The Frontiers of New Energy Paradigm:

Cultivating the Courage to Create The New Dynamics

Partha S. Ghosh

Global Energy Scenario

The Fletcher School

Our Planet's Energy Future is a matter of Choice, *Not Fate*, a matter developing clear logic in midst of *confusion* and *chaotic views*

Contents

- ***Laws of Large Numbers & Network Effect?*** *Slow Pace of Large scale world wide Energy disruption?*

- ***More & better of the Same or New Game?*** *Market Mechanisms vs. Cross Border Strategic Diplomacy?*

- **A Call for a Renaissance:** ***Time to rethink, repurpose and reform?***

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Since the Early Nineteen Hundreds the world economy has developed extractive relationship with nature

Early days of Electricity & Auto *2006*

Era of Extraction & Automation

Overcoming barriers of socio-economic development

New Realization of space and time

Supply Infrastructure to fuel demand

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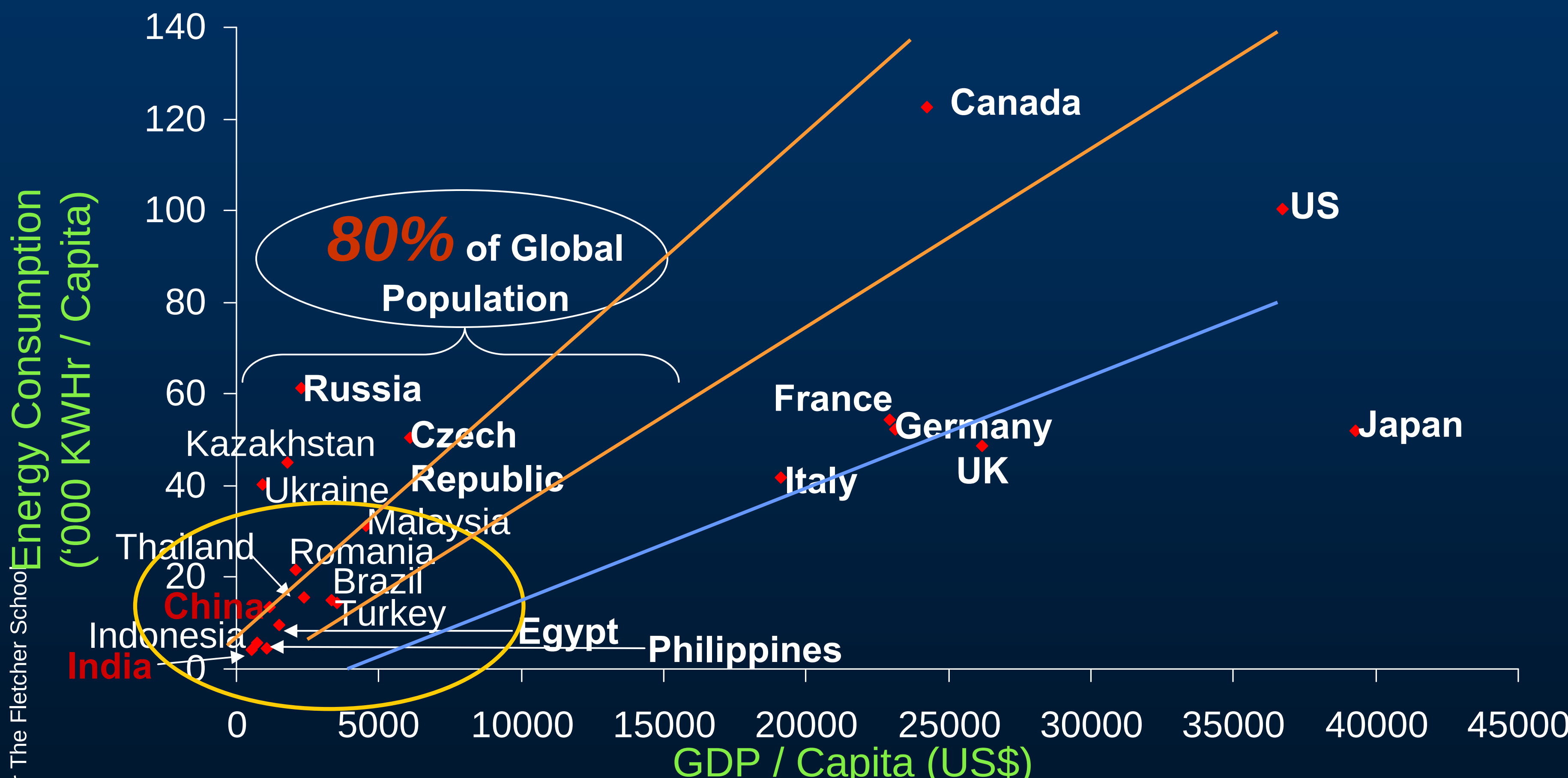
Most of the world however is still in the early stage of Economic development

Energy Consumption per Capita vs. GDP per Capita (2004)[1]



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

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Energy Scenarios ? (Terawatt Challenge)

Billions of people x kilowatts/person = Terawatts

Today: **6.3 billion people x 2.5 kW/person = 16**

With 9 billion people at Japanese energy efficiency (5kWcapita): **9 B people x 5 kW/capita = 45**

With 12 billion people at the 1970 US energy use rate of 10 kW/capita: **12 B people x 10 kW/capita = 120**

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For example China and India alone could change the politics of natural gas

Future Natural Gas requirement of Asian countries

(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

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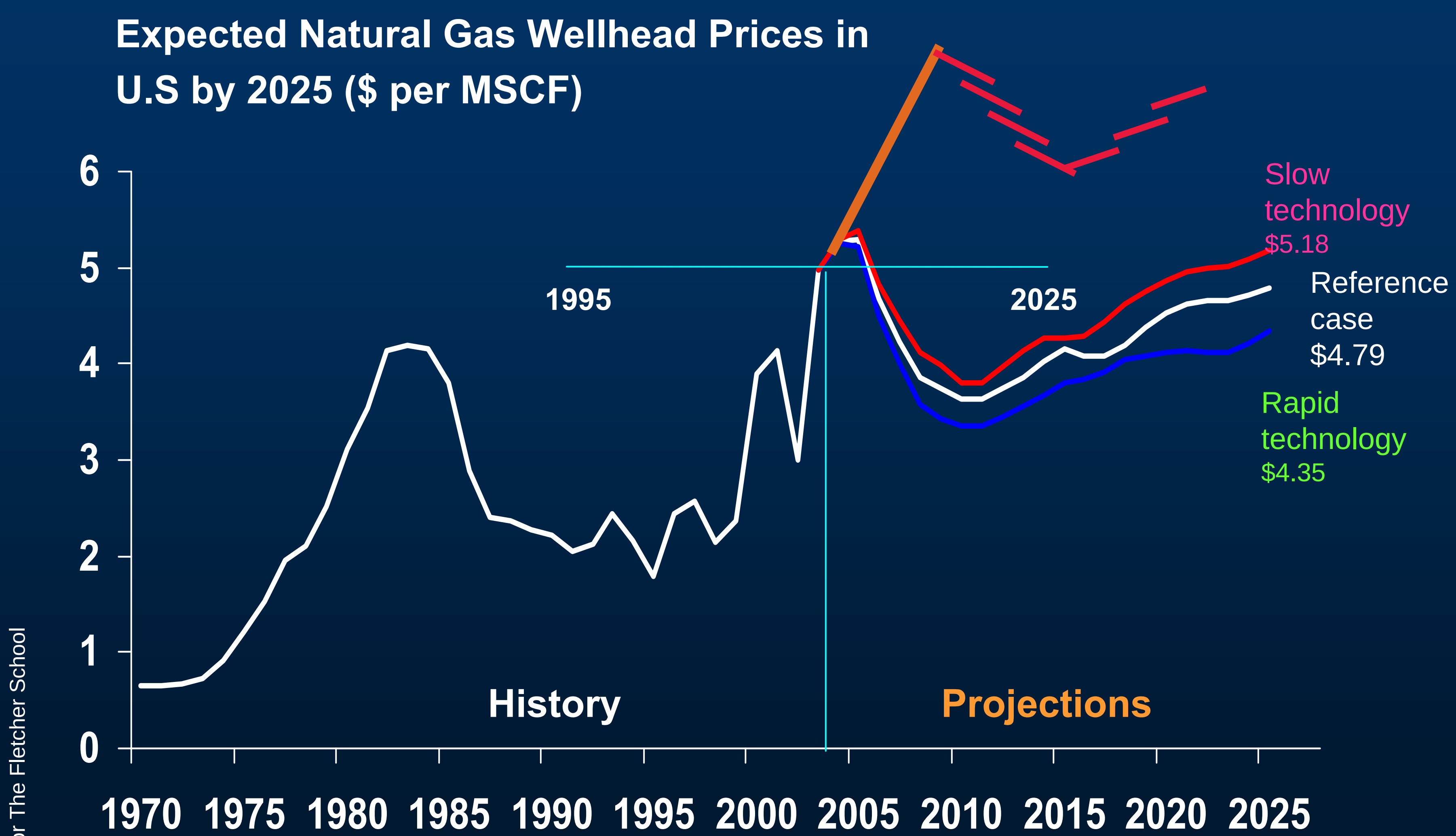
Forecasting will continue to be Futile



Source: Annual Energy Outlook 2005

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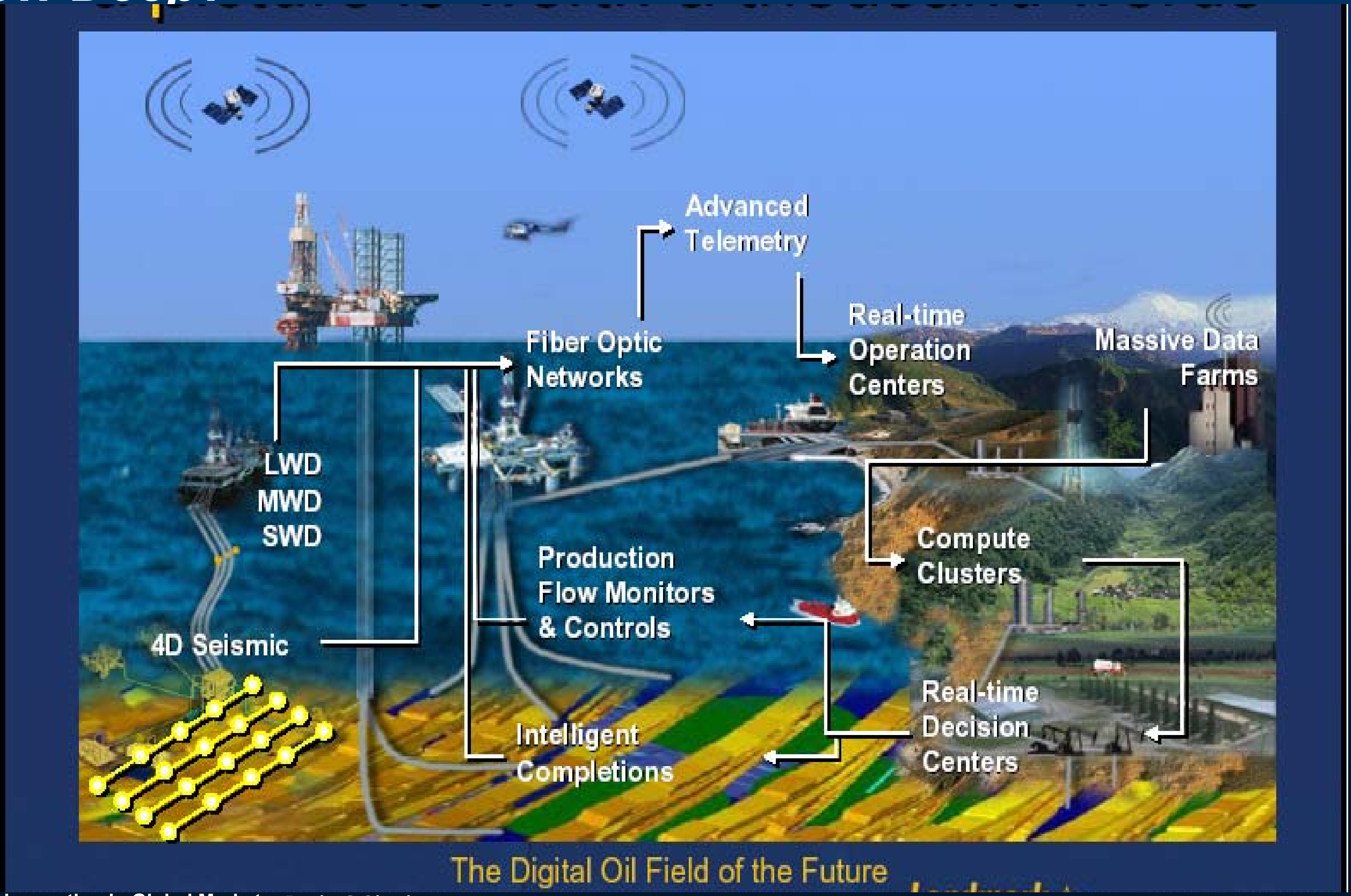
Higher Prices might enable more risk taking: e.g. *Convergence of Technologies for ultra deep drilling but How Deep?*



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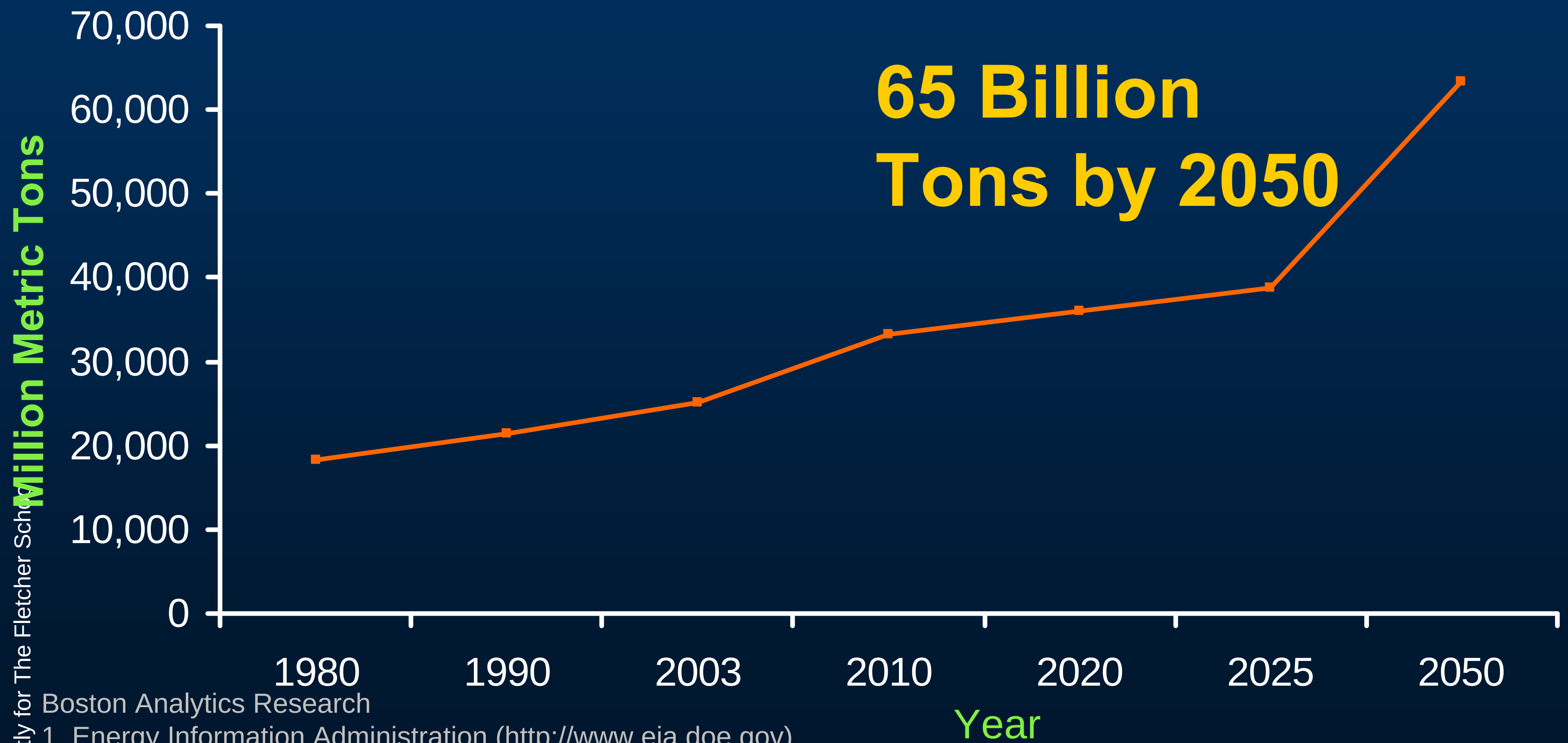
Certainty of Global CO_2 emissions will continue = Slow Pace of Dangerous Change

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)

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In fact, multiple Powerful Forces at Work?

Changing Geopolitics
NOCs versus IOCs

New Technologies

Increasing Capital Intensity

Volatile Prices

Sudden events: Terrorism, Natural Disasters

Mega Infrastructure/P&L large Stakes

Ecology Concerns

Equity

Wall Street Expectations

Interruption free Hydrocarbon infrastructure

New requirements of Digitization

Reliable, Affordable and eternal source

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Mega Challenge = Managing a Mega Transition to avoid Mega disruption

1800s *2005* *2050*

Era of Extraction & Automation

Overcoming barriers

New Relationship of Space & Time

Supply to Fuel Unidirectional Demand

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

Era of Multidimensional Energy Renaissance

1. Multi track models of social Experiments ?
2. New Paradigm of Knowledge Creation & Recycling ?
3. Hybrid Infrastructure ?

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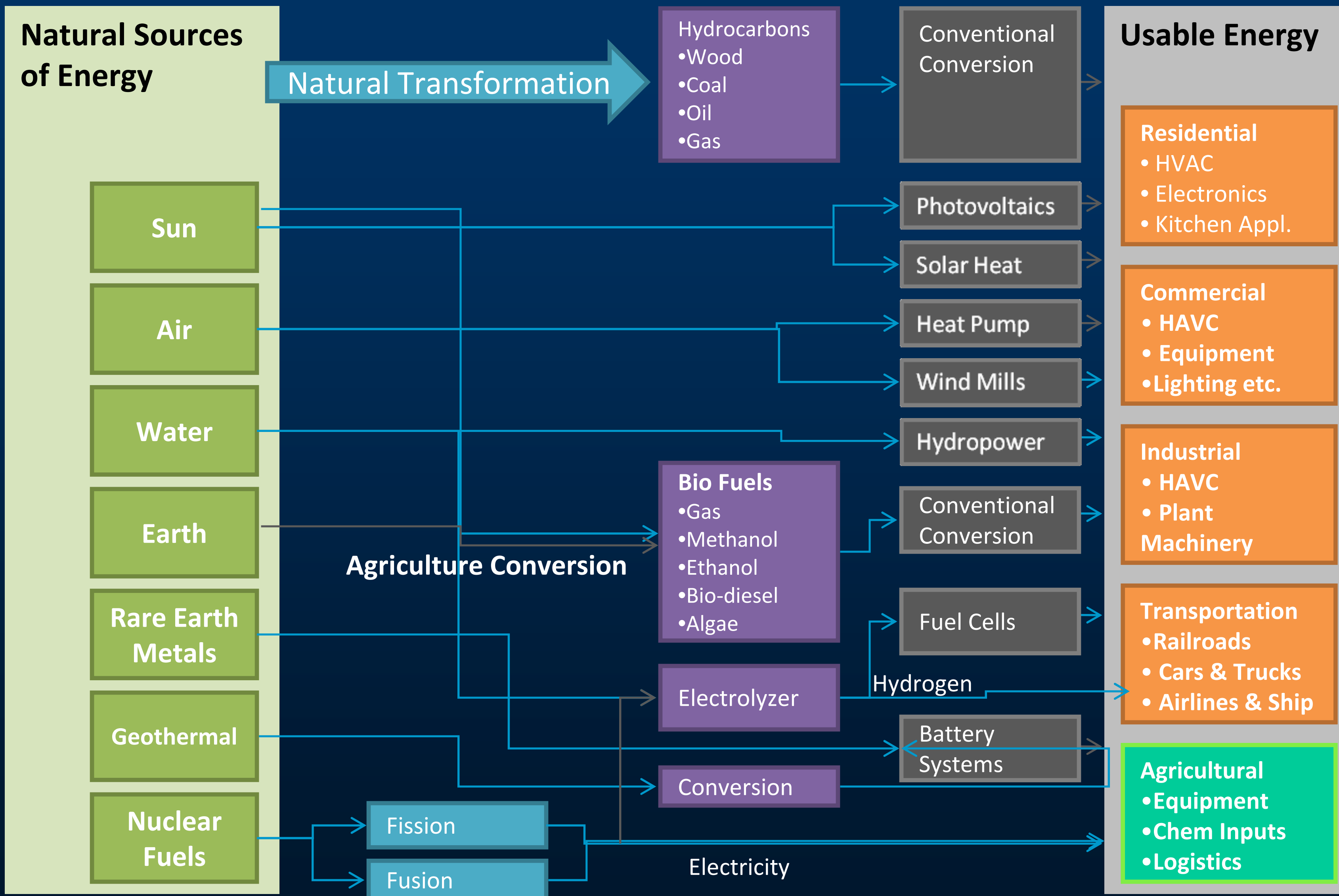
Mega Transition through holistic view of the linkages

Energy Map (*Supply and demand side linkages*)



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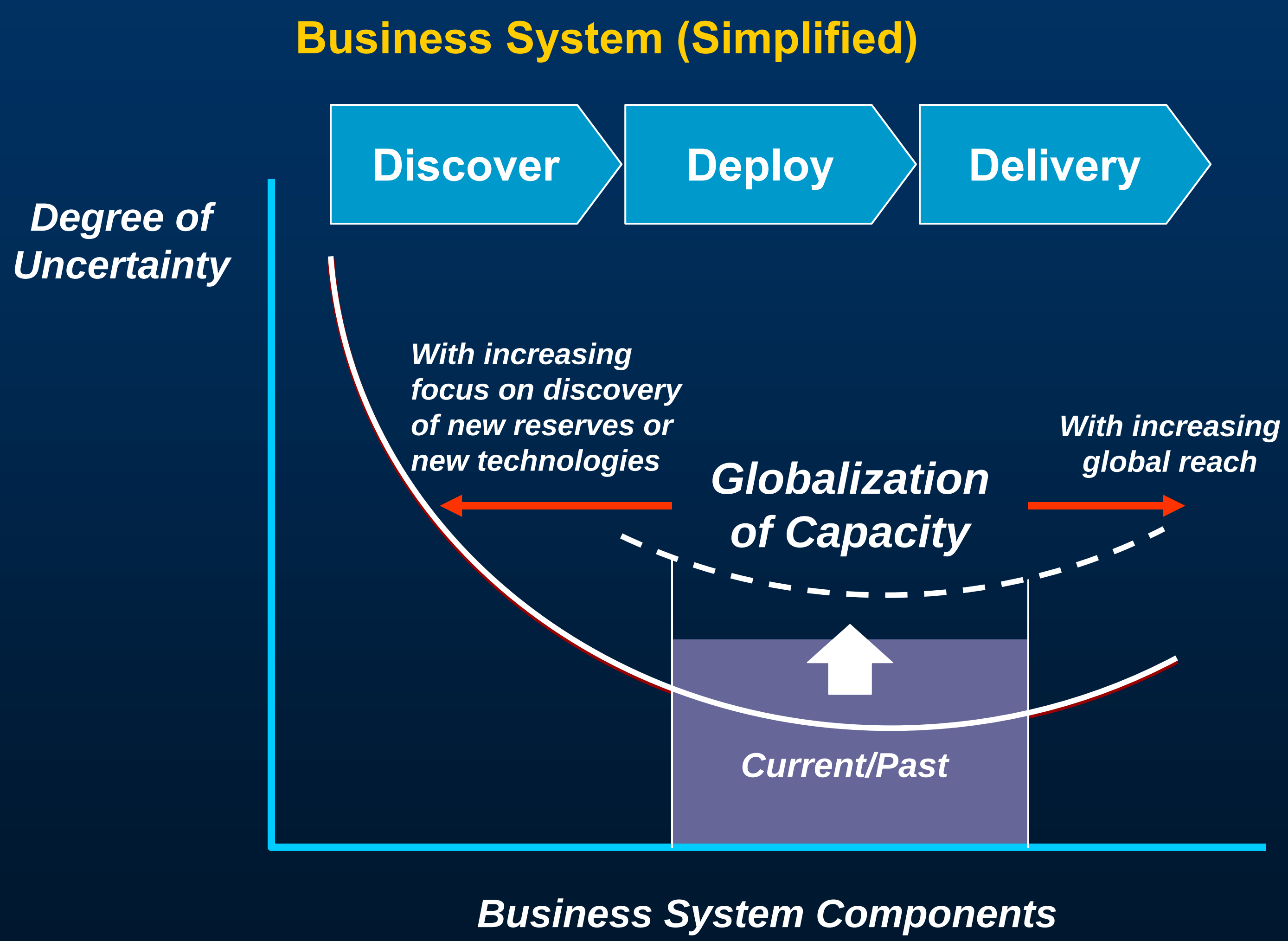
Risk Management Capacity Will Need to Be Fundamentally Reviewed



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Supply side possiblities?

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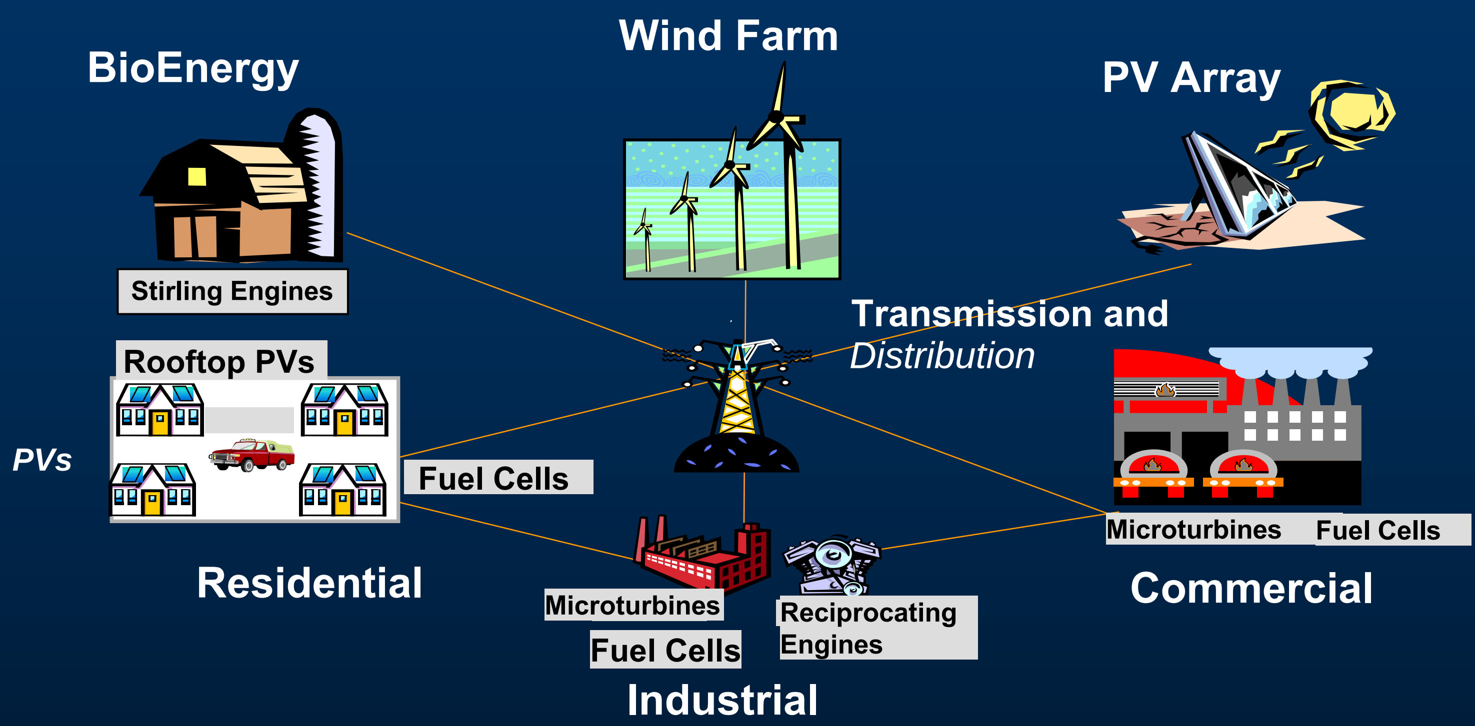
Multiple different technologies will come to play: *Vision of NextGen Distributed Power Infrastructure*



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***

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At National level countries will need to strategize and plan terra scale Systems Engineering

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Sources:

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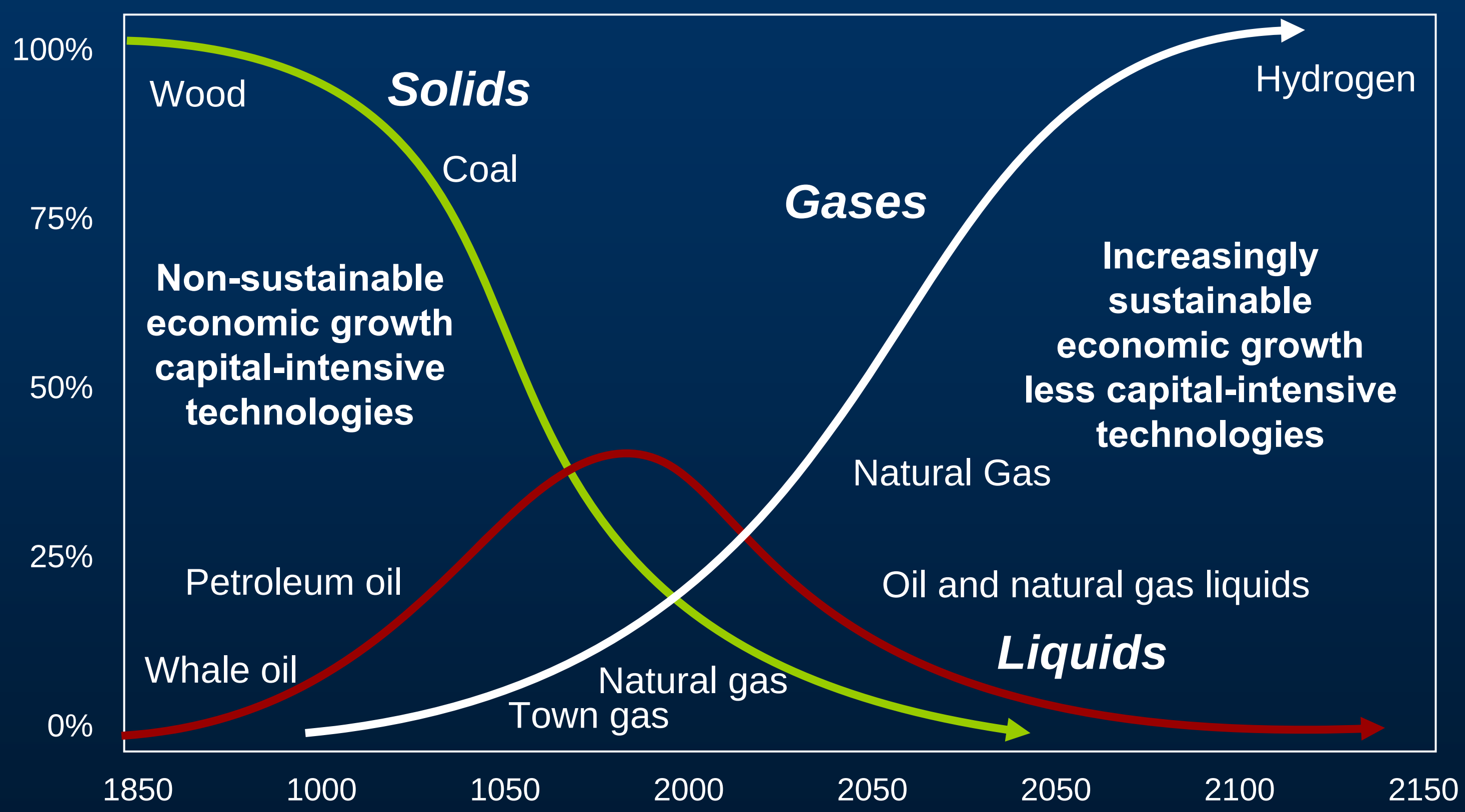
As a result Shape of things to come…



…beyond carbon?

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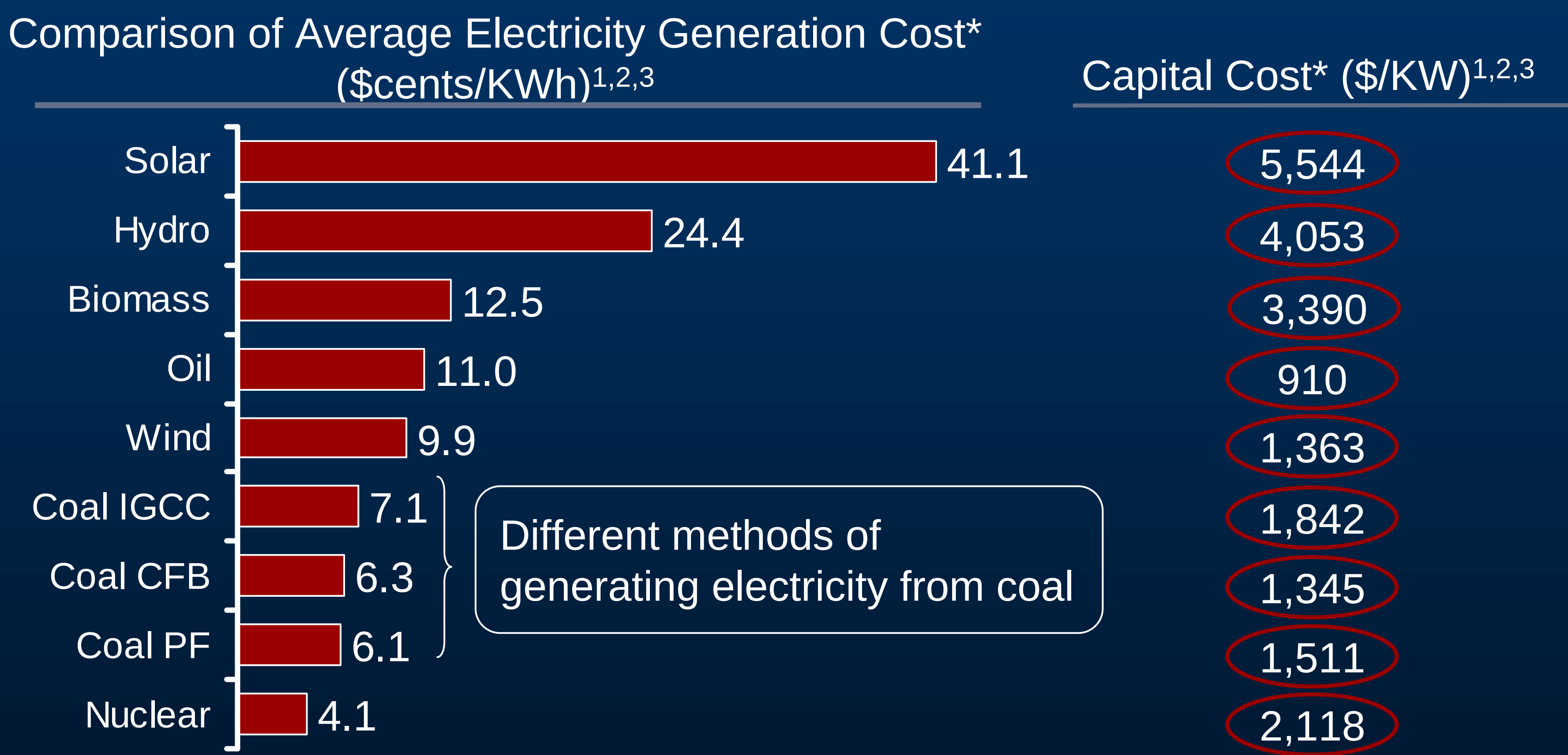
New Accounting for Depletion and Ecology



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

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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.pbpower.net/inprint/pbpubs/powerthenation/powerthenation.htm)

3. "Solar Energy in SGM, Renewable Energy Modeling Series", Allen Fawcett, December 2004 (http://www.epa.gov/cleanrgy/pdf/fawcett-

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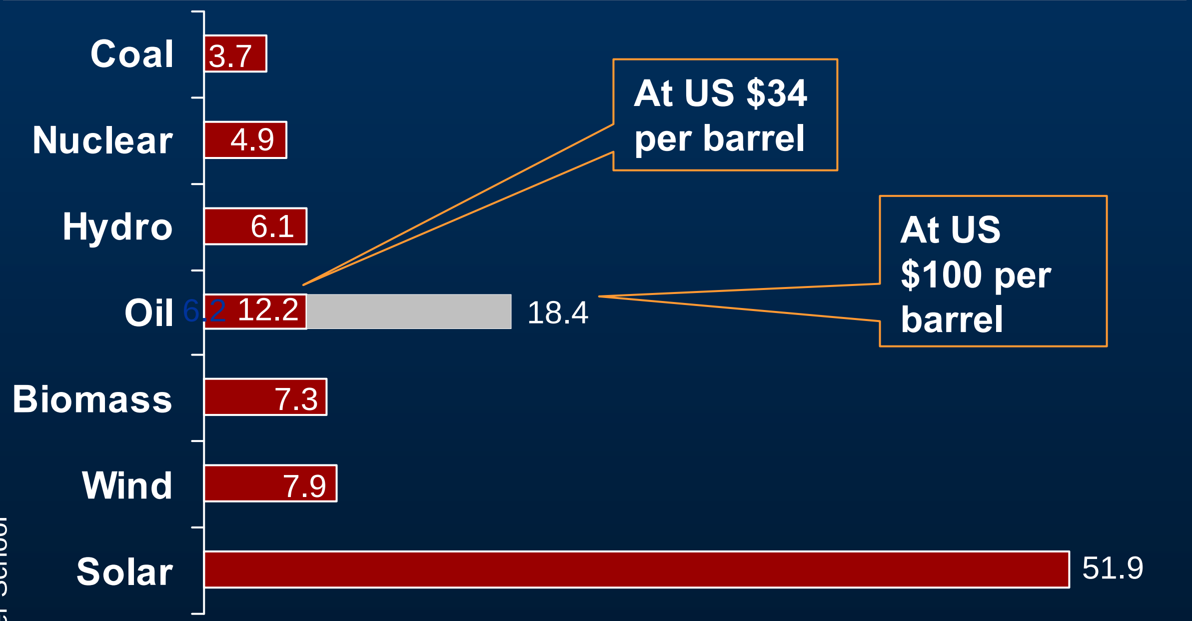
Electricity generation dynamics

Comparison of Average Electricity Generation Cost ($cents/KWh)[1]



Capital Cost ($/KW)[2,3,4,5,6,7]

Source	Capital Cost ($/KW)
Coal	1,000
Nuclear	3,500
Hydro	1,900
Oil	910
Biomass	2,500
Wind	5,300
Solar	15,000

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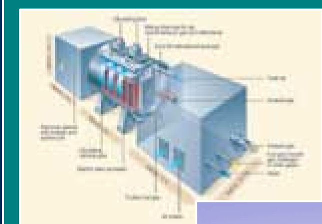
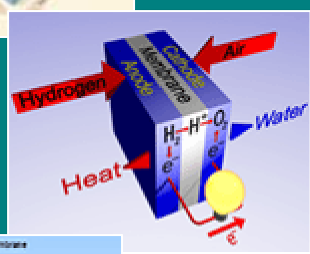
Collaborative Problem Solving & Synthetic Approach

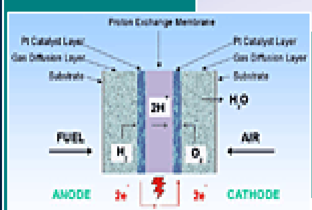
Competing Technologies and Barriers to Commercialization



DMFC
PEMFC
SOFC

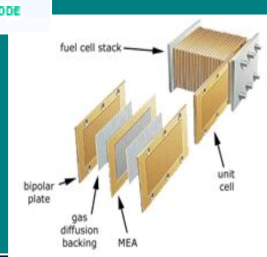


Size
Cost
Heat



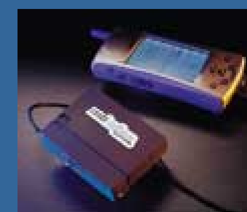
MCFC
PAFC

Reliability
Efficiency
Fuel Storage
Fuel Type



Automotive
Oil & Gas
Utility
Consumer Electronics
Specialty Chemical
Plastics
Raw Material
Mining
Nanotechnology
"Pure Play" Fuel Cell

Uncertain Market Opportunities




Portable Devices

Military Applications

Transportation

Stationary Power

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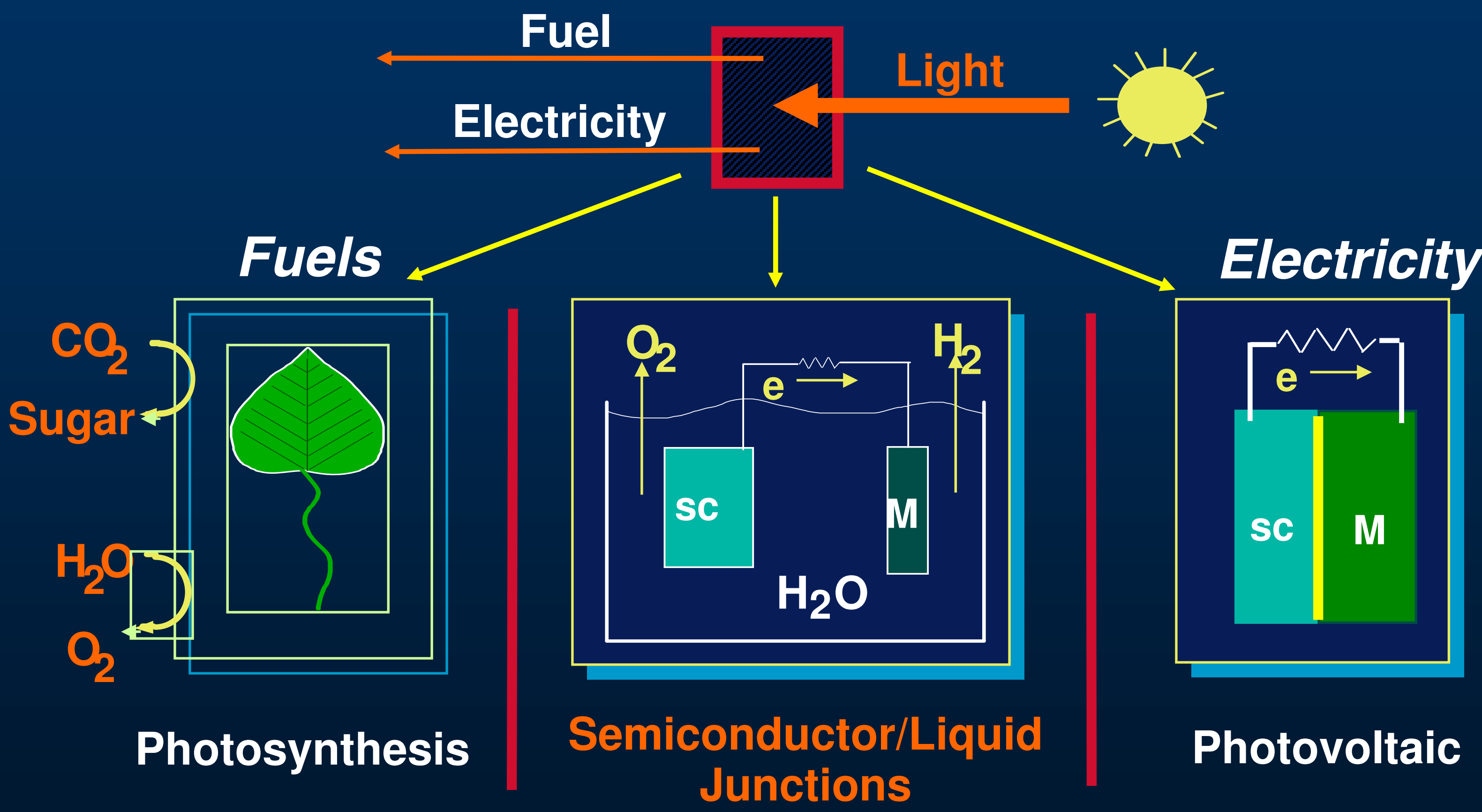
Solar Energy has the potential to address our growing energy needs in an environmentally-friendly way

Basic Mechanisms of Solar Energy Conversion[1]



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

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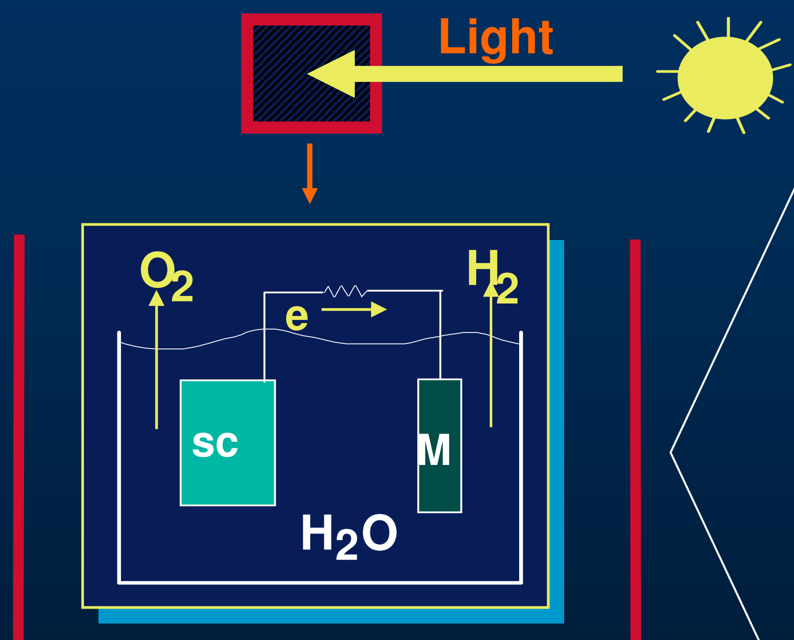
Poor efficiency and intricate material processing techniques are major issues with the solar cell

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

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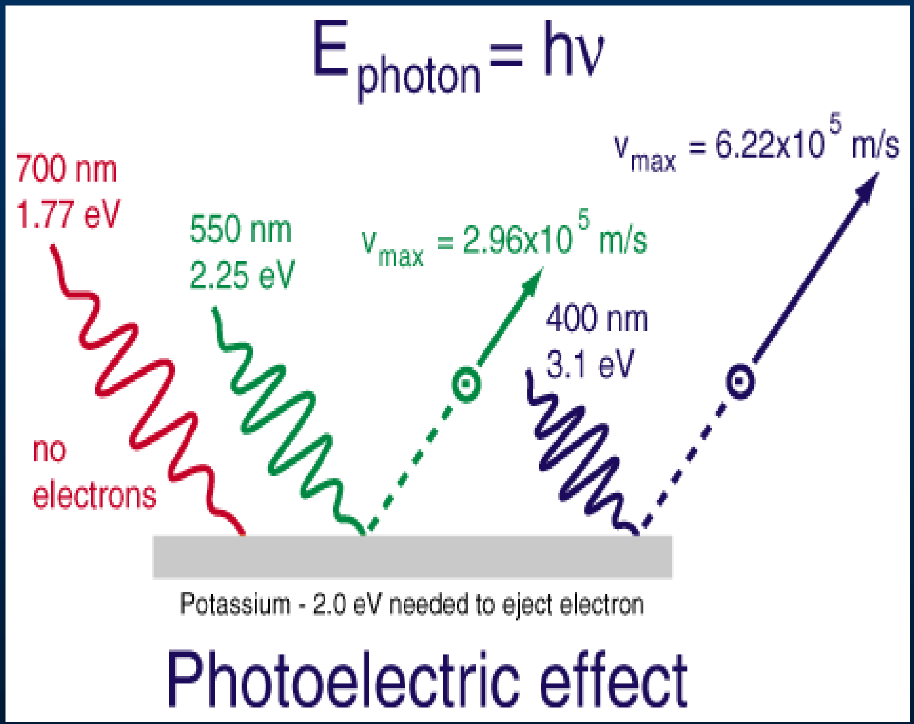
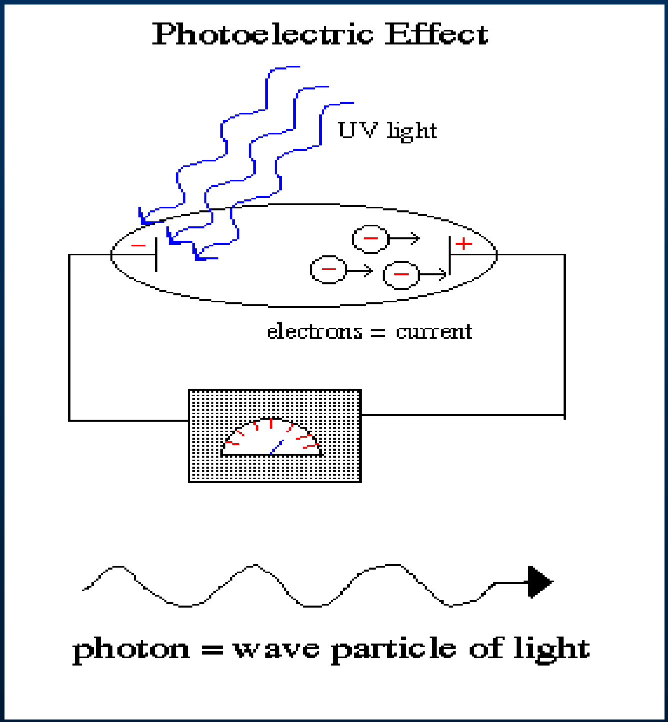
Photo electric cells

Photo electric effect: When light shines on a metal surface, the surface emits electrons.





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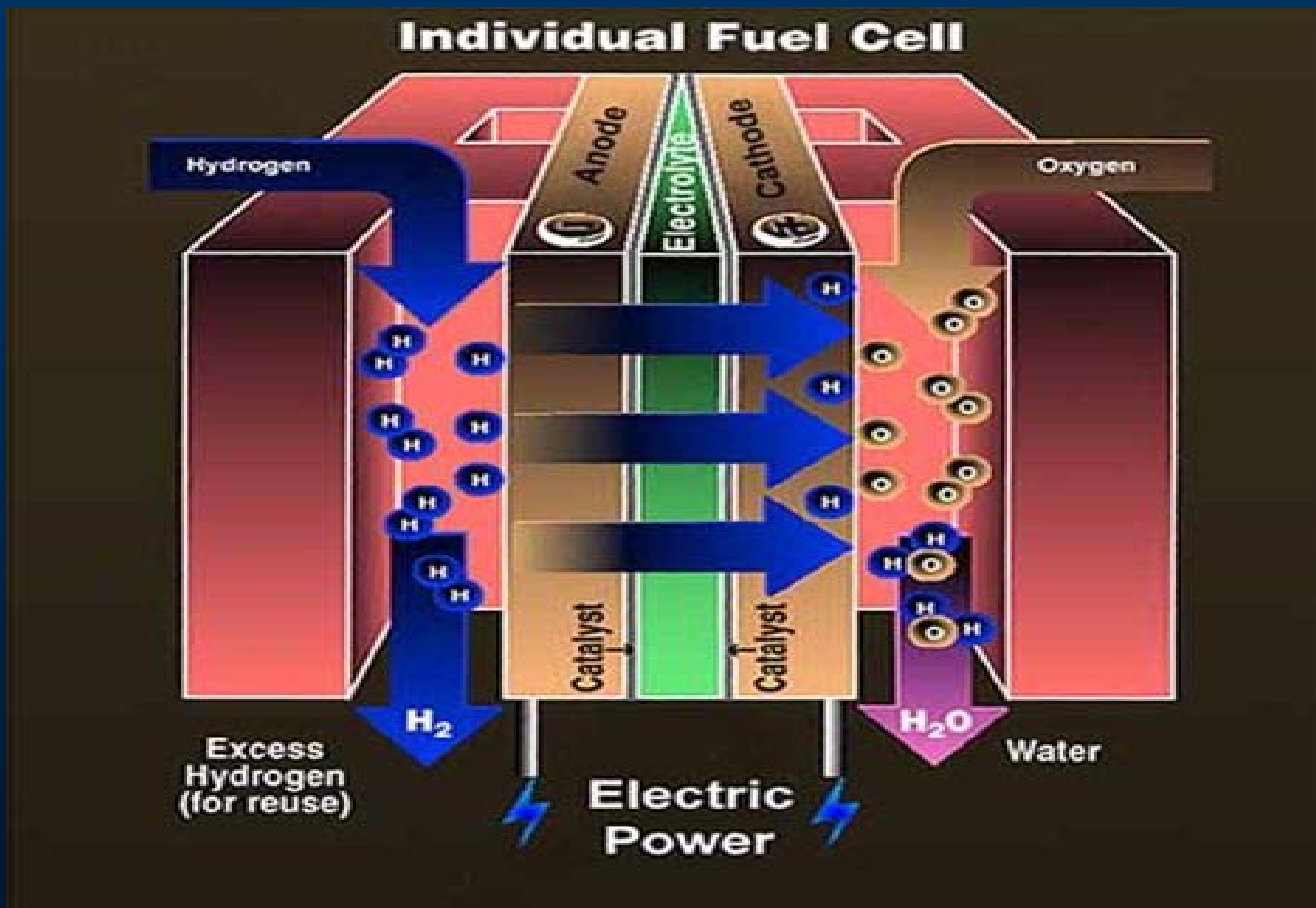
Fuel Cells works by converting chemical energy to electrical energy On Demand

Basic Mechanism of a Fuel Cell[1]



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1. http://www.mobile-weblog.com/50226711/images/fuel-cell-thumb.jpg

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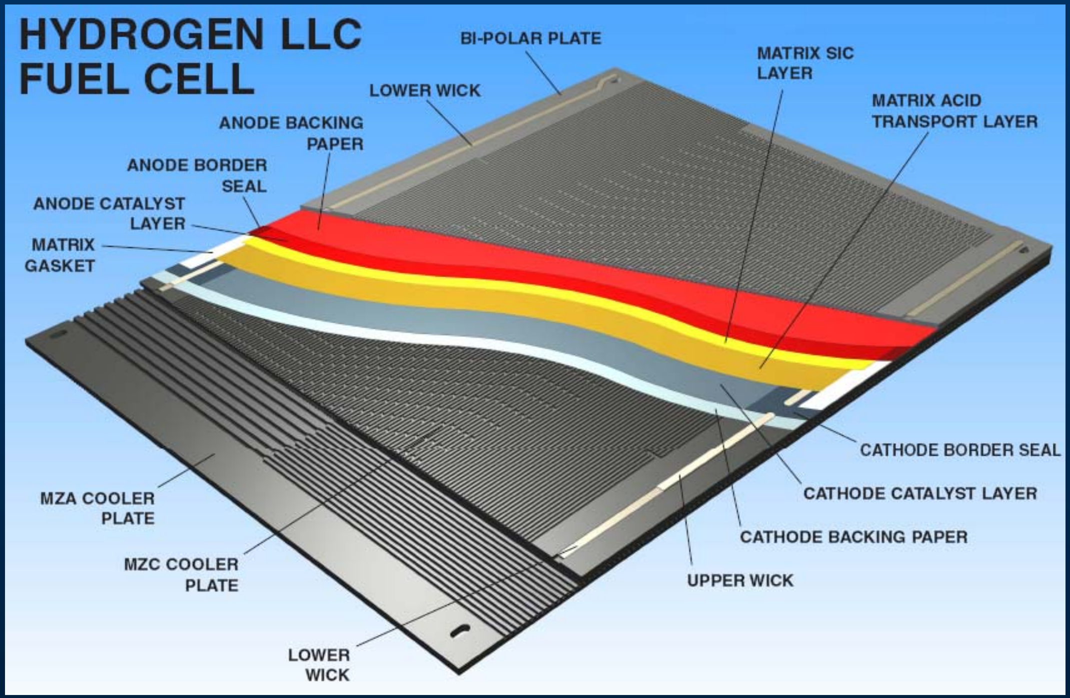
Convergence of multiple Technologies is essential

Key Drivers:

Chemical Recipes, assembly processes for designing and manufacturing PAFCs

Technology focused on innovations for system performance, stack/module lifetime and cost reduction



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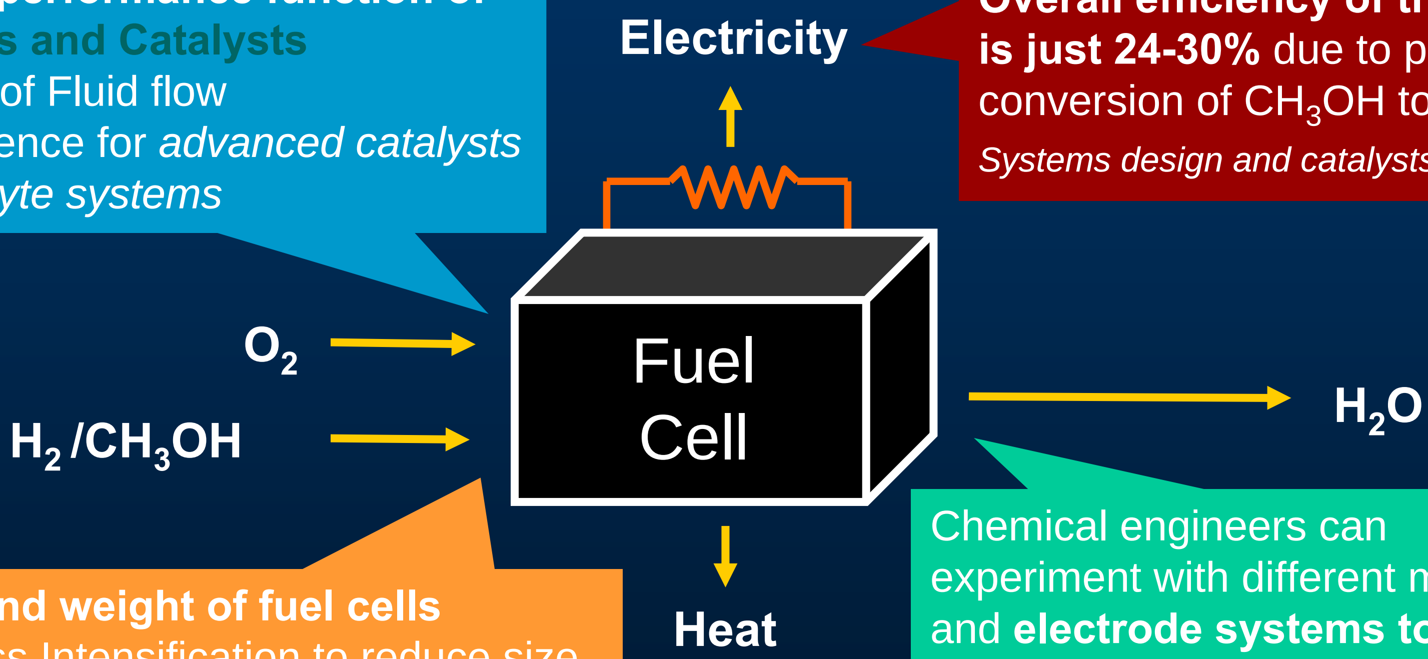
Fuel Cells have been around since the 19th century: *Could we take on the Challenge of commercialization ?*

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**

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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

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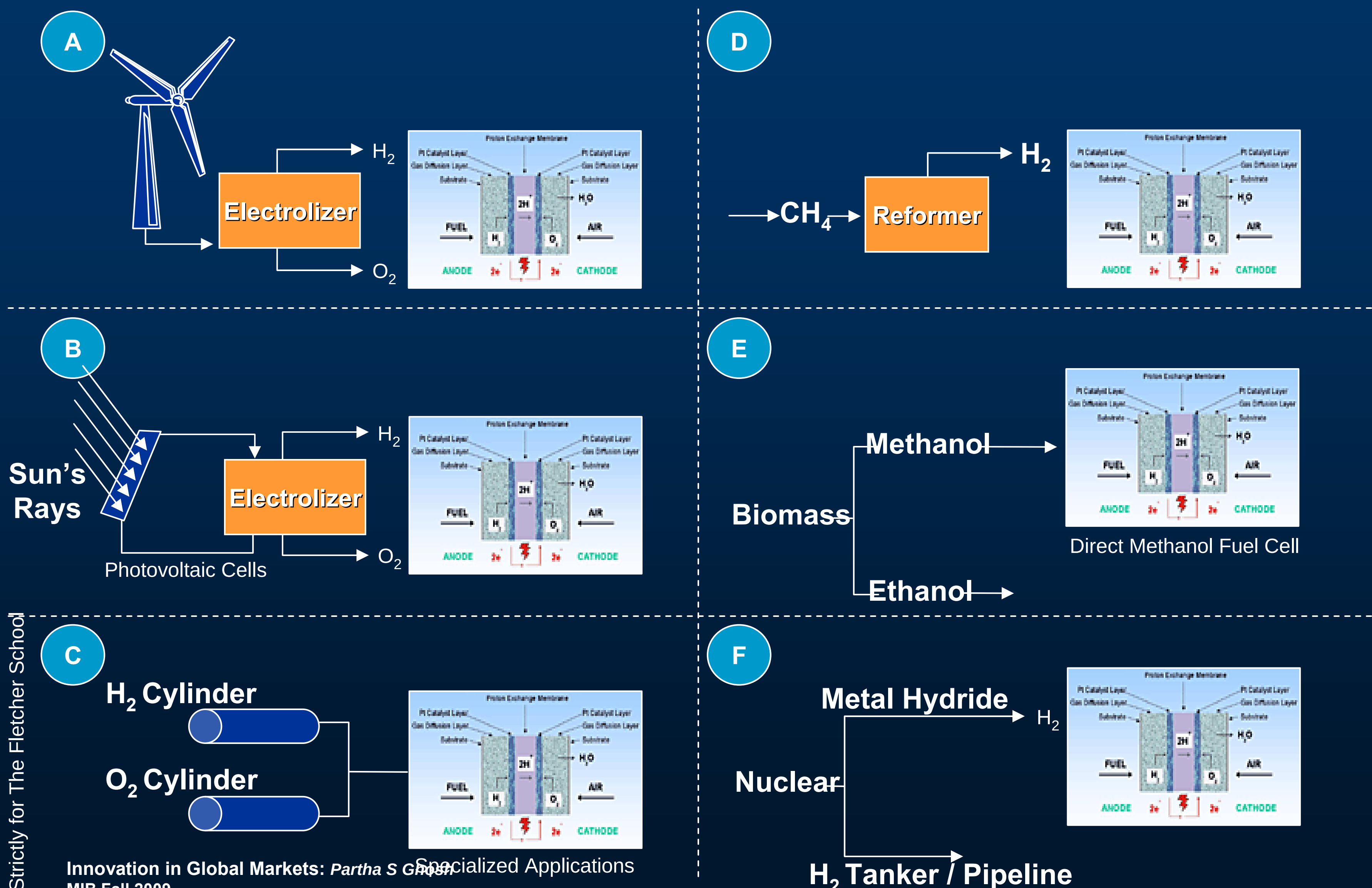
Not Either Or, it is all about Unification



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Innovative systems engineering capacity will be essential …….*at Macro level*

Value Proposition to Customers

Byproduct H2 from chemical plant

HydroGen PAFC

< Zero-emission power
< Byproduct heat, H2O
< Emission credits

Grid

Power

Cl_2 -- NaOH

Savings on energy costs and improved profitability

Low opportunity cost H2-rich gas stream offsets purchased power from grid, generates additional value streams:

- Heat
- Water

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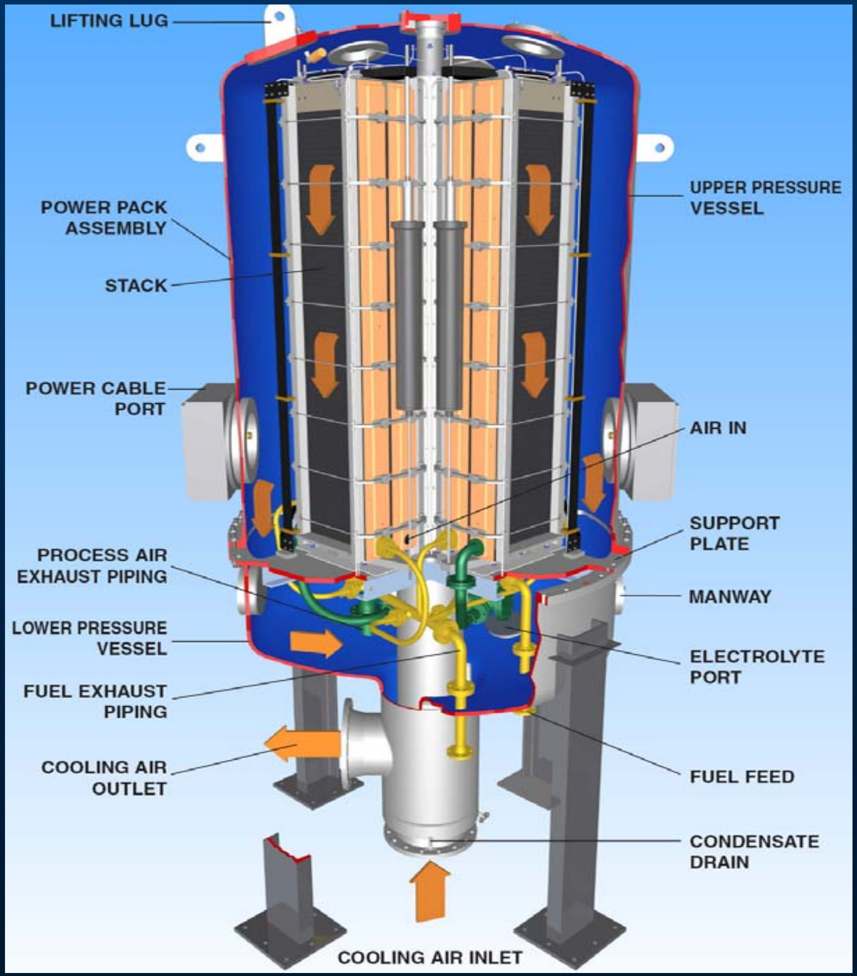
Innovative systems engineering capacity will be essential …….*at Micro level as well*

Fuel Cell Module



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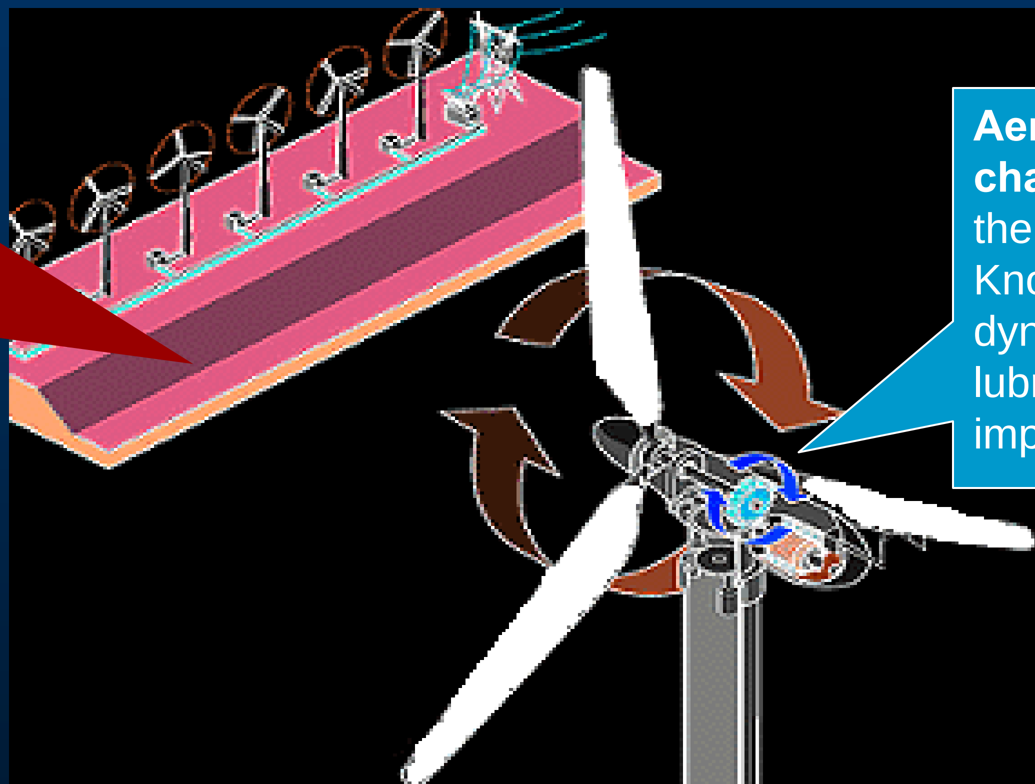
Reducing cost of production of electricity by wind turbines could be a significant challenge

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 Ellis
4. FPDC – Technical Brief, Wind Electricity Generation

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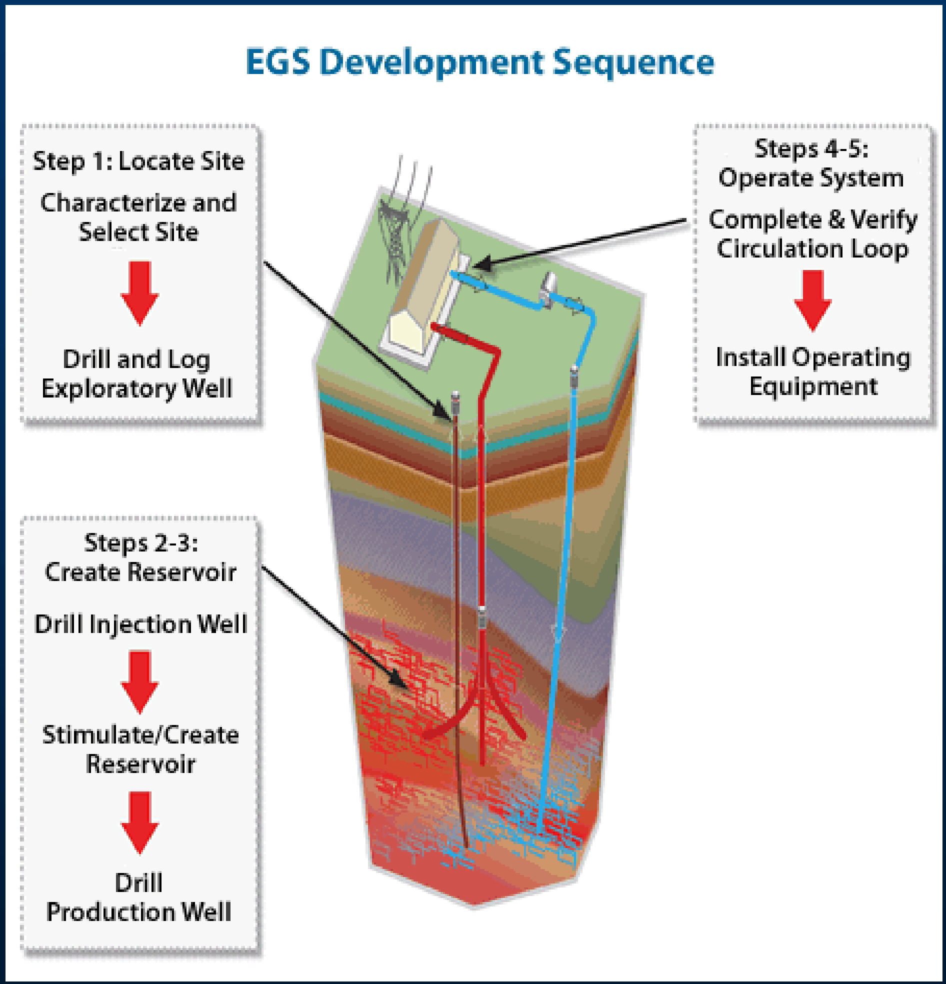
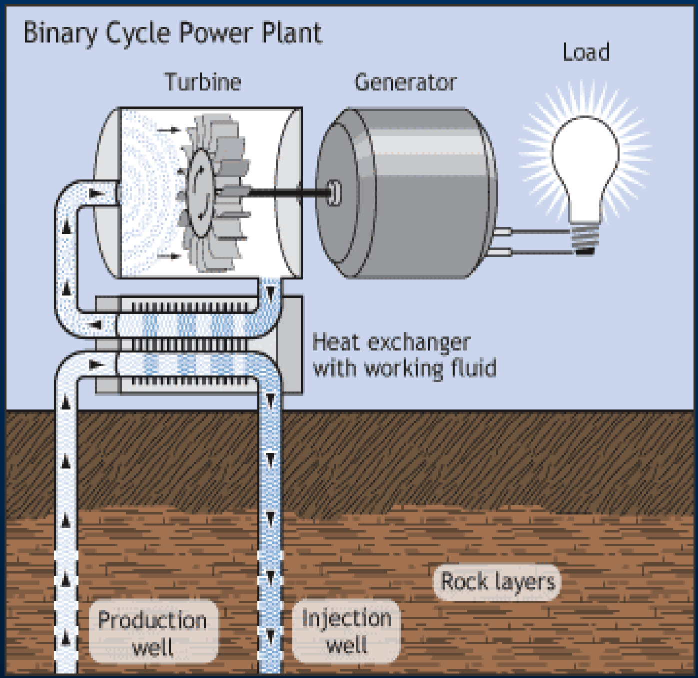
Enhanced Geothermal Systems (EGS)





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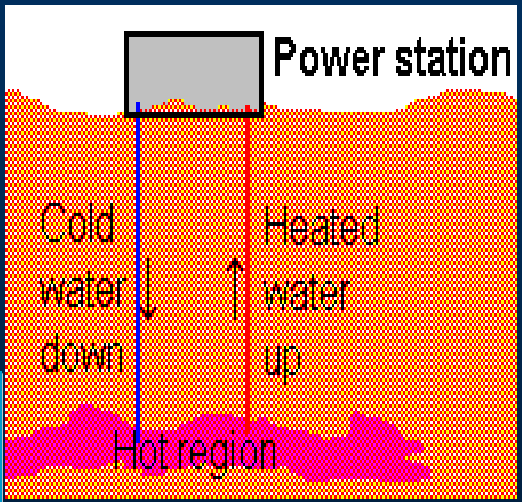
Heat Mining: Health & safety concerns due to materials ejecting from the Earth are issues that will need attention

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

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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

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Do you know the weight of Air in this class room?

≈200 KG

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Do you know how many horse power you have in the Air of your class room ?

16 Horse Power

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Technologies to Extract Internal Energy of Air Efficiently

Air as Solar Energy Storage Battery
Air Energy is available every where: *Day & Night, Rain & Shine or Hot & Cold* ***Reliable, Renewable & Clean Source***

A room of size 10'x20'x30': 170m3 of volume x 1.16KG/m3 of density = 200KG of weight

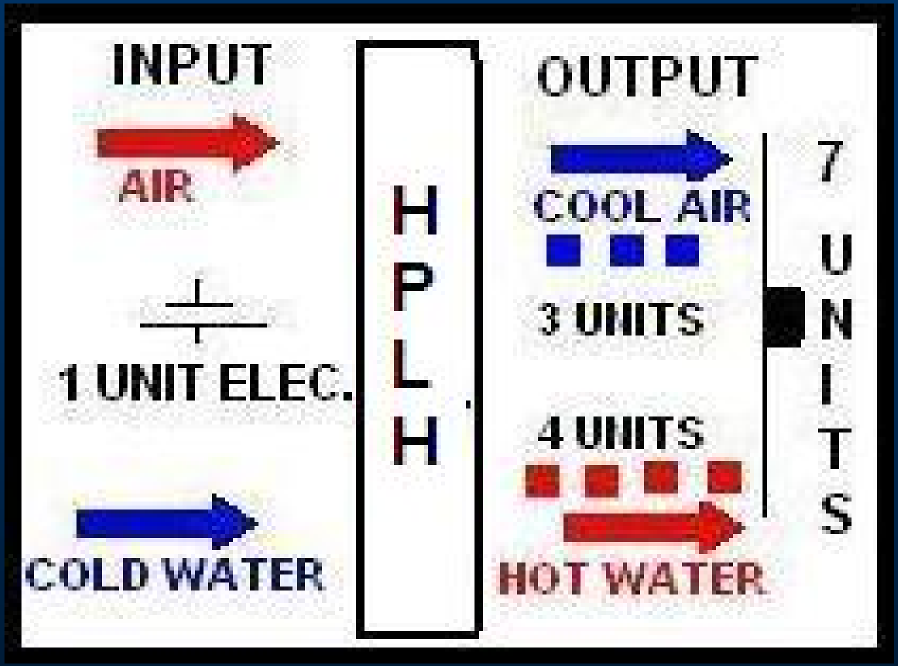
Energy Content in the Air

$\Delta Q = m.cv.\Delta T$

200Kg x 2.2 x 0.17 Btu/lbm °F x (86 °F-(-473 °F)) /(3412btu/kw)

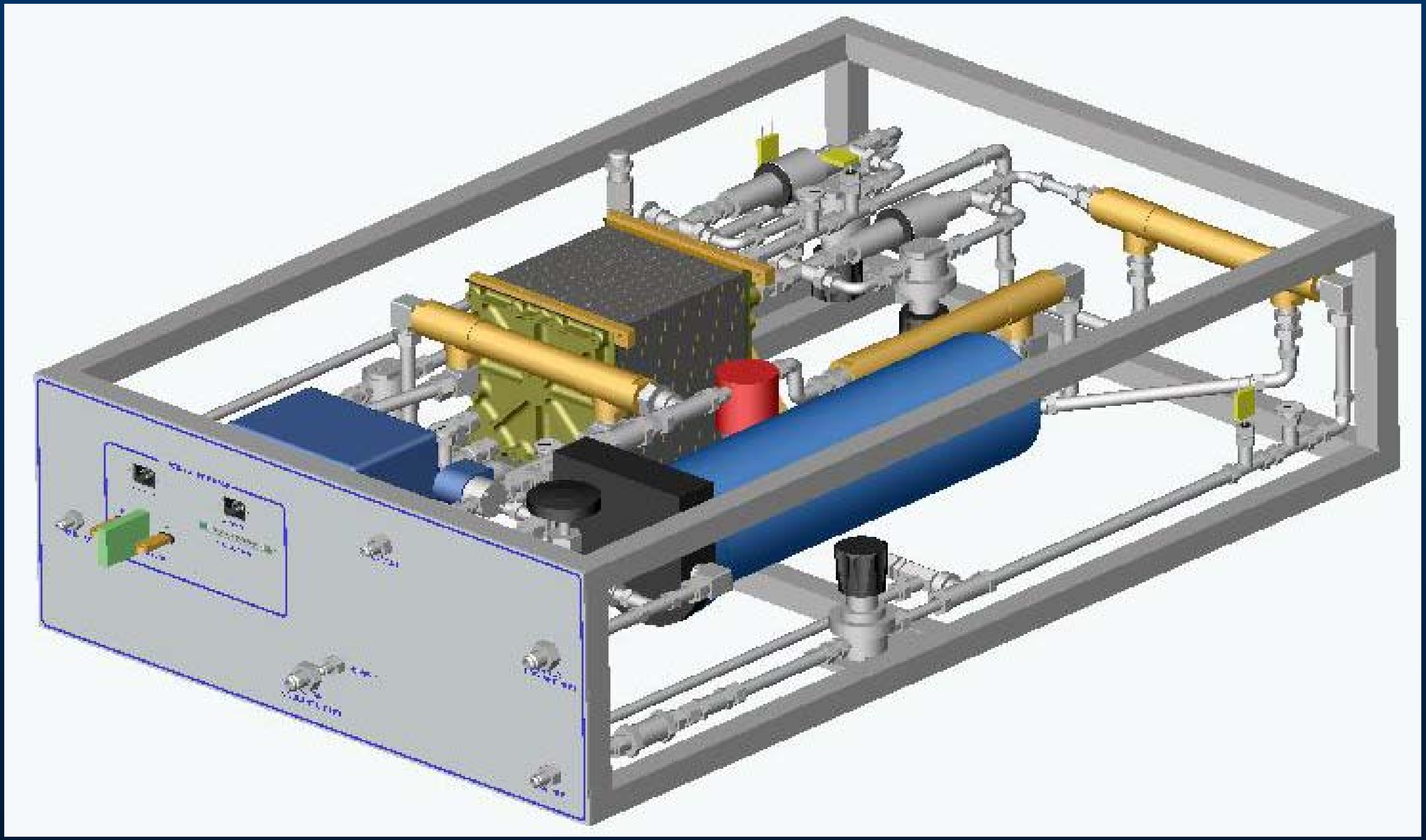
> 12KiloWatt >16 Horse Power

Heat Pump Liquid Heater



Heat Pump Liquid Heater

Engineering Systems Advanced Solid Modeling Capability



Engineering Tools Include Autocad, Solidworks, Thermal Analysis System, Fortran, C++

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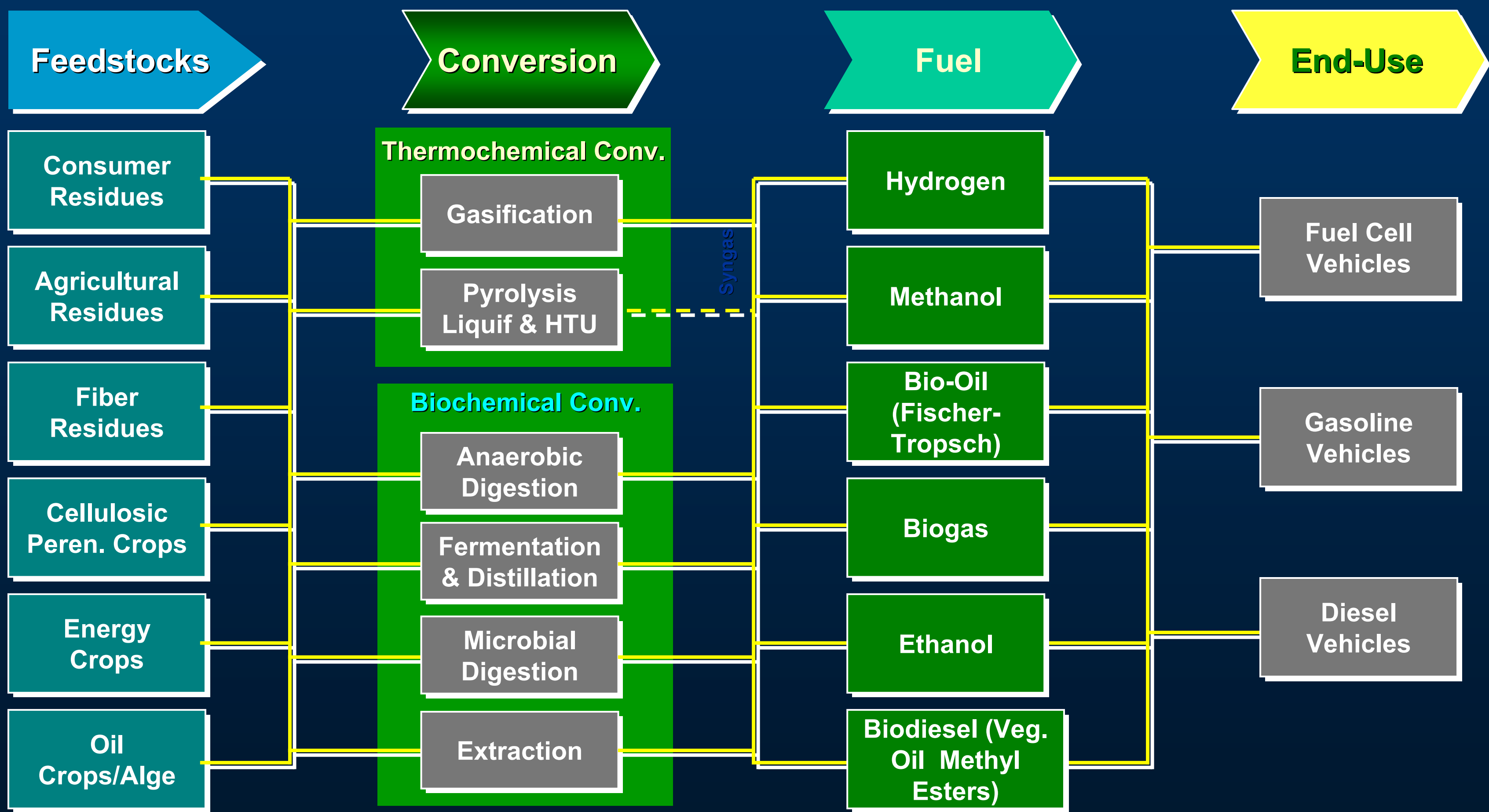
Biofuels Technologies are maturing



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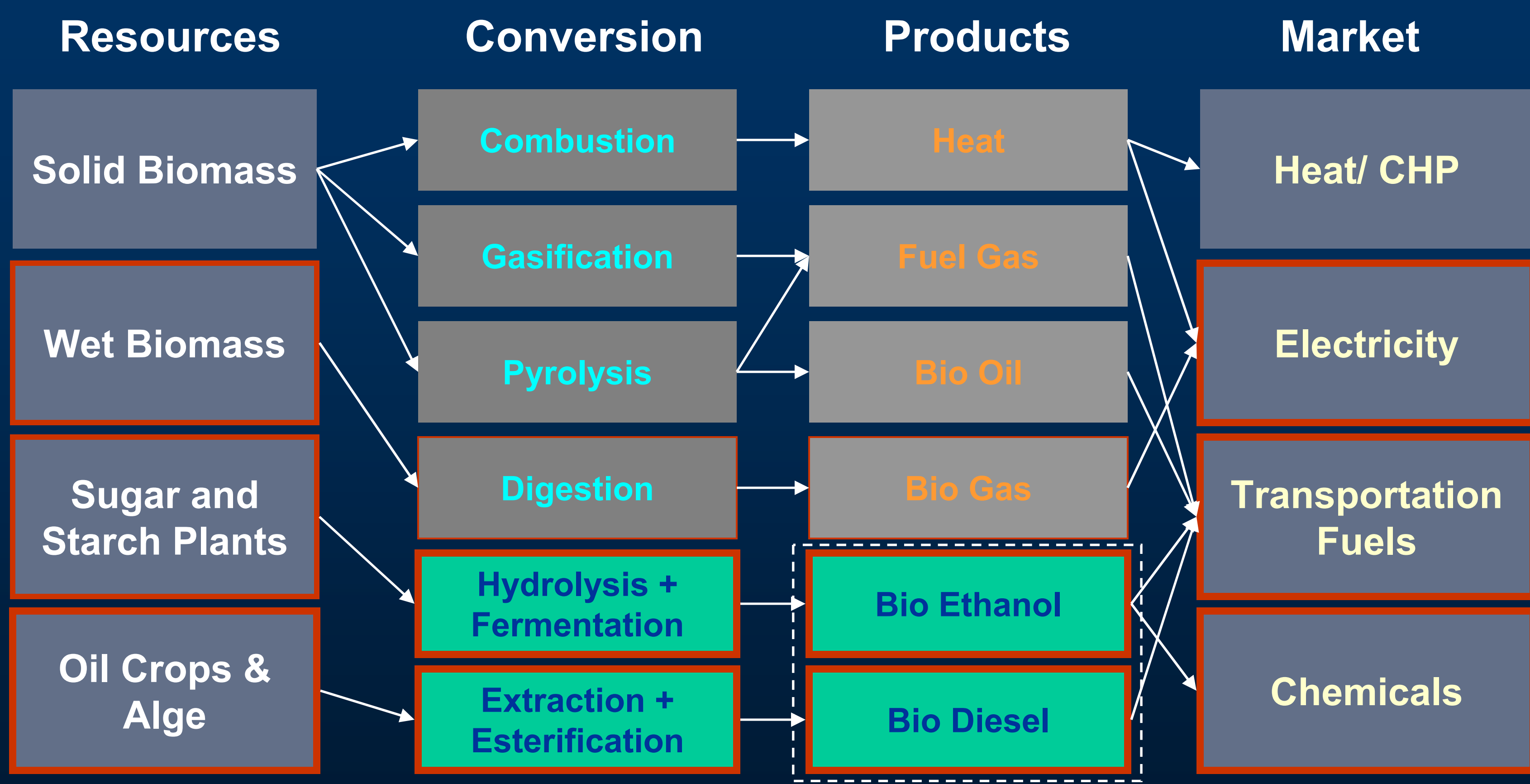
Bio Fuels landscape is complex



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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)

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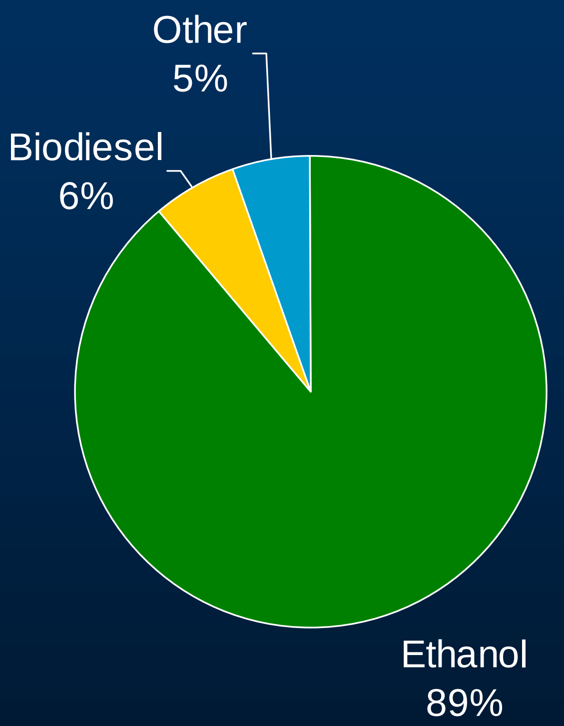
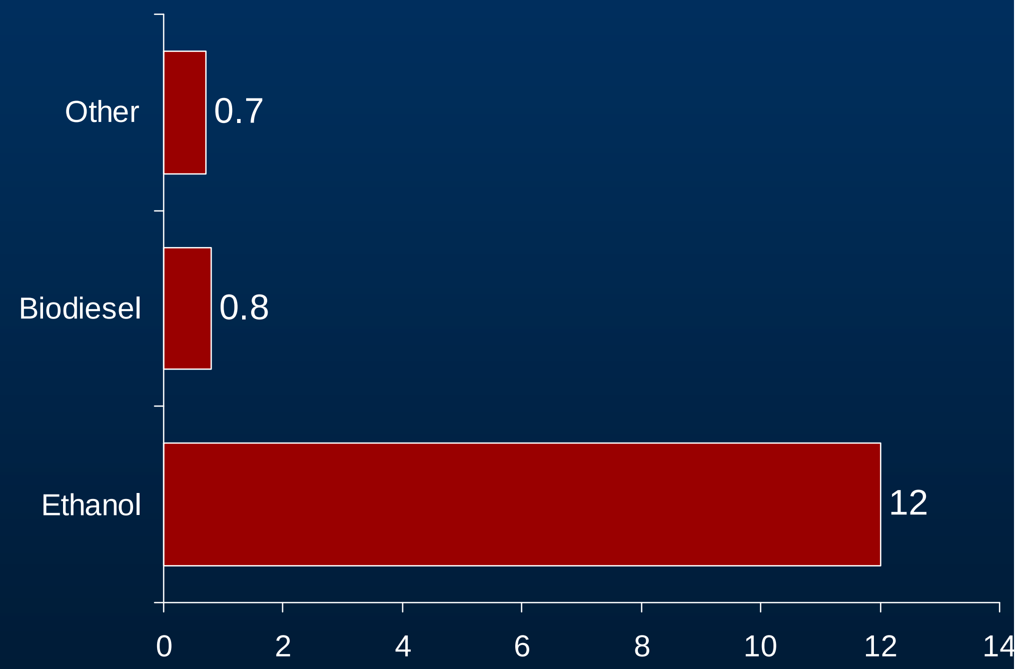
Global Biofuels market in 2005 was approximately 13.5B gallons, with the majority of that coming from ethanol

World Biofuels Market



100% = 14 Billion Gallons/Year (BGY)

World Biofuels Market (BGY)



Total=14 BGY

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(1) Source: Think Equity Partners LLC, Industry Report

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US Energy Potential in 2030

Total = 93.58 Quadrillion BTU

Geothermal – 1.5%

States – UT, ID, MT, and WY

Partners – China, Sweden, Turkey, and Iceland

Biomass – 8.1%

States – ND, MN, IA, and IL

Partners – India, Brazil, and China

Wave – 7.0%

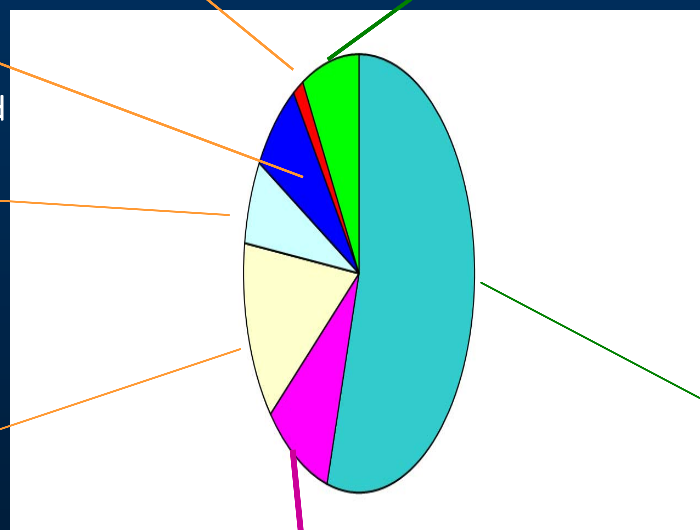
States – HI and West Coast

Partners – Argentina, Australia, and

Wind – 6.2%

States – Texas and the Midwest

Partners –China, Argentina, and UK



Fossil 54.5%

Solar – 13.3%

States – AZ and NM

Partners – Brazil, China, Australia, and Middle East

Nuclear – 9.4%

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Sources:

See notes

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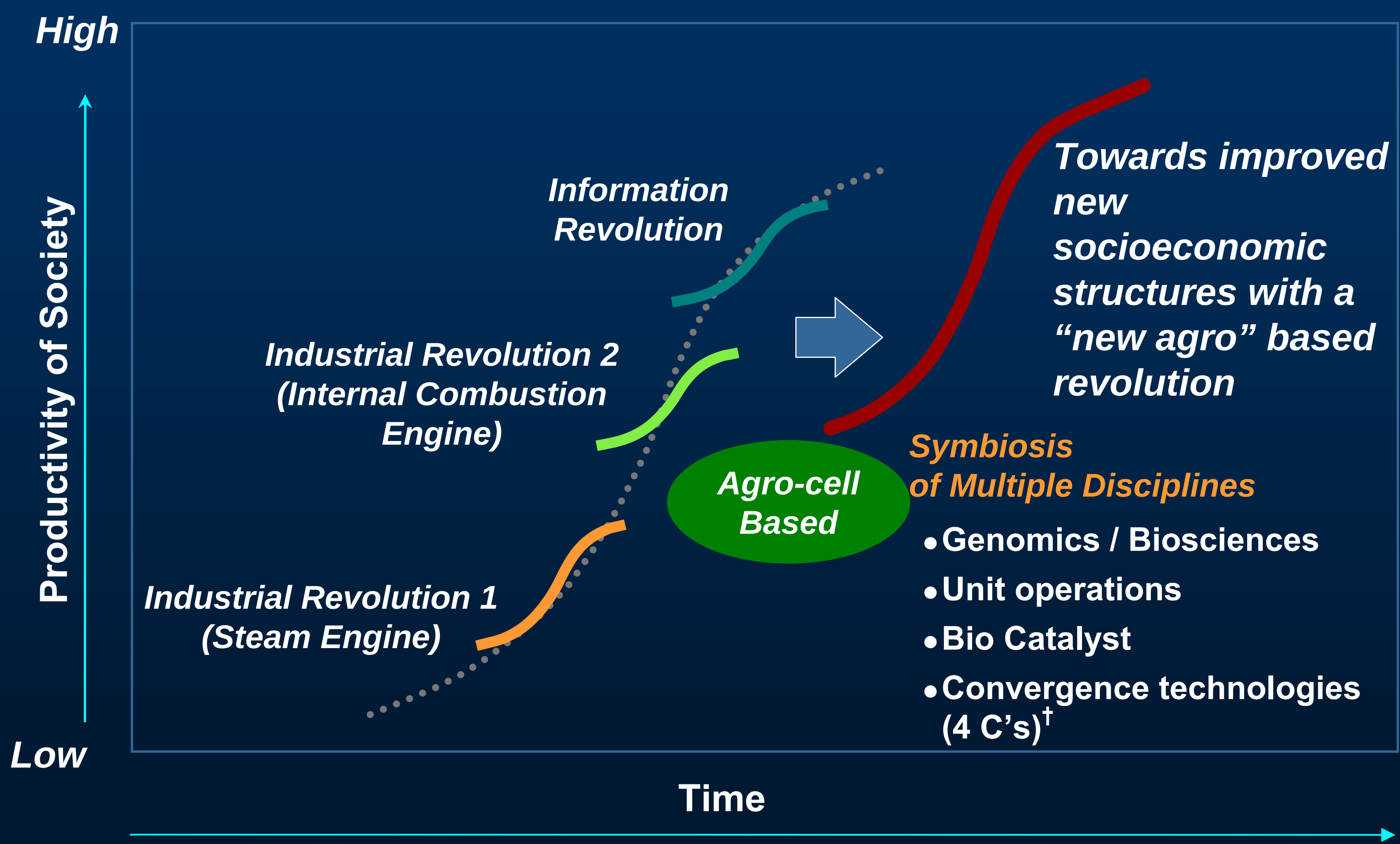
Towards an Agro cell based Economic Revolution?

Development of a More Sustainable Economic Model



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For Example: *An Agro Complex*?

Resource	Industry	Critical Issues
Cereal Crops, Fruits, Tea, Vegetables, Aqua Products	Food and Beverage	• Increase in yield (kg / hectare) • Quality and consistency? • Distribution system? • Down stream value addition and branding?
Cotton, Silk, Jute	Fiber, Fabric and Fashion	• Cost Effectiveness? • Quality consistency? • Familiarity with fashion trends? • New application on development?
Bio-mass, Wind Farming, Seed Oils, Starches	Energy	• Knowledge sharing • Low cost equipment development? • Promotional activities?

Specialty Chemical Industry

Resource	Industry	Critical Issues
Herbs, Medical Plants, Algae / Azola	Pharmaceuticals and Ayurvedics	• Awareness building? • Involvement of university professionals? • Incentives for corporate sector? • Venture funds "bottom up" development?
Algae / Azola, Vegetable Oil, Flowers	Perfume Personal Care	

Resource	Industry	Critical Issues

Chemical Industry

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

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Demand side?

≈ Innovating User Space

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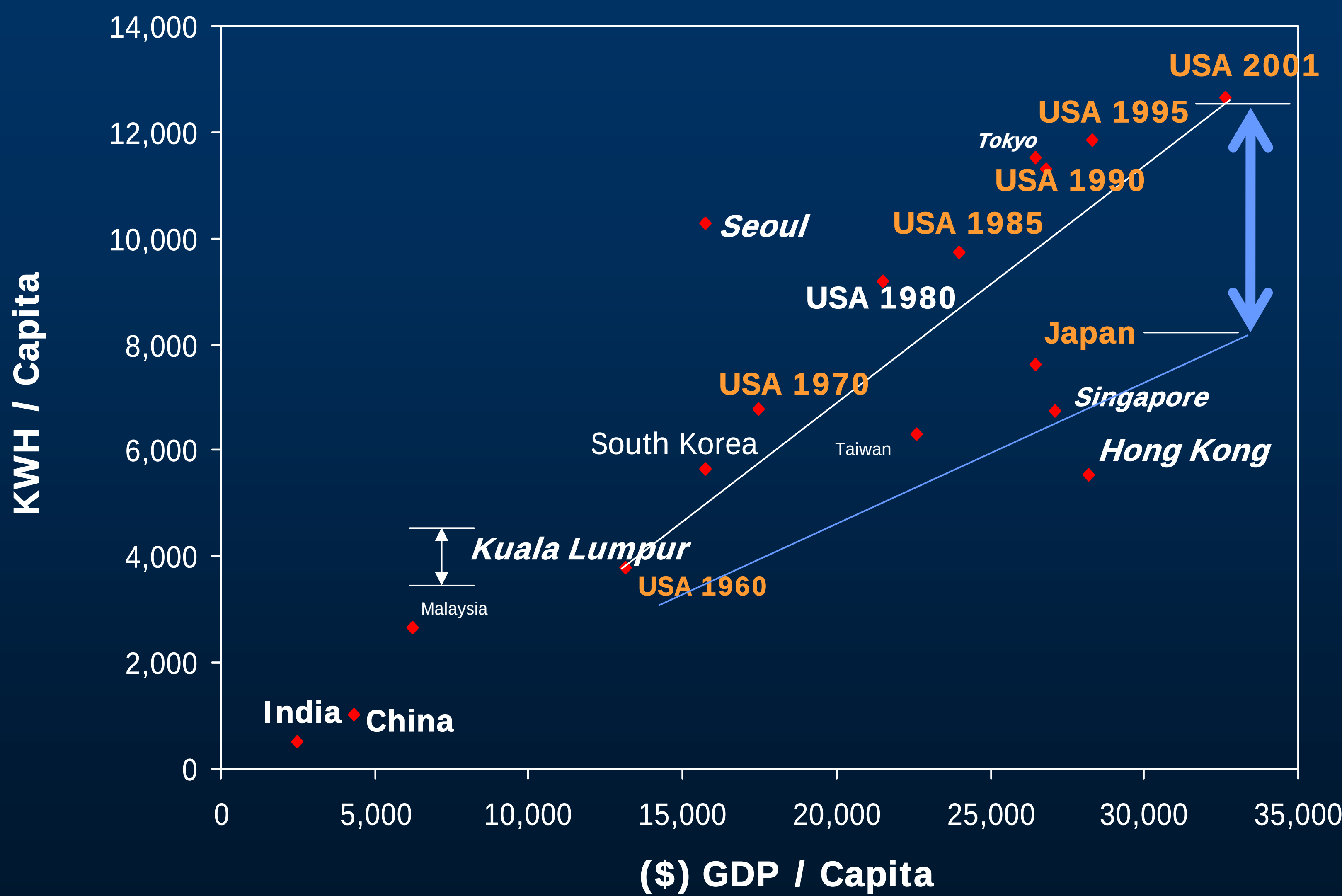
Demand side Challenge :*Shaping social and use behavior?*



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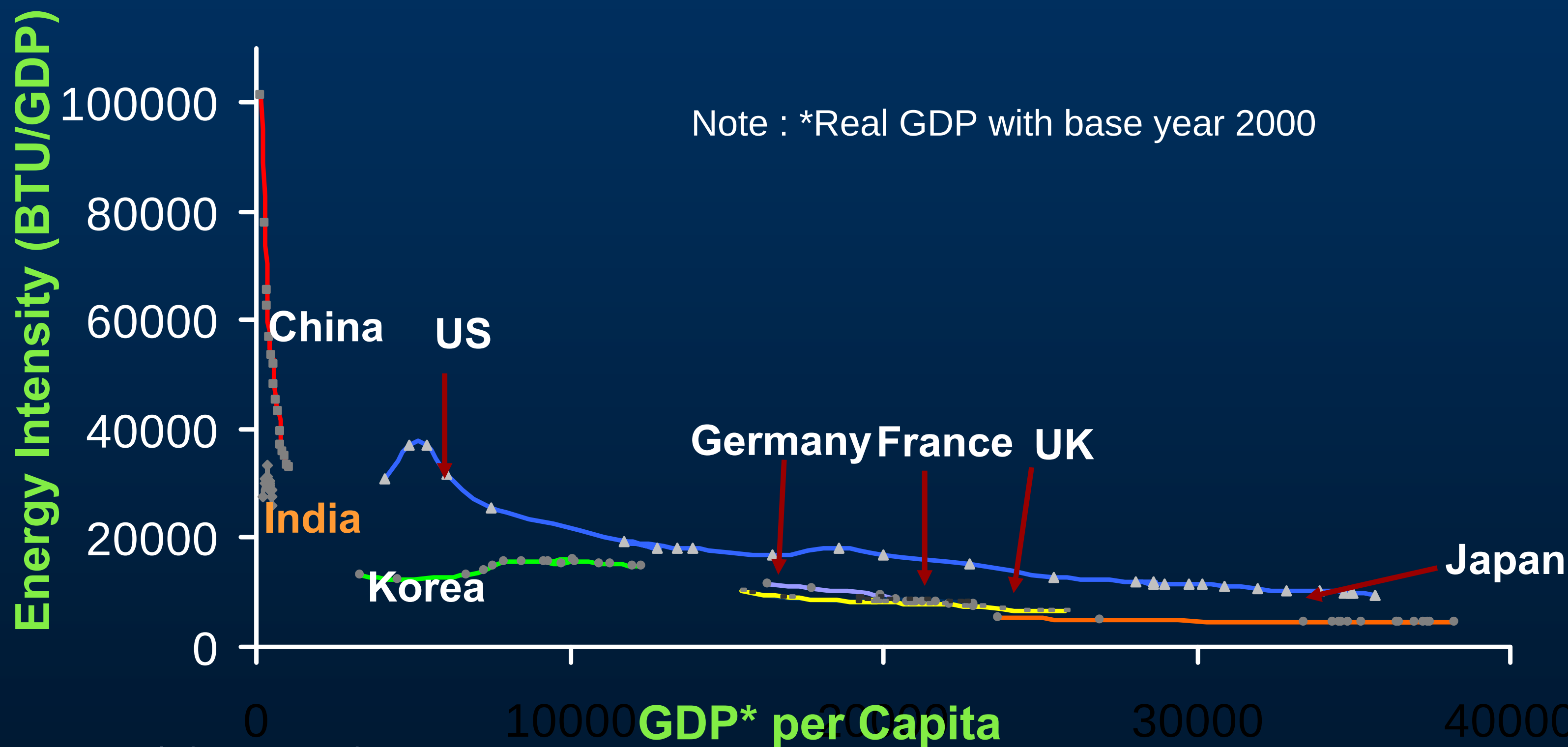
Energy intensity has been declining with economic advancement

Energy Intensity vs. GDP per Capita of Selected countries (1980 to 2003)[1,2,3,4]



Boston Analytics Research

1. Energy Information Administration (http://www.eia.doe.gov)
2. http://www.census.gov/popest/archives/1990s/popclockest.txt
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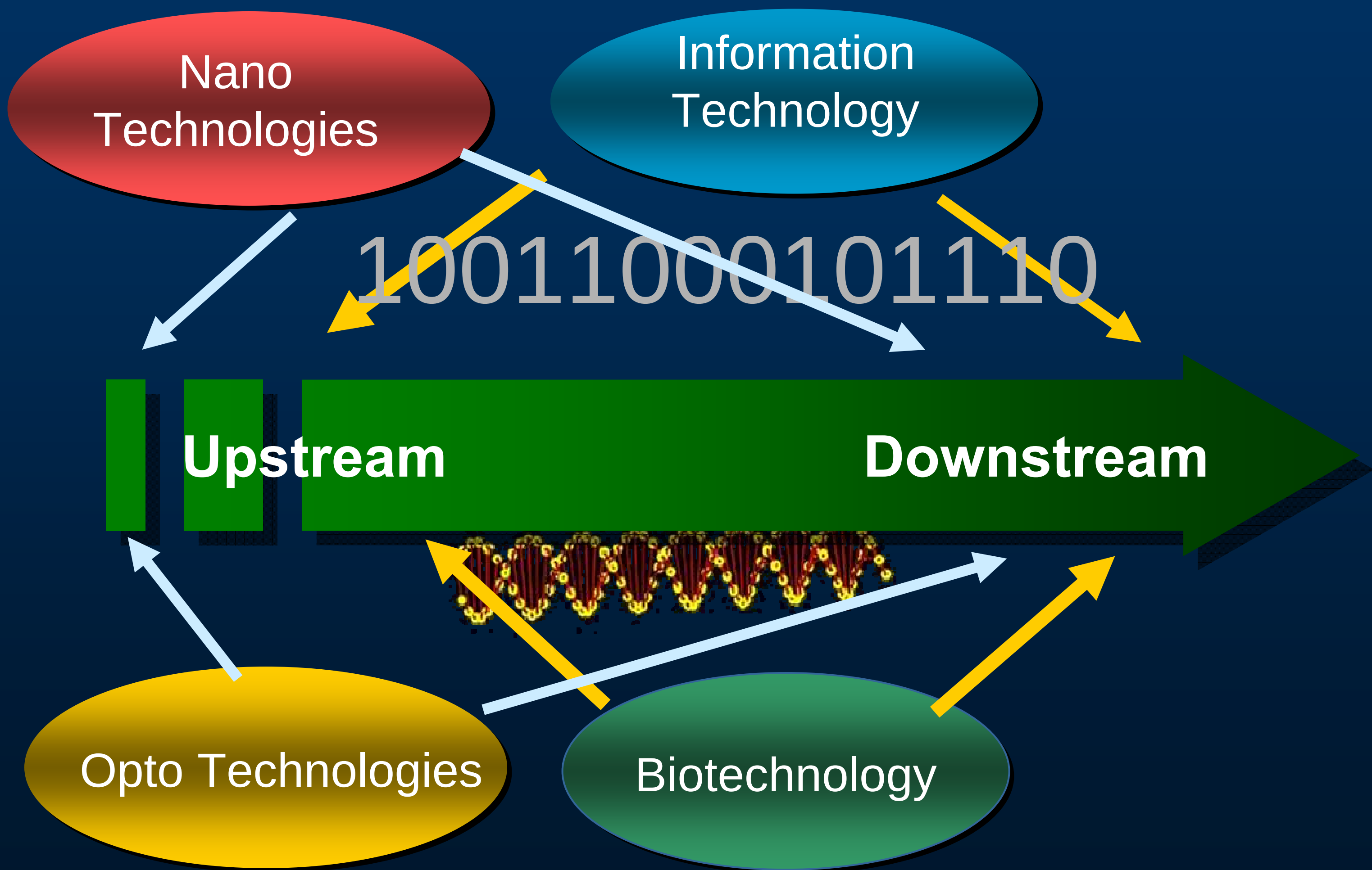
Aggressive use of New technologies

