The Frontiers of New Energy Paradigm:
Cultivating the Courage to Create The New Dynamics

Partha S. Ghosh

Global Energy Conference
Houston 2006
**Choices:** Where will the Oil & Gas Profits go?

Total Net Profit in Billion US$ of Fortune Global 50 Companies (2005)\(^1,2\)

- 8 cos. = $139 Billion
- 42 cos. = $214 Billion

- Healthcare & Pharma: 4 cos. = $3 Billion
- FMCG: 2 cos. = $16 Billion
- Manufacturing: 10 cos. = $38 Billion
- Tech: 9 cos. = $50 Billion
- Retail & Wholesale: 2 cos. = $17 Billion
- FIs: 11 cos. = $89 Billion
- Oil: 8 cos. = $139 Billion

Boston Analytics Research
**Courage**: 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

- **Reduction in India**: 645.0
- **Reduction in China**: 38.2
- **Reduction in Western Europe**: 15.2
- **Reduction in US**: 26.5
- **2025 total**: 554.8

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

Boston Analytics Research
Commitment: To Shape social behavior?

The graph illustrates the relationship between GDP per capita and KWH per capita for various countries and years. The countries shown include USA 1960, USA 1970, USA 1980, USA 1985, USA 1990, USA 1995, USA 2001, Tokyo, Japan, Singapore, Hong Kong, Seoul, Malaysia, South Korea, Taiwan, Kuala Lumpur, India, and China. The data points suggest a positive correlation between GDP per capita and KWH per capita, indicating that as a country's wealth increases, so does its energy consumption.
Contents

- **Laws of Large Numbers & Network Effect?** Slow Pace of Large scale worldwide 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?*

*Note: Analyses supported by Boston Analytics*
Since the Early Nineteen Hundreds

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
Expected Natural Gas Wellhead Prices in U.S by 2025
($ per MSCF)

- Slow technology: $5.18
- Reference case: $4.79
- Rapid technology: $4.35

Source: Annual Energy Outlook 2005
Certainty of Global CO₂ emissions: Slow Pace of Dangerous Change

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

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

65 Billion Tons by 2050
Energy intensity has been declining with economic advancement

Energy Intensity vs. GDP per Capita of Selected countries (1980 to 2003)

Note: *Real GDP with base year 2000

Energy intensity has been declining with economic advancement.

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1. Energy Information Administration (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 (5kW/capita): 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
## Future Natural Gas requirement of Asian countries

<table>
<thead>
<tr>
<th></th>
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</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>
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<tr>
<td>Japan</td>
<td>79</td>
<td>91</td>
<td>99</td>
<td>108</td>
<td>119</td>
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<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>Total</td>
<td>288</td>
<td>391</td>
<td>473</td>
<td>565</td>
<td>685</td>
</tr>
</tbody>
</table>
Center of Gravity of Global Economy is also shifting

Percent of GDP Distribution
Geo-Political Alliances are In Transition

Paradigm Shift

Past

U.S. → USSR

EC → Japan

Japan → Asia

Asia → ROW

ROW → OPEC

NATO

Cold War

Future

U.S. → Russia

U.S. → Japan

Japan → China

China → India

ROW

OPEC

Single Market Politics

WTO Issues

Uncertainties

Middle East Uncertainties

New and Independent Identity

Deconstruction of Past Geopolitical Architecture

Bond by Cold War Forces of Alliances

Reconfigure New Role?
Convergence of Technologies but
How Deep?

The Digital Oil Field of the Future
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
- Reliable, Affordable and eternal source
- Ecology Concerns
- Equity
- Wall Street Expectations
- Interruption free Hydrocarbon infrastructure
- New requirements of Digitization
Net, a Tornado is in the making?

Changing Geopolitics
NOCs versus IOCs

New Technologies
Increasing Capital Intensity
Volatile Prices
Sudden events: Terrorism, Natural Disasters
Mega Infrastructure/ P&L large Stakes

Reliable, Affordable and eternal source

Ecology Concerns
Equity
Wall Street Expectations
Inter叮嘱 free Hydrocarbon infrastructure
New requirements of Digitization

Energy Speech PG 6-28-06
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Four Types of Nations in the Game? *Who will win?*

**Two Critical Vectors**

- **Net Energy Balance**
  - **Positive**
    - Heavy spending on infrastructure and/or weak manufacturing base
  - **Negative**
    - Very Vulnerable if resource constrained

- **Balance of Trade**
  - **Negative**
  - **Positive**
    - Benefit from strong manufacturing demand
    - Energy driven Power Plays

Energy Speech PG 6-28-06

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India is most vulnerable?

Percentage Trade Balance/GDP vs. Net Energy Balance of Selected Countries (2003)¹,²,³

Net Export of Energy (US$ B)

% Deficit/GDP

Net Import of Energy (US$ B)

% Surplus/GDP

-100 -75 -50 -25 0 25 50 75

-200 -100 -50 -25 0 25 50 75

India Italy Japan Germany Indonesia India

Saudi Arabia

China Brazil France Korea Germany Malaysia Nigeria

¹ International Energy Agency (http://www.iea.org)
² International trade statistics, 2004, world trade organization
³ Energy Information Administration (http://www.eia.doe.gov)
Contents

- Laws of Large Numbers & Network Effect? Slow Pace of Global Energy disruption?

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

- The Challenge: Time to rethink, repurpose and reform?
India & US will require similar strategic moves beyond Nuclear Energy Coop

- Positive
- Negative

Balance of Trade

Net Energy Balance

Create New Energy Game

Investment in Next generation Knowledge Intensive Energy Start-ups?

Manufacturing Competitiveness

Positive

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

Era of Extraction & Automation

Overcoming barriers
New Relationship of Space & Time
Supply to Fuel Unidirectional Demand

Era of Multidimensional Energy Renaissance

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

1947  2005  2050

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

- Mega World wide Energy disruption? Laws of Large Numbers & Network Effect

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

- The Challenge (7 Imperatives): Time to Rethink, Repurpose and Reform?
**Imperative 1**: Holistic Approach?

**PROBLEMS ≈ OPPORTUNITIES**

- Holistic Approach
- Renewable and Clean Energy Source
- Energy, Food and Health for All
- Sustainable Economic Development
- Ecology
- Equity

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Imperative 2: Equal amount of commitment on Supply and Demand side

Supply
- New Materials
- Precision Controls
- Nanotechnology / Catalysts
- Miniaturization
- Convergence / Broadband infrastructure

Demand
- Clean Energy
- Six Sigma Power
- Efficiency of Consumption
- Education to shape habits
- Design of living and work spaces
**Imperative 3**: Aggressive use of New technologies

Energy Industry Reconfiguration

- Nano Technologies
- Information Technology
- Opto Technologies
- Biotechnology

Upstream

Downstream
**Imperative 4: Equipment efficiency?**

![Graph showing equipment efficiency](chart)

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

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

- **Lighting Devices**
- **IC Engines**
- **Air Conditioners**
- **Heaters**
- **Boilers**

Boston Analytics Research

[¹,²,³,⁴,⁵]
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

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

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

Energy Demand* in India in Quadrillion Btu (1980 to 2025)\textsuperscript{1,2}

\begin{align*}
\text{Year} & \quad \text{1980} & \quad \text{1990} & \quad \text{2003} & \quad \text{2010} & \quad \text{2015} & \quad \text{2020} & \quad \text{2025} \\
\text{Energy Demand (Quadrillion Btu)} & \quad \downarