH_3OH to H_2
Systems design and catalysts

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

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

Boston Analytics Research

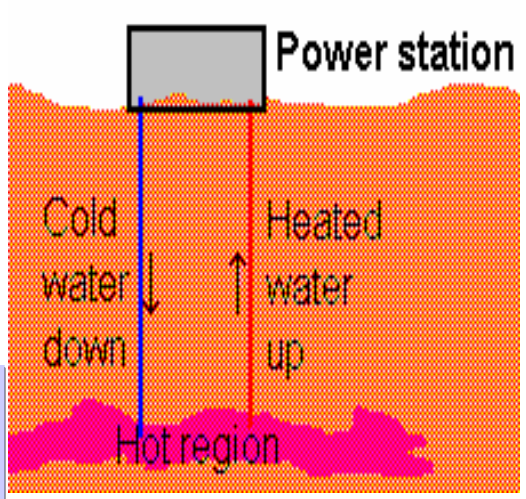
1. www.howstuffworks.com
2. "Changing the way America drives: WPI chemical engineer works on fuel-cell power", WPI News & Events
3. http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_challenges.html

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

Injection well → **Injecting water** → **Hydro fracture** → **Doublet**



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

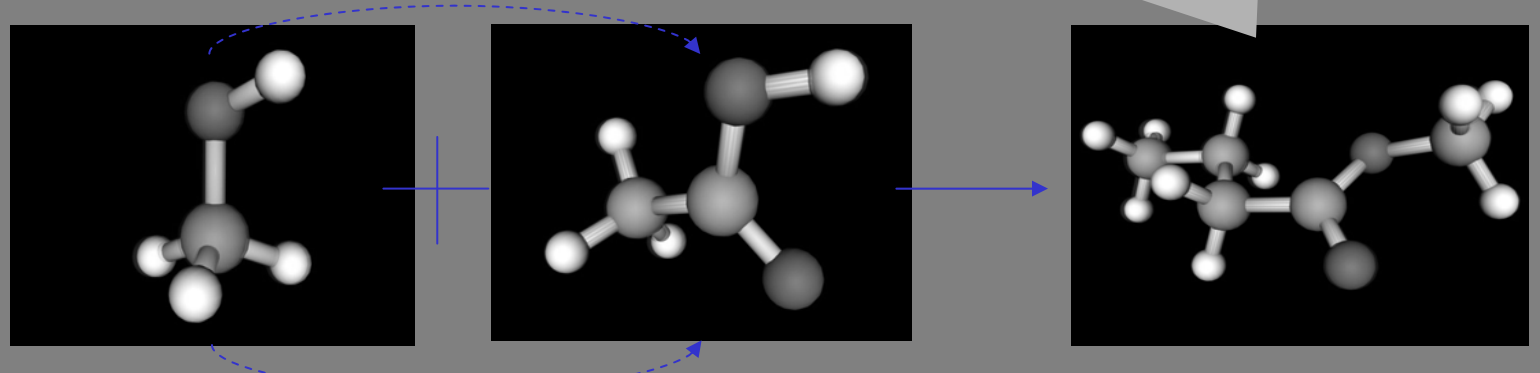
Boston Analytics Research
1. www.darvill.clara.net/altenerg/geothermal.htm#more ,2. www1.eere.energy.gov/geothermal/egs_animation_text.html
3. “Geopowering the West”,Susan Norwood, Sept 2, 2004, 4. “Geothermal Energy Development Overview”, National Park Service, US Dept. of Interior

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

Challenges of Nano-Manufacturing[1,2,3]

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

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



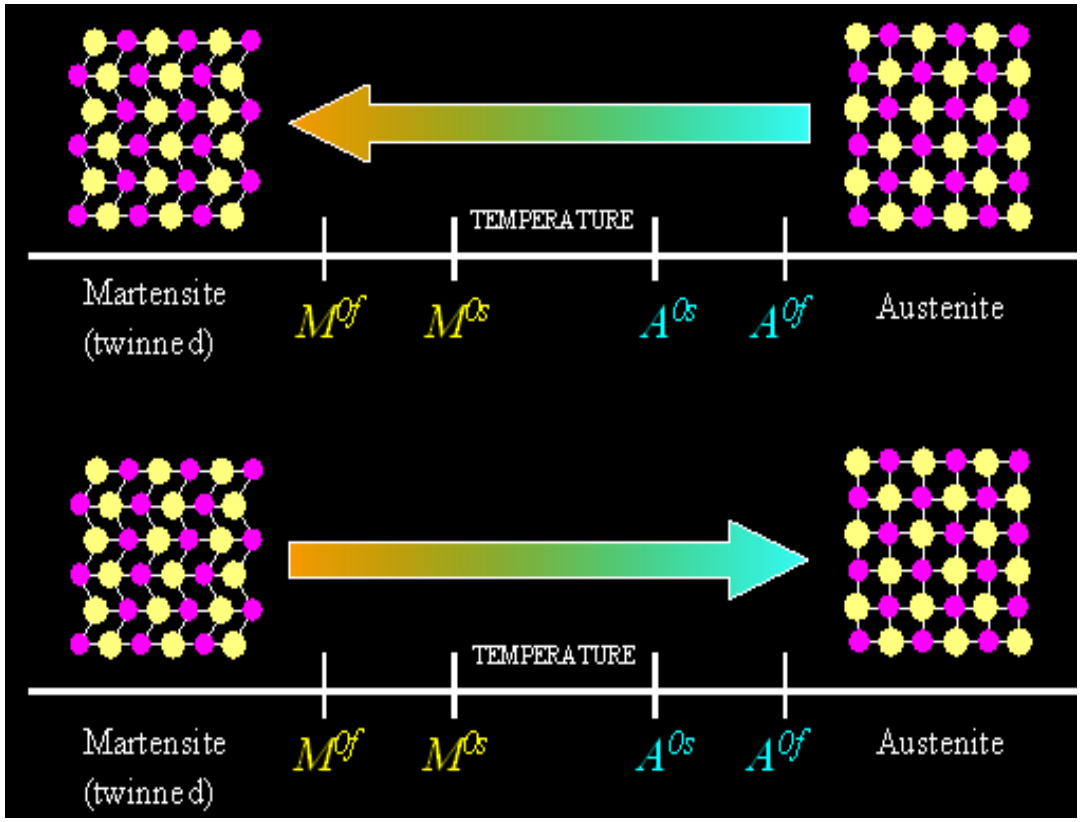
Molecule A

Molecule B

Product

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

Basic Mechanism of SMAs[1]



- 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.

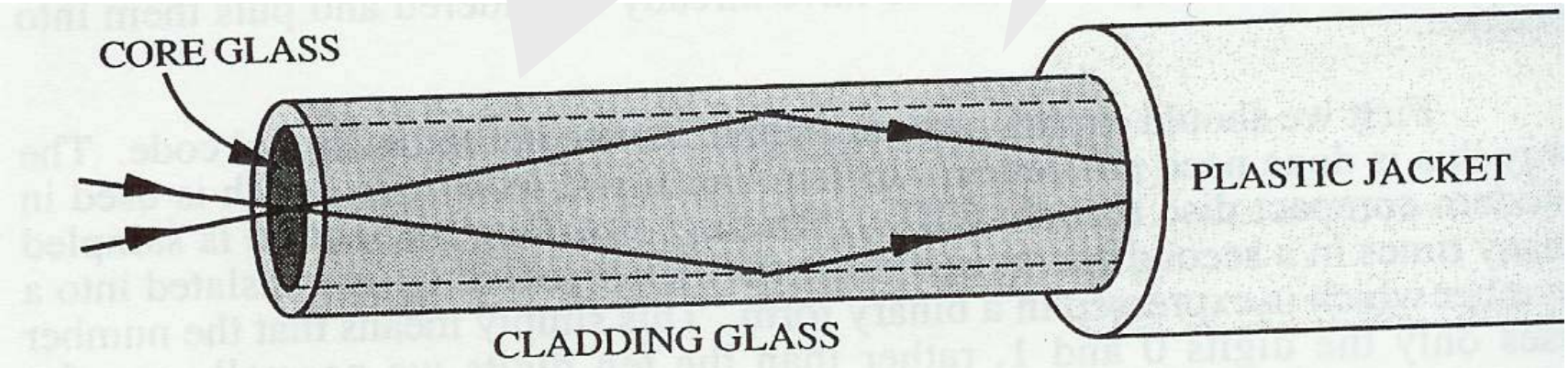
1. Shape Memory Alloys (SMAs) Presentation - E^3 AEROSPACE ENGINEERING RESEARCH - Moses Z. Horto and Ali A. Jafry

Current Research is directed towards improving the data quality and biodegradability of optical fibers

Issues in Transmission[1,2,3]

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

Improve over systems functionalities of fibers and biodegradability



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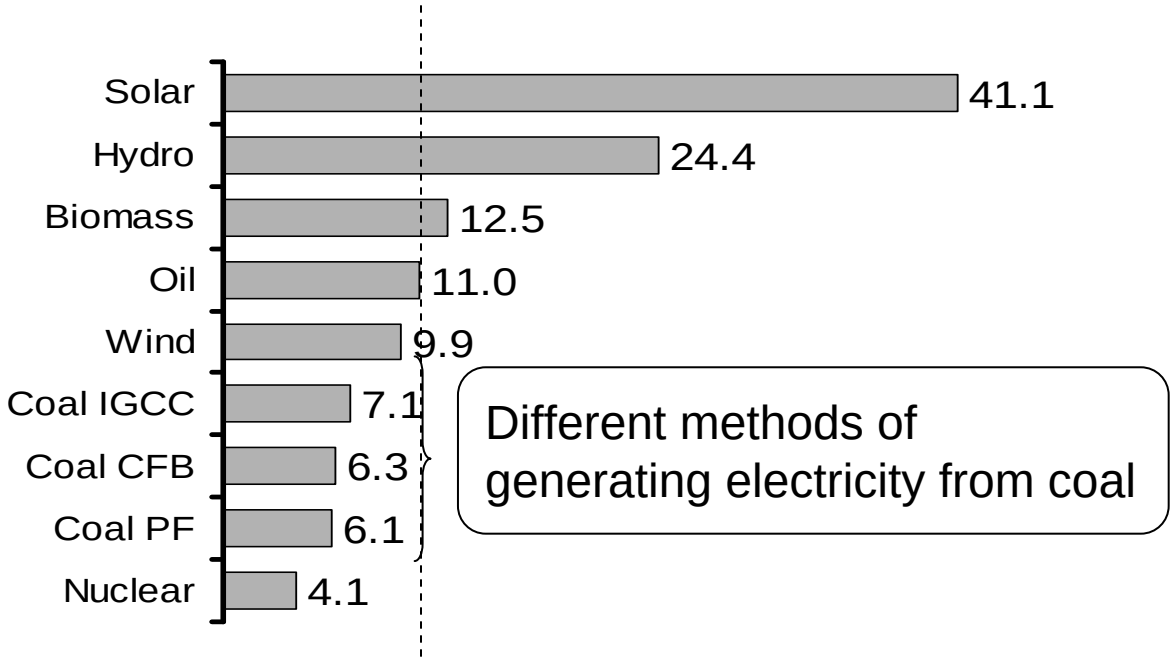
1. “10 emerging technologies that will change your world”, Technology Review, February 2004, www.technologyview.com
2. http://www.ntcresearch.org/pdf-rpts/Bref0595/B05C9404.pdf
3. http://www.ims.uconn.edu/~rampi/ENGR166/Topic16.ppt#306,12,Properties of optical fibers

As micro technologies develop macro systems solutions will become more affordable

Comparison of Average Electricity Generation Cost* ($cents/KWh)[1,2,3]



Capital Cost* ($/KW)[1,2,3]

5,544
4,053
3,390
910
1,363
1,842
1,345
1,511
2,118

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

Boston Analytics Research
1. "The Cost of Generating Electricity", Royal Academy of Engineering, March 2004 (213.130.42.236/wna_pdfs/rae-summary.pdf)
2. "Powering the Nation", Parsons Brinckerhoff Ltd, March 2006 (http://www.[illegible])
3. "Solar Energy in SGM, Renewable Energy Modeling Series", Allen Fawcett, December 2004 (http://www.epa.gov/cleanrgy/pdf/fawcett-

The Essential Points:

1. Indeed Challenging & Interesting times ahead

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

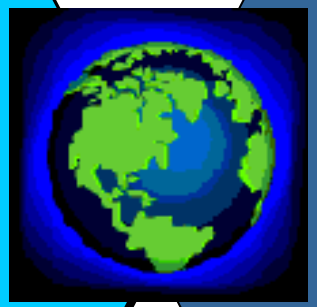
3. 21st Century Chemical Engineer: ***Three in One Strategic Problem Solver***

We have the tools: We need the commitment to link Supply and Demand

Supply-Demand Dynamics

Supply

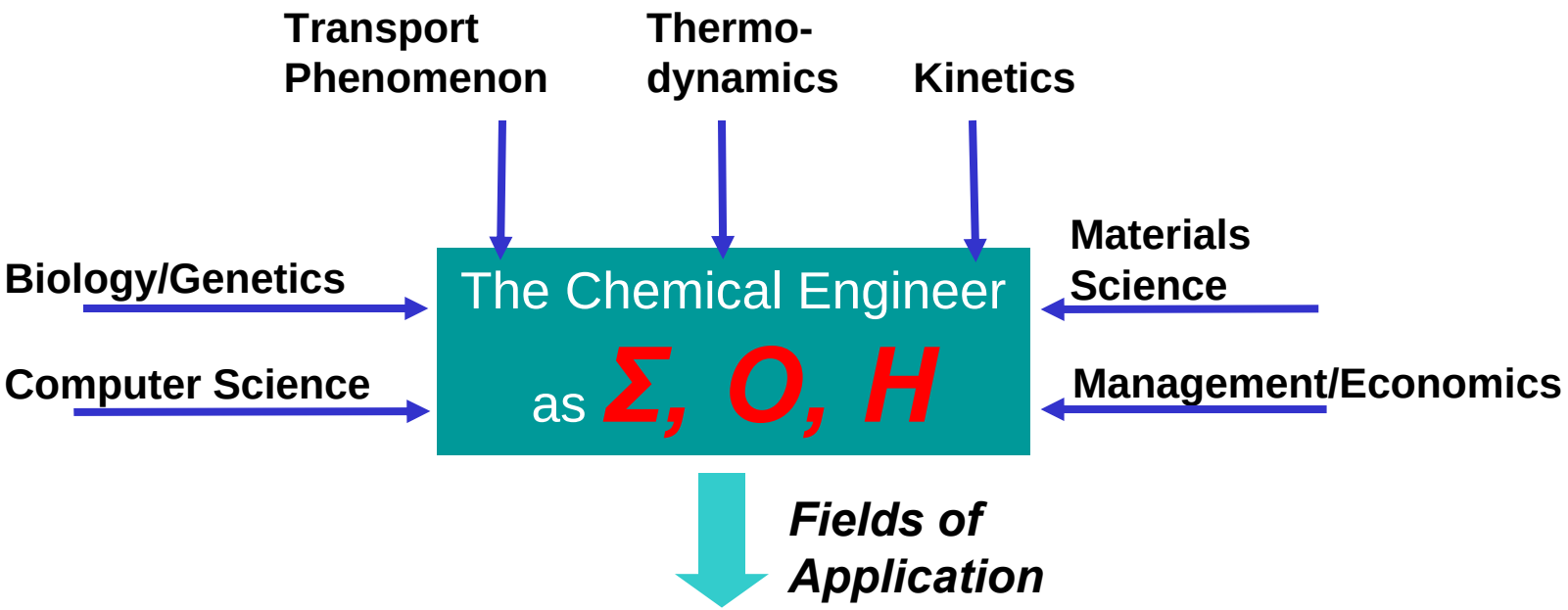
- New Materials
- Precision Controls
- Nanotechnology
- Life Sciences
- Miniaturization/Process Intensification
- Convergence / Broadband infrastructure



Demand

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

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

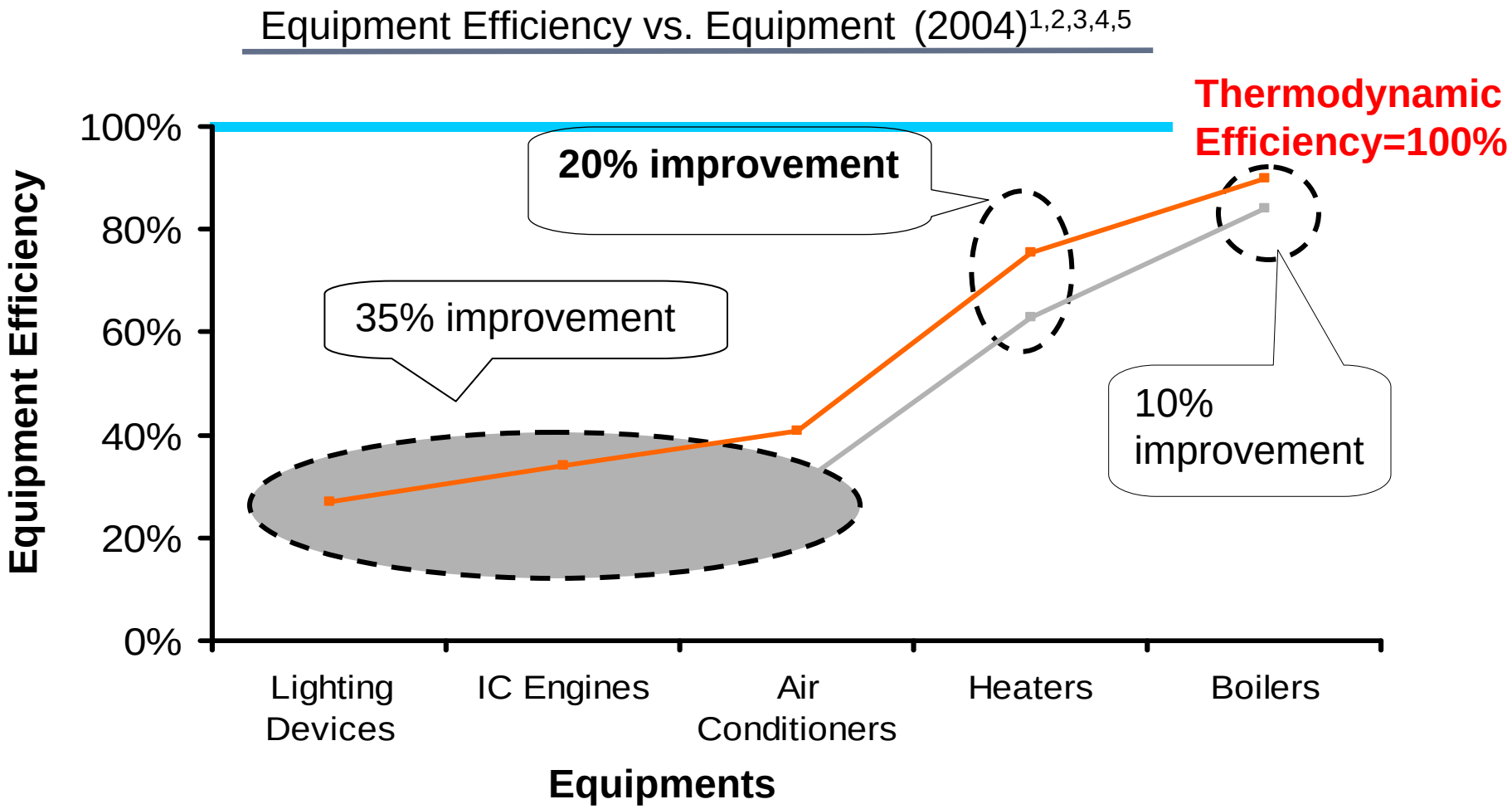


Design Engineering, Plant Operations, Process Optimization, Engineering balance of Living Systems, Energy Engineering, Material Research, Environmental Engineering, Biotech, Safety Engineering, Nano Engineering

Boston Analytics Research

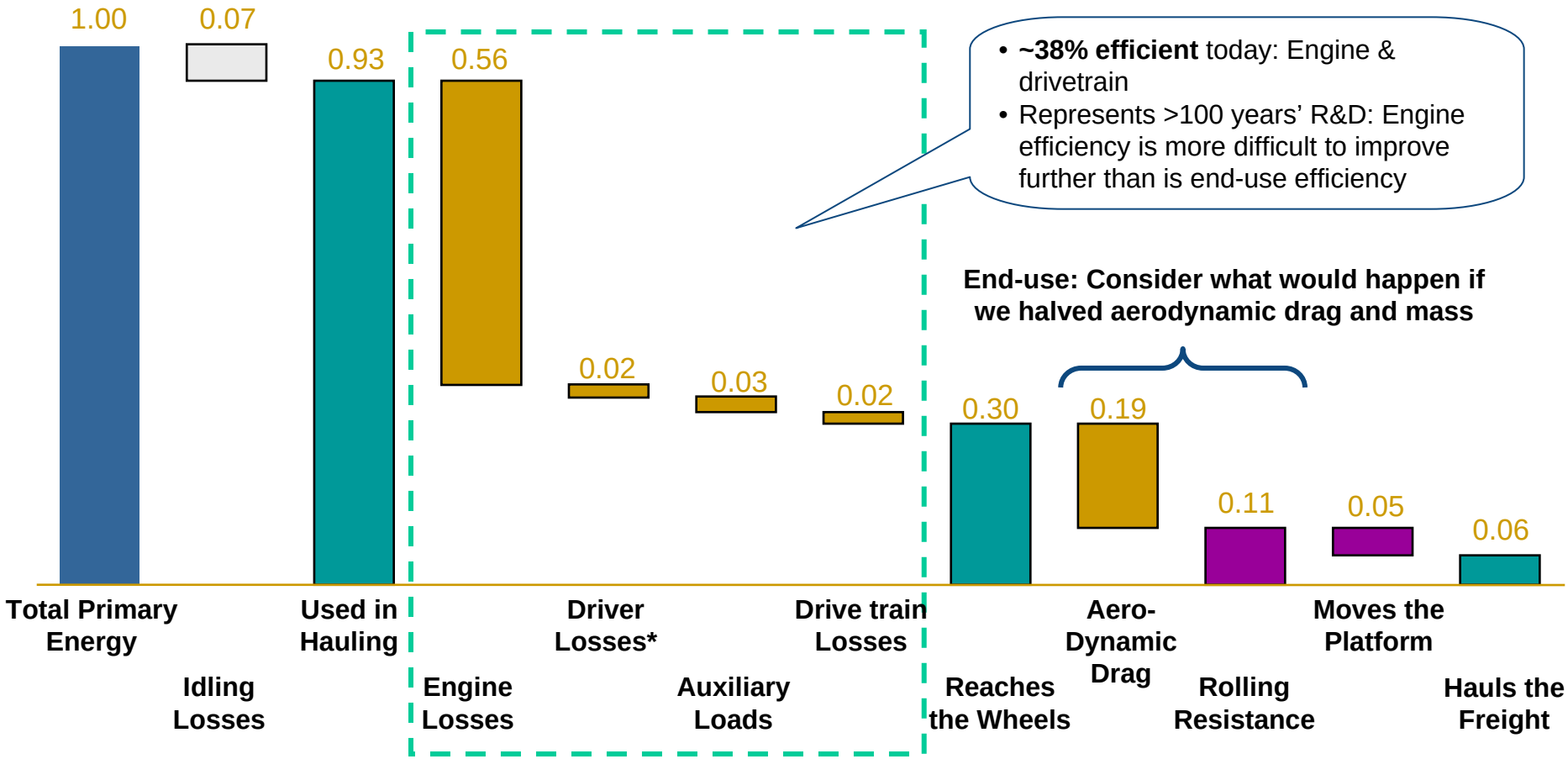
1. http://www.ecs.umass.edu/che/

Equipment efficiency?



Where a long-haul Class 8 truck's diesel fuel goes ?

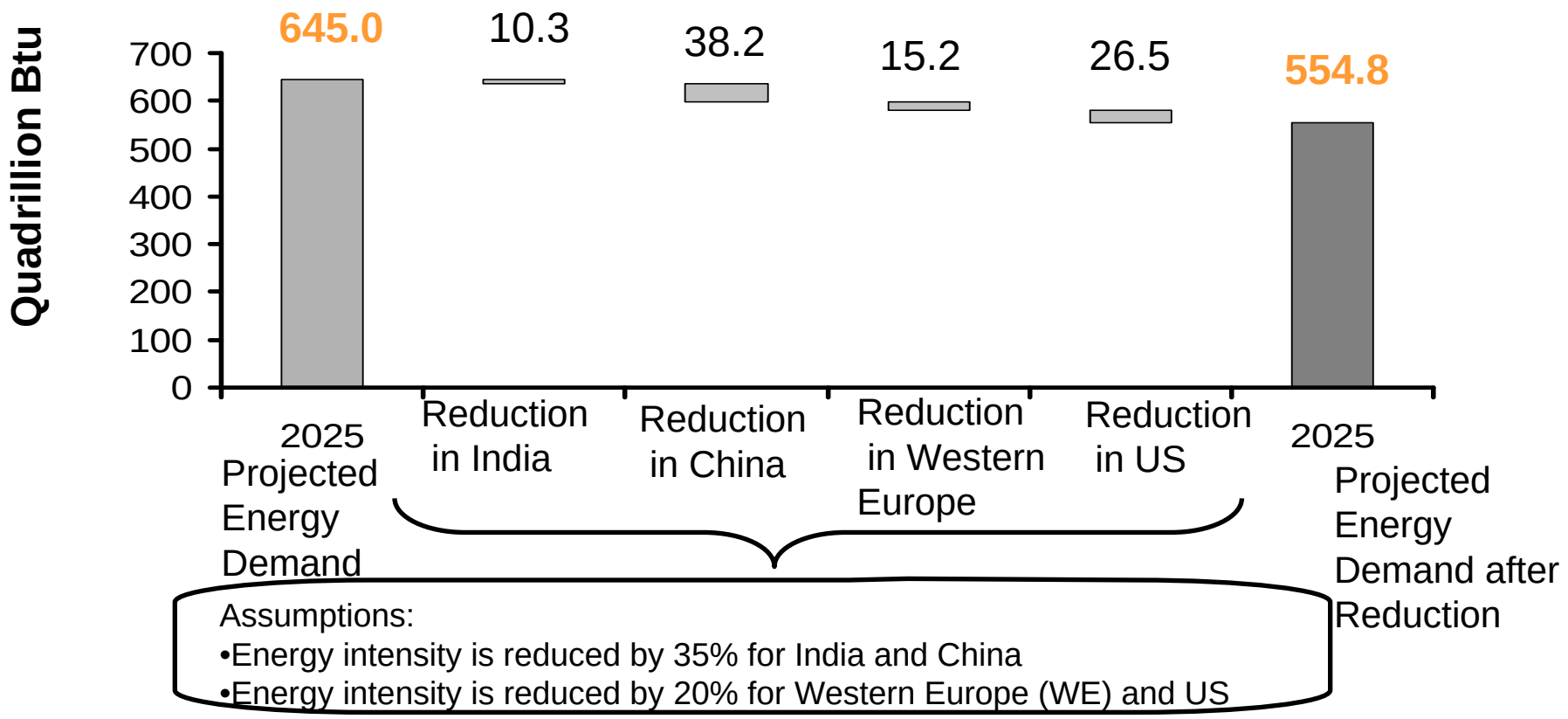
Focus: End of Chain [Fuel] → [Engine] → [Drivetrain] → [Tractive Loads]



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

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

World Energy Demand in Quadrillion Btu (2025)[1] :If Energy Intensity is Reduced in Selected Regions



The Essential Points:

1. Indeed Challenging & Interesting times ahead
2. The Process Industry will become more dominant & will be the driver
3. The 2st Century Chemical Engineer
4. A Vision of the Future

The New horizons…

Frontier Areas	Brief Description
Alternative Energy	Ecology friendly, Sustainable and Safe Energy for all
Nano-Manufacturing	Taking a bottom-up approach to manufacturing mechanisms at nanoscale to yield products of high quality with zero wastage
Novel Materials	Efficiency of Usage of Materials e.g. Shape memory alloys, new fibers etc.

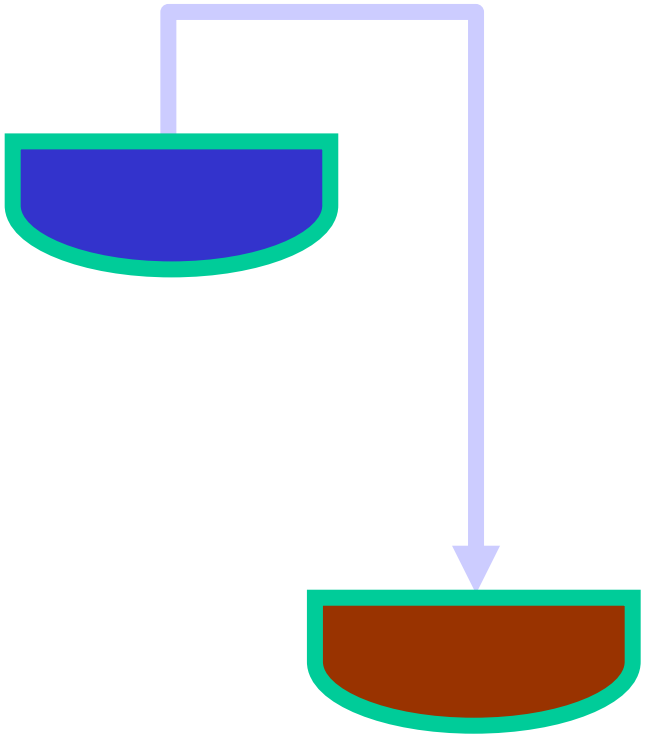
… beyond current framework of plant design and engineering

Frontier Areas	Brief Description
Biocatalysis	Microorganisms and enzymes to catalyze reactions such as polymerization – without any harmful or toxic releases and at normal conditions
Genetic Reforestation	Production of healthier and fast-growing trees using principles of genetics and biotechnology
Waste Recycling	Making optimum use of recycling to productively utilize waste materials

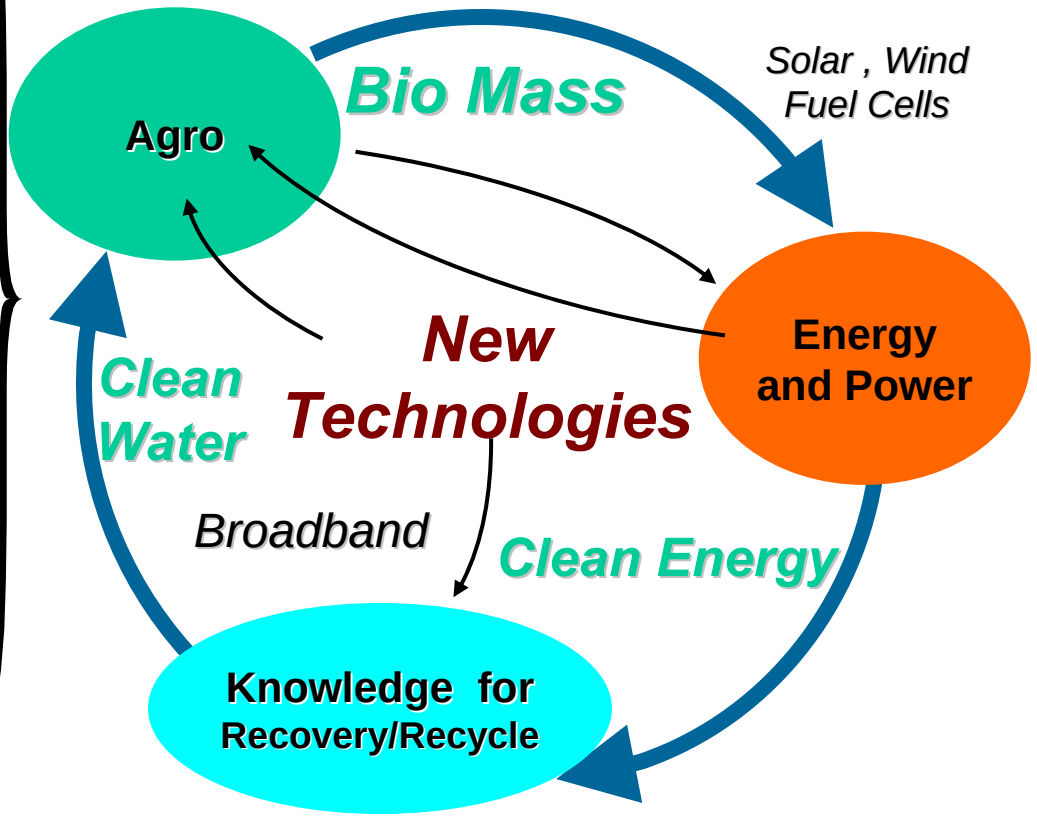
Last 5,000 Years…

…..Future Possibilities..

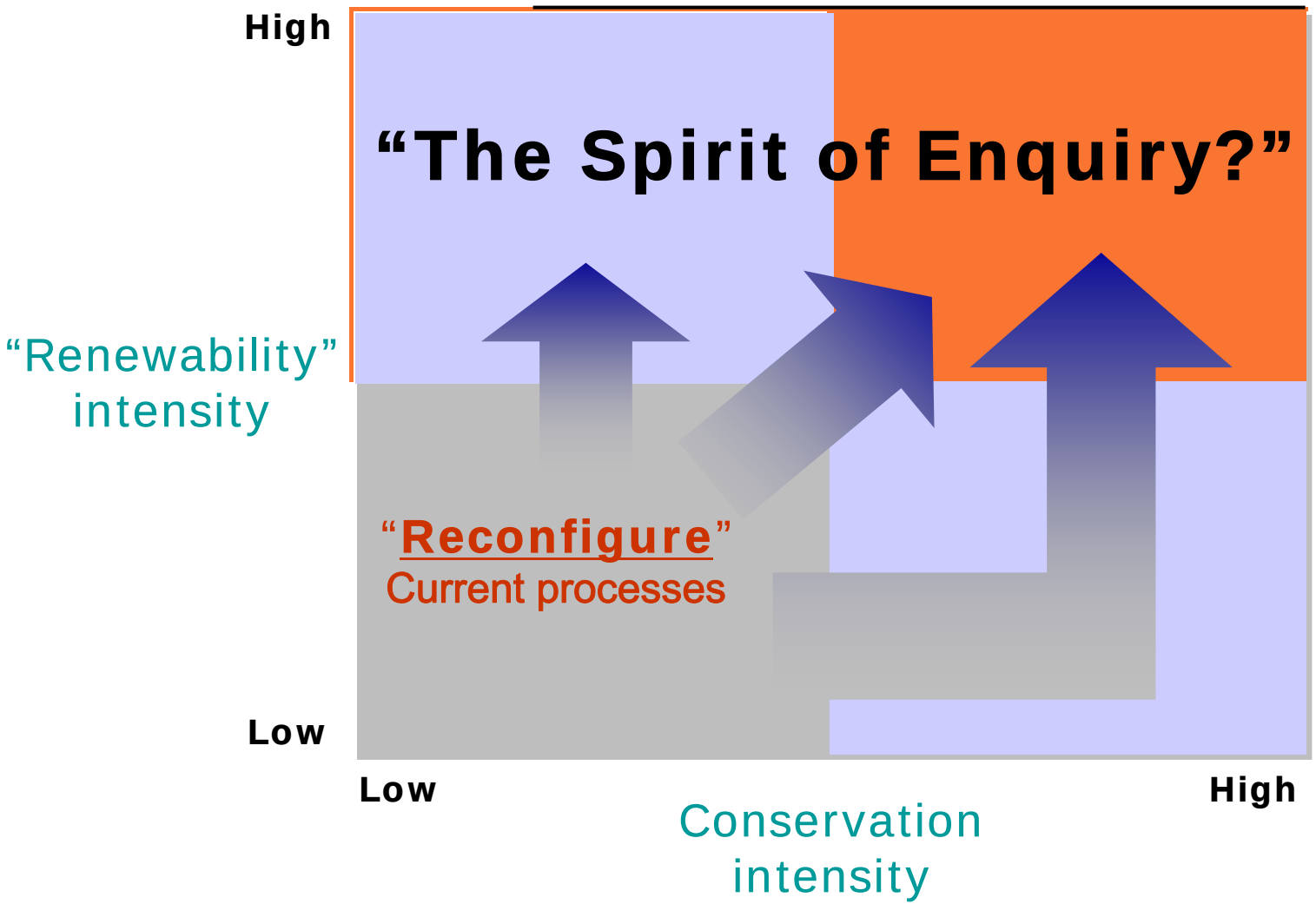
***Economics of Linear Mechanics**: Extraction, Exploitation & Experimentation*



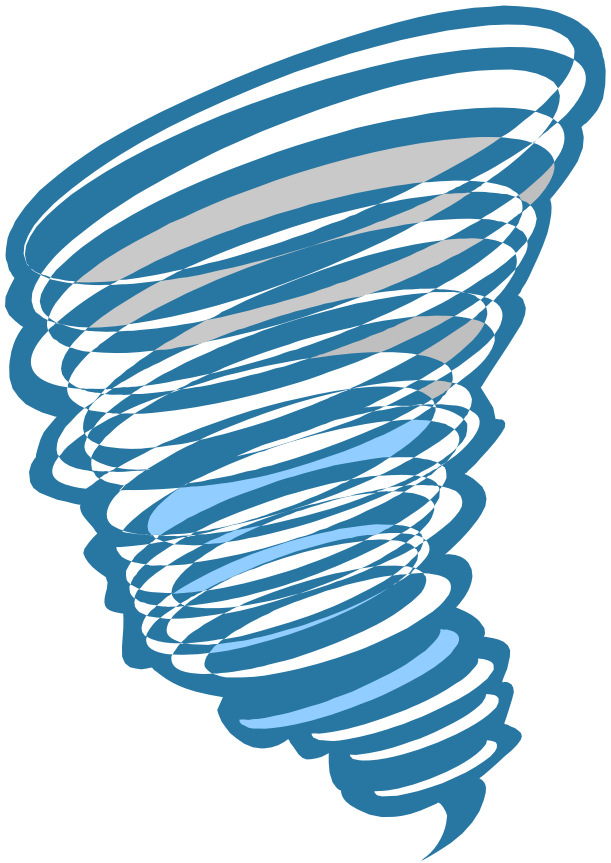
Economics of Closed Loop Harmony



.. Chemical Engineering Education & Industry has to *Rekindle the Sprit of Enquiry*



The Journey forward . . .

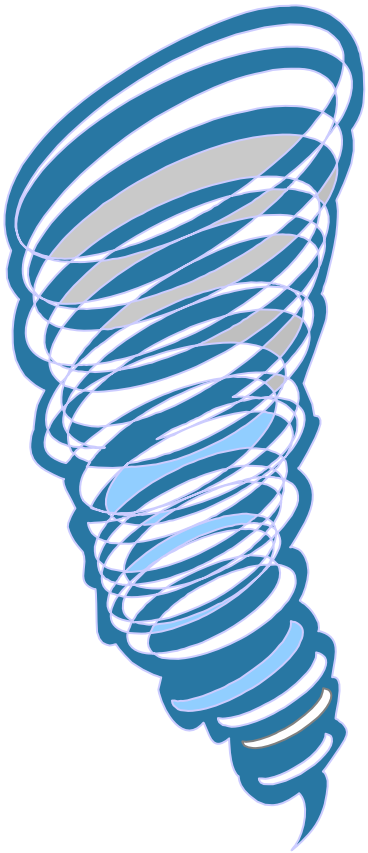


Toward a New Integrated Vision for Intelligent Holistic "Mass & Energy Balance" Plays

It is not in the Seeming , it is in the being,

….but even more in the Becoming . . .

Lets wish for the best



Questions ???