Energy Industry Reconfiguration



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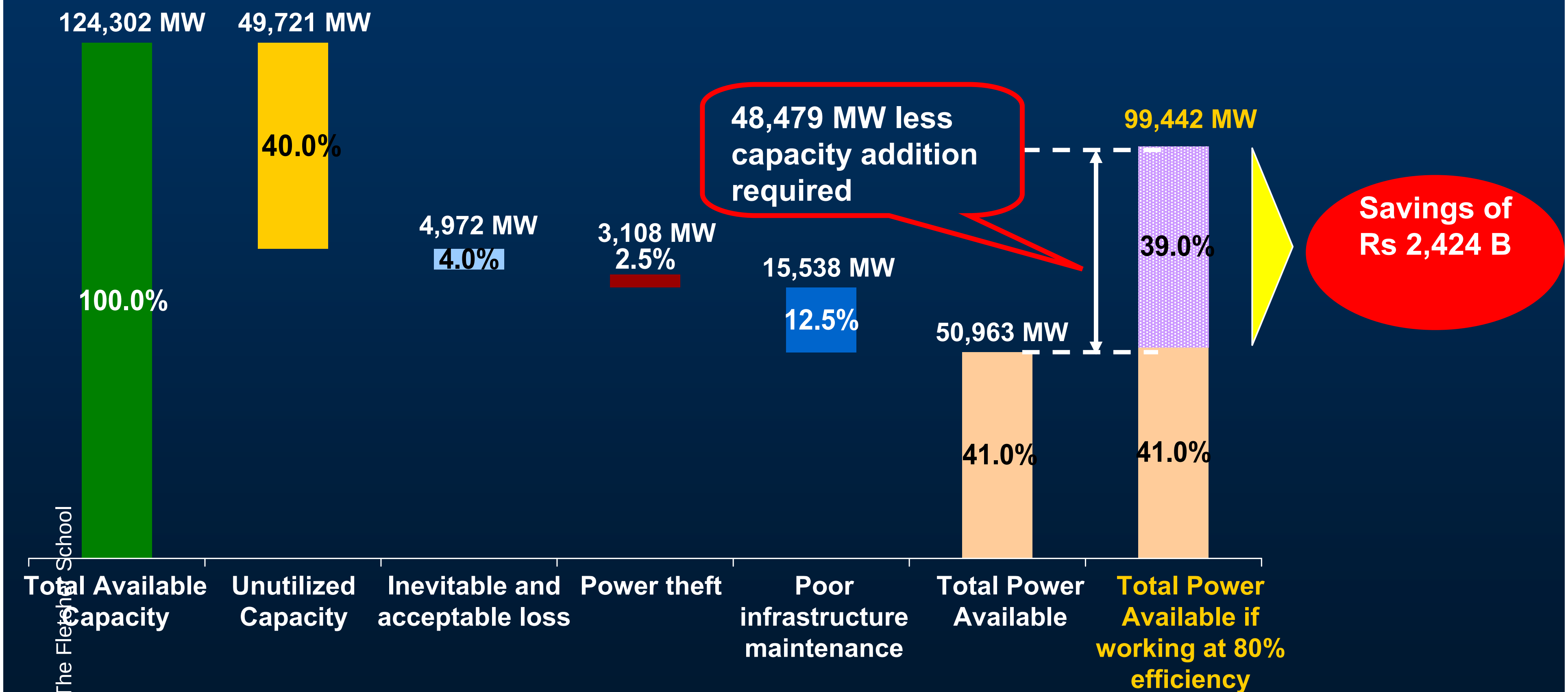
To unlock inefficiencies in existing infrastructure For example India can save almost $50 Billion

Utilization of Power in India in MW (2006)[1]



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1. "Power", Motilal Oswal, 2005
2. "6 police stations to track power theft in Maharashtra", (http://www.thehindubusinessline.com)
3. "A State of concern", (http://www.thehindubusinessline.com)

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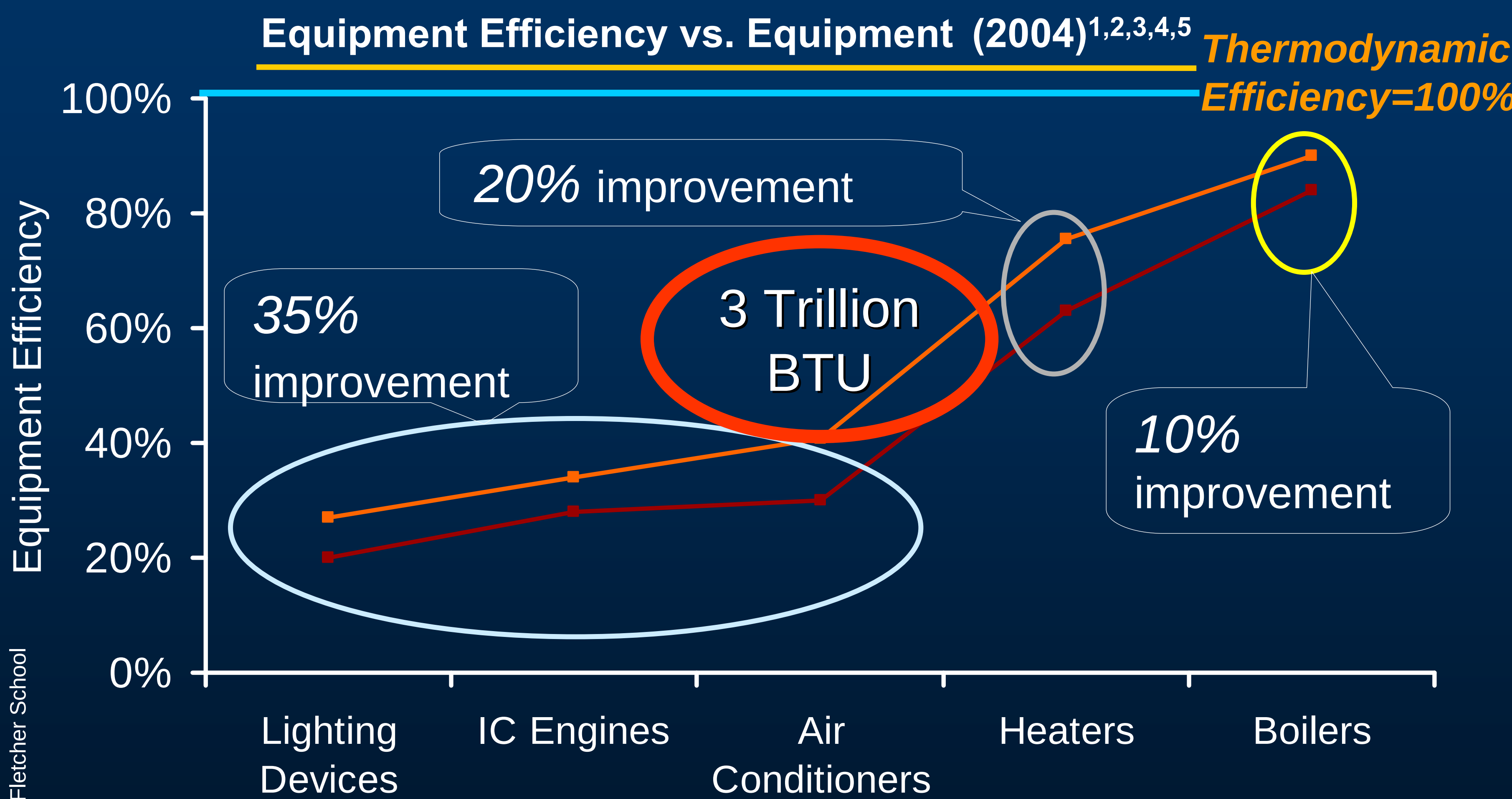
On the demand side significant efficiency opportunities need to be addressed



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1. http://www.cleaver-brooks.com/Service15.html
2. www.cader.org/2005Conference/DavidBerokoff.pdf
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5. www.ashrae.org/template/AssetDetail?assetid=32274

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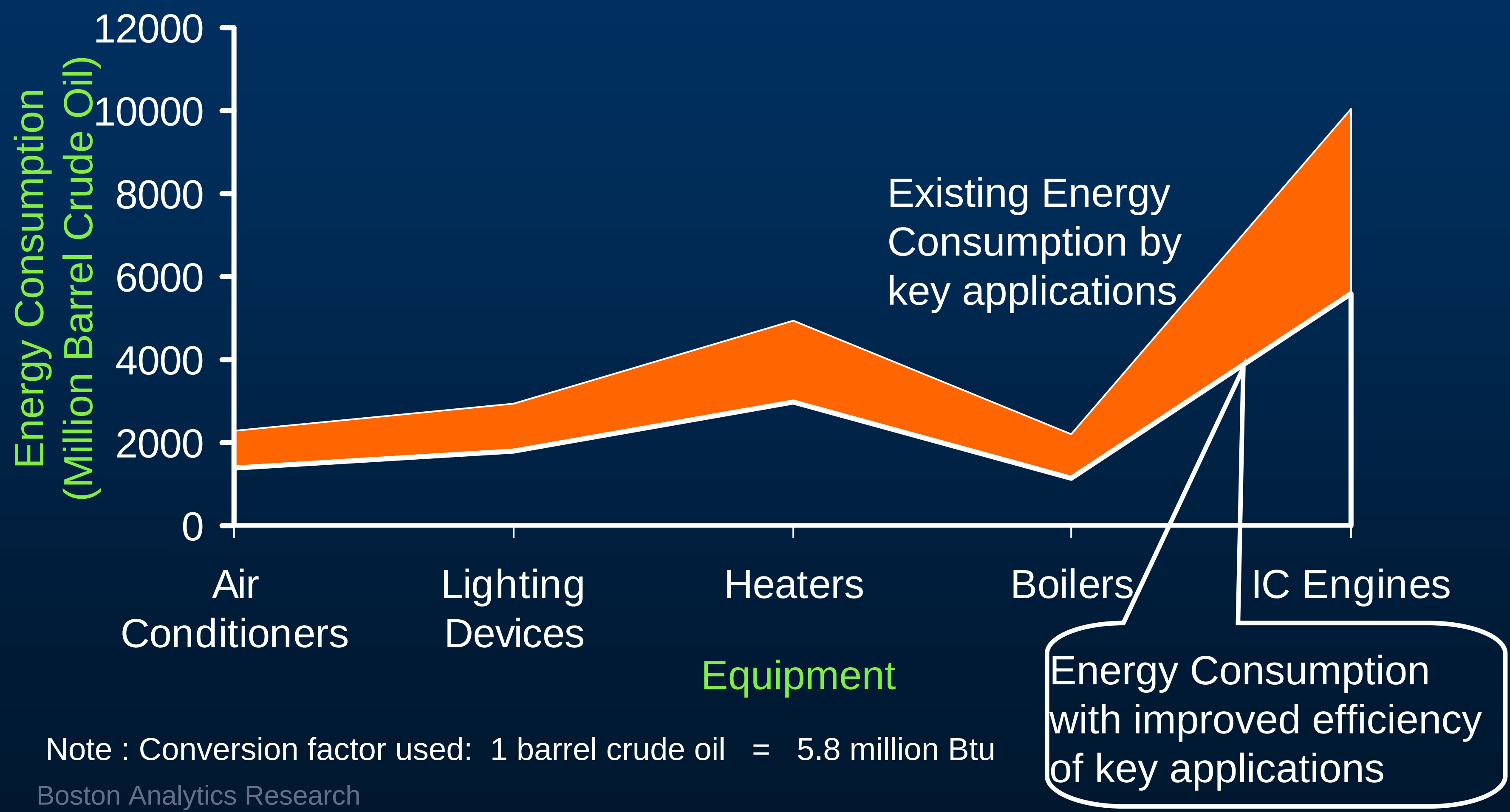
The proposed increase in efficiency could have saved ~*3.4 B barrel crude oil of energy in 2004*…

Energy Consumption vs. Equipment (Million Barrel Crude Oil) (2004)[1,2]



Note : Conversion factor used: 1 barrel crude oil = 5.8 million Btu

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

2. http://en.wikipedia.org/wiki/Energy_conservation

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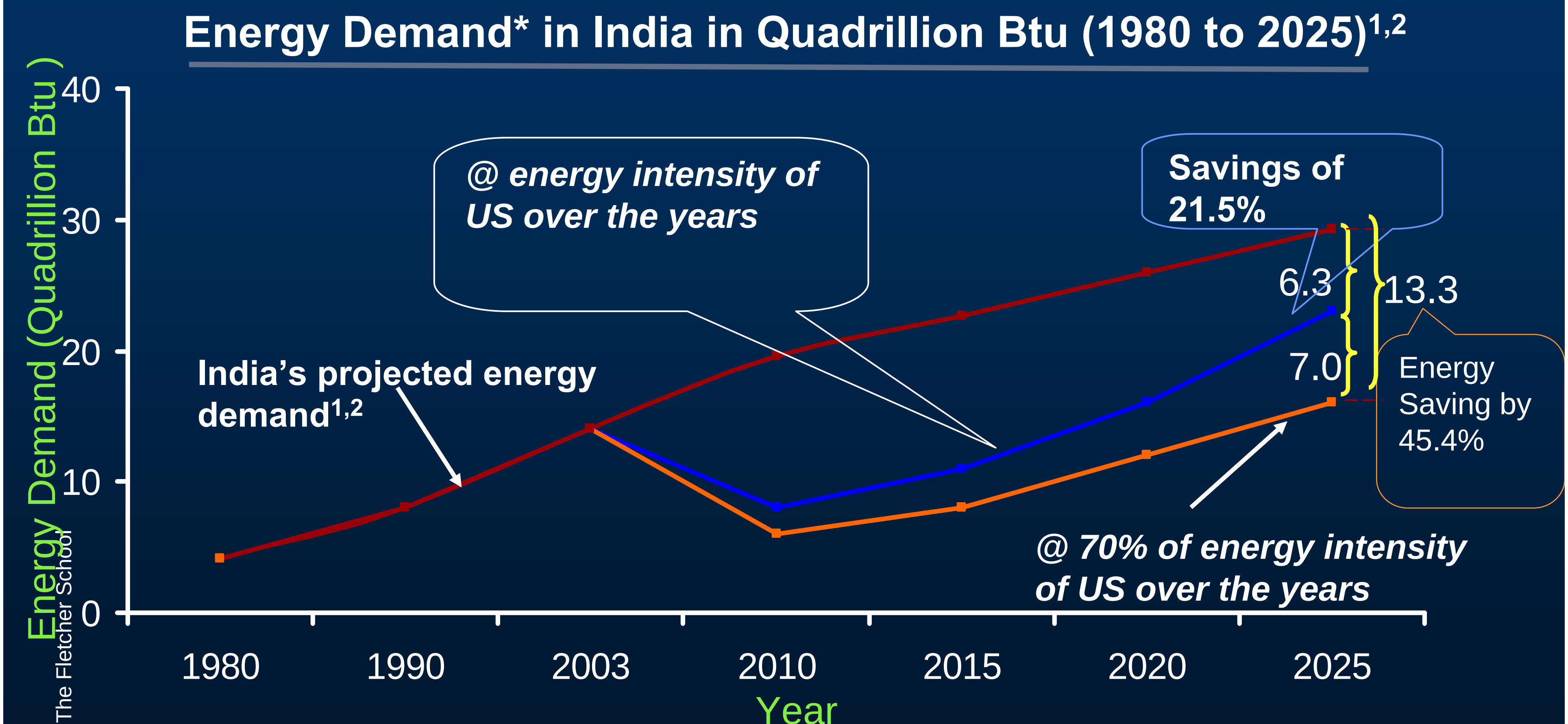
India could reduce its energy consumption by as much as 45.4% in the year 2025 = 13.3 QB Btu



Note : Energy Demand* = (Population)*(Energy Intensity)*(GDP per Capita)

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

2. "World Energy and Economic Outlook", Energy Information Administration/ International Energy Outlook 2005

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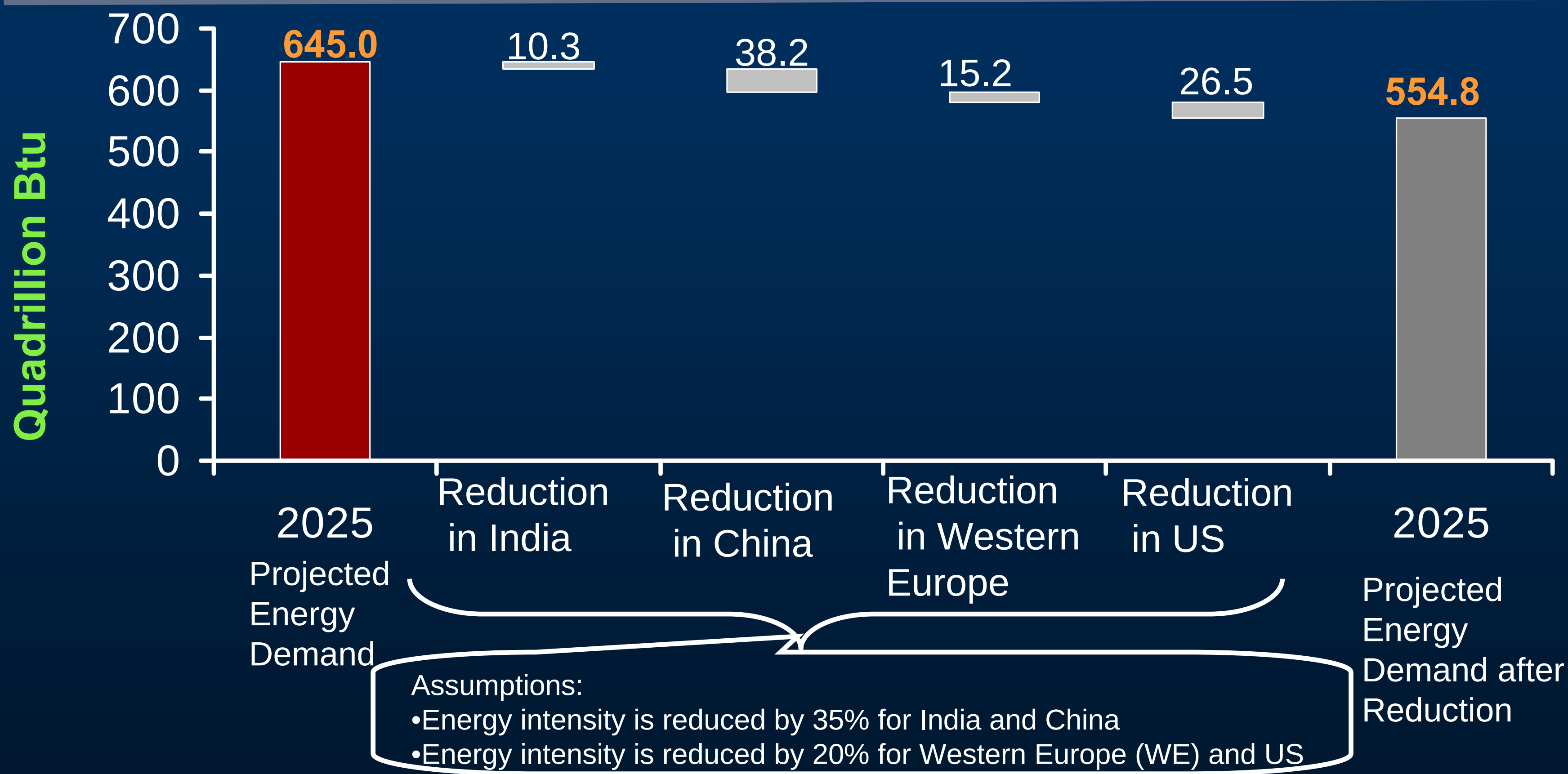
Reduction in energy intensity could reduce world energy demand by 14% in 2025

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



1. Energy Information Administration (http://www.eia.doe.gov)
2. "World Energy and Economic Outlook", Energy Information Administration/ International Energy Outlook 2005

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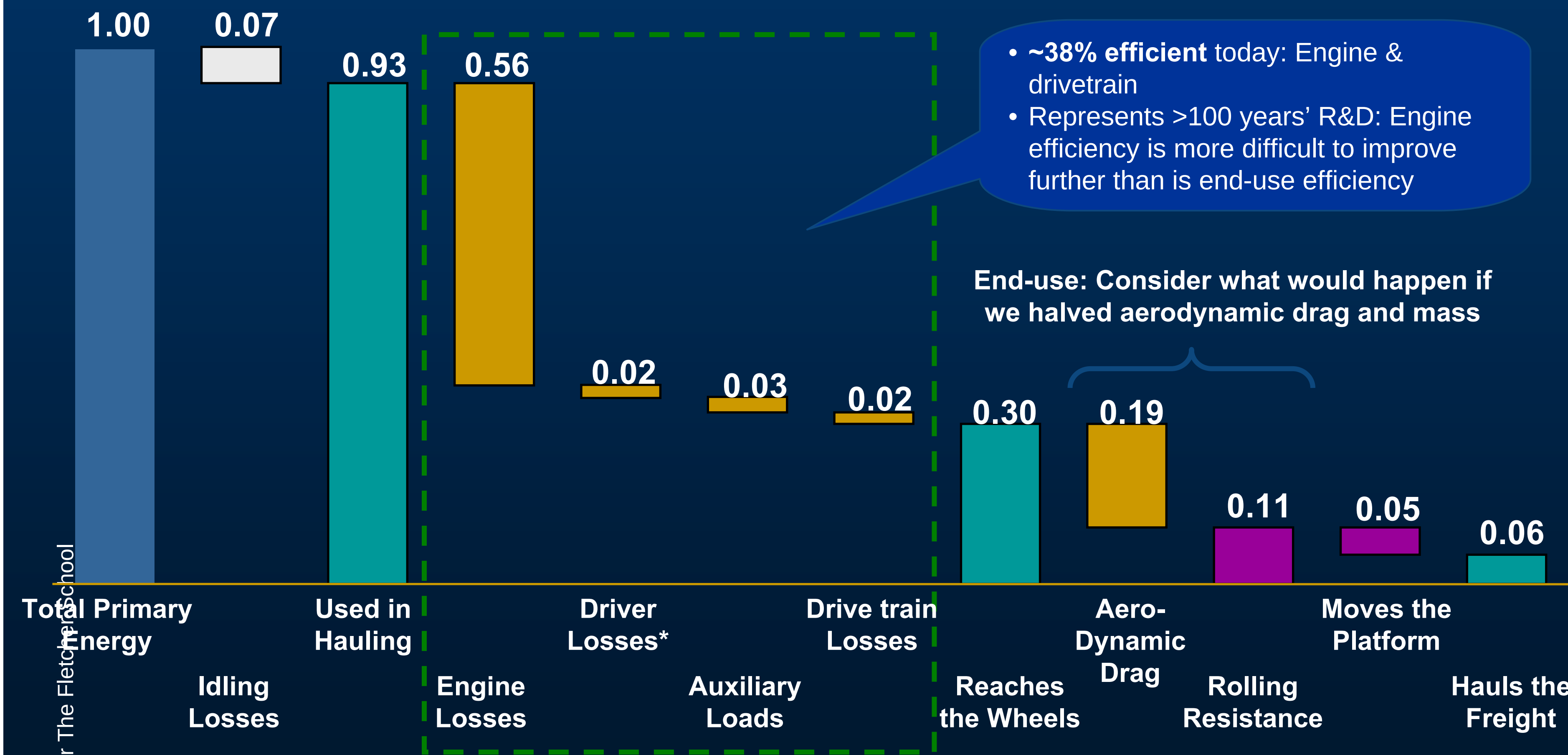
Where a long-haul Class 8 truck's diesel fuel goes ?

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



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

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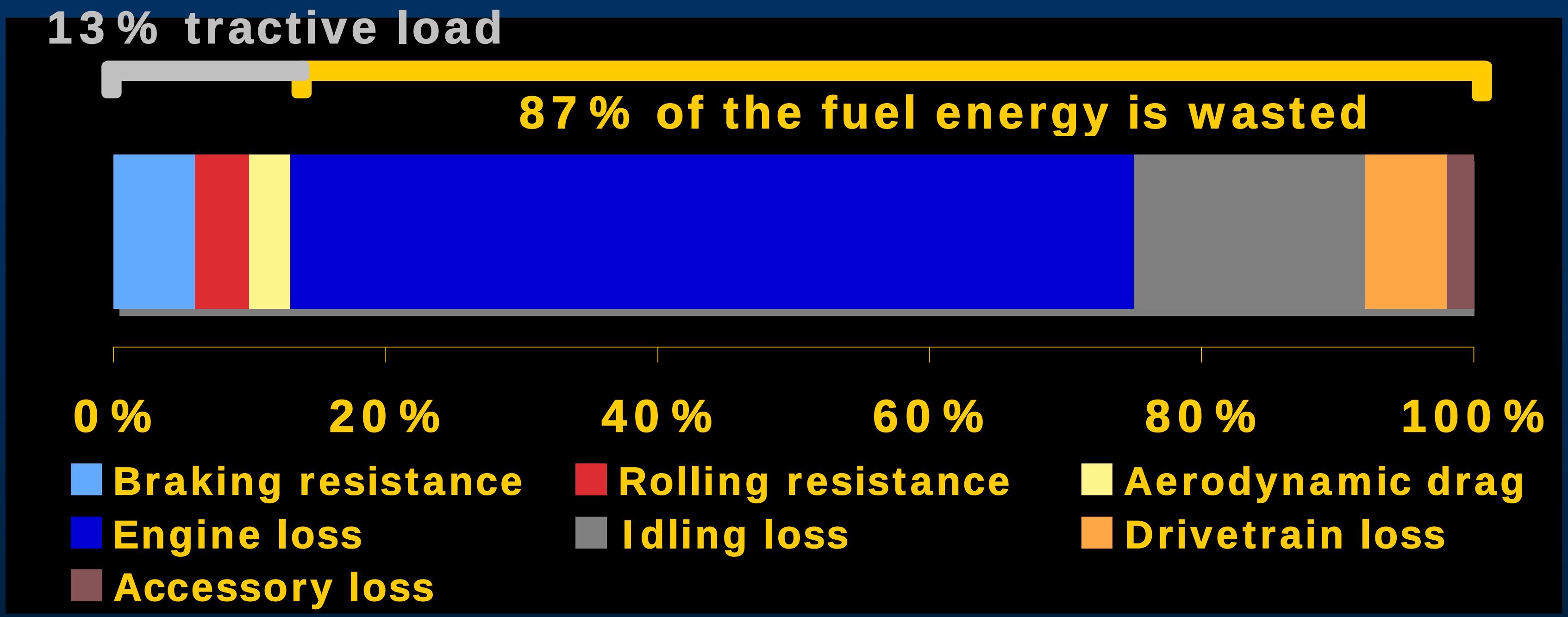
Where does a car's gasoline go?



- 6% accelerates the car, <1% moves the driver
- 2/3 to 3/4 of the fuel use is weight-related
- Each unit of energy saved at the wheels saves ~7–8 units of gasoline in the tank (or ~3–4 with a hybrid)
- **So first make the car much lighter!**

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Integrating low mass & drag with advanced propulsion saves ~2/3 of demand very cheaply

CARS: save 69%

TWO-WHEELERS: save 20%

TRUCKS: save 65%

Technology is improving faster for efficient end-use than for energy supply

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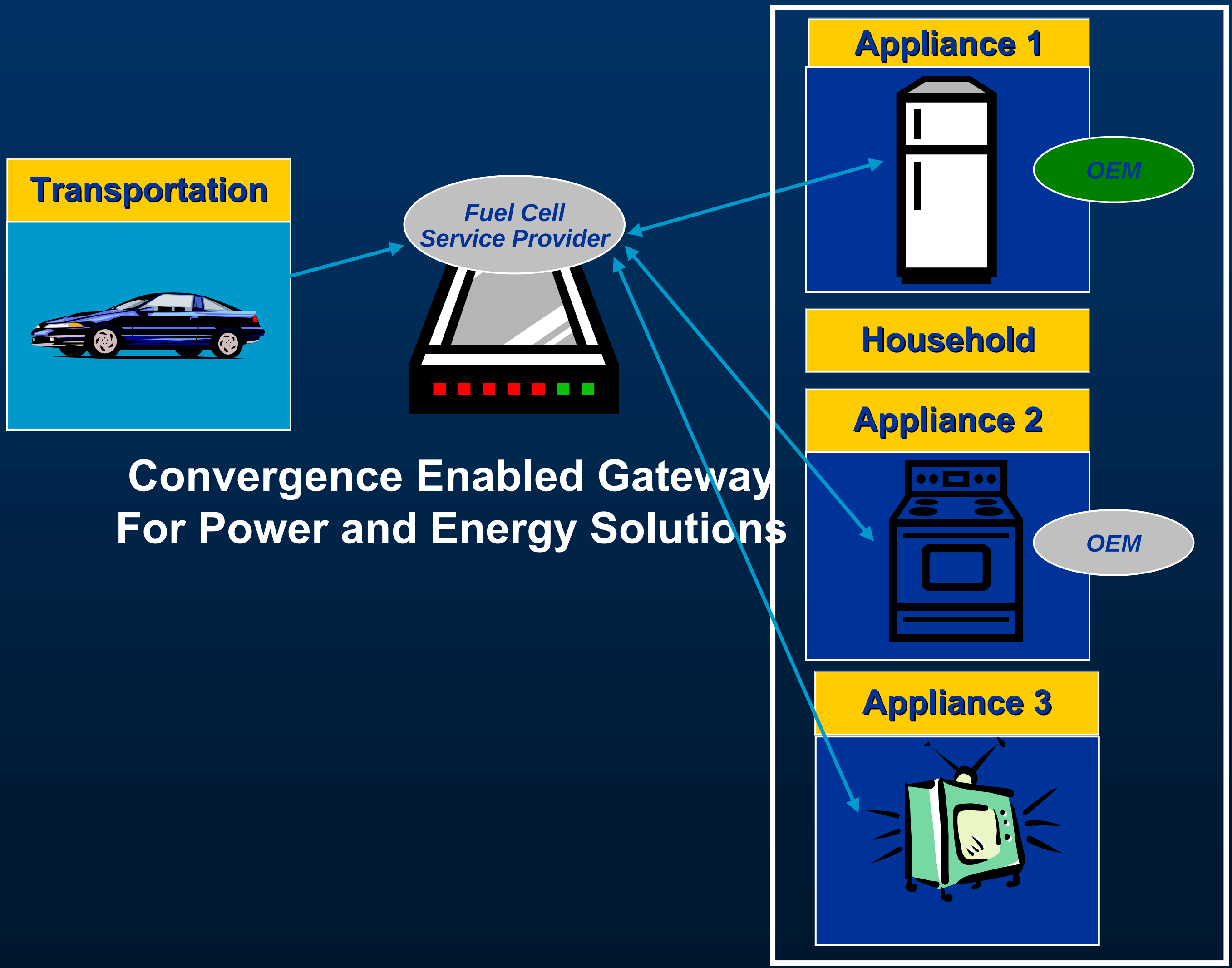
Networked Intelligence Everywhere = Productivity Gains ?



Convergence Enabled Gateway For Power and Energy Solutions

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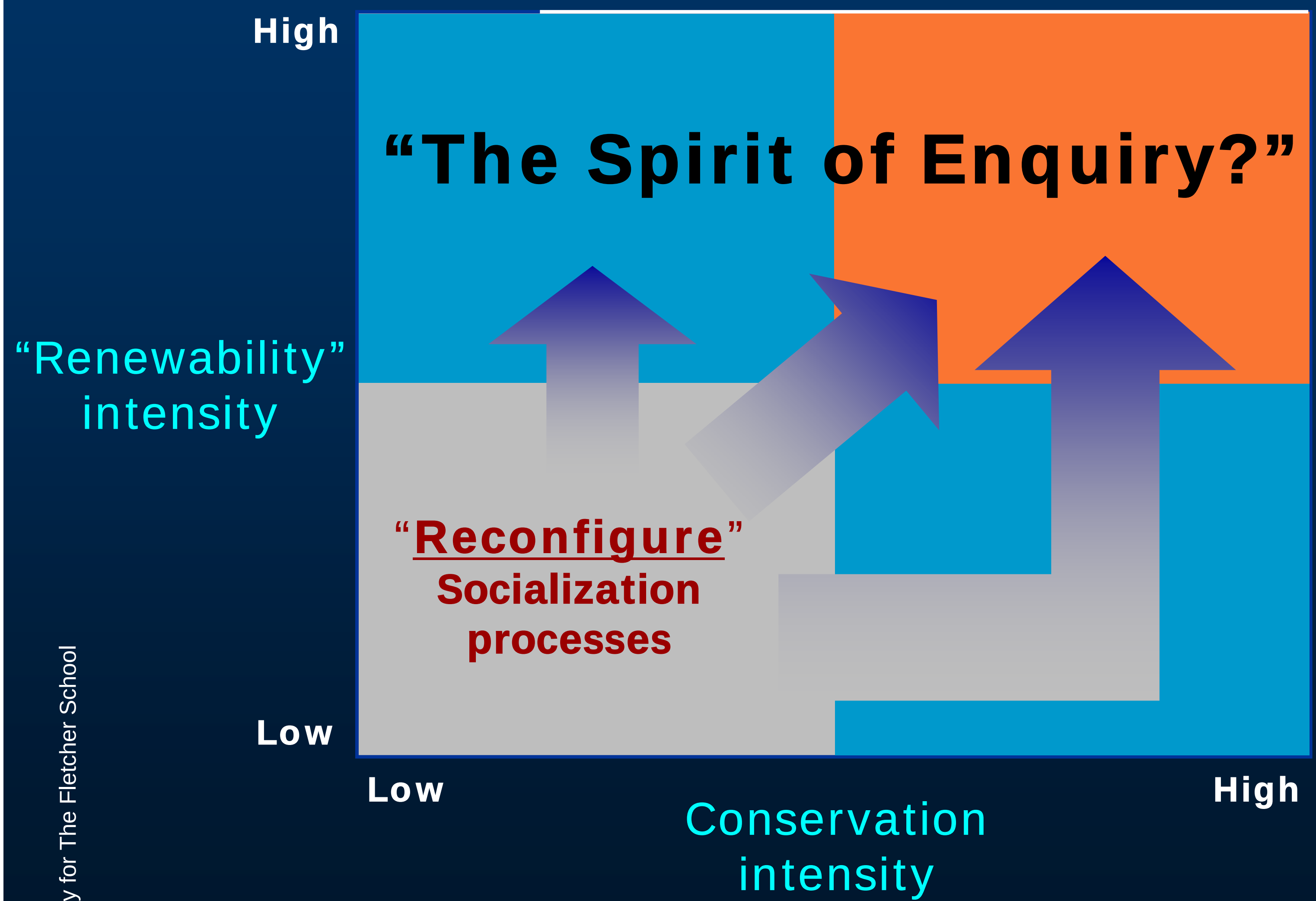
.. Possibilities are indeed limitless as long as we could stretch the limits that might constrain the Sprit of Enquiry…..



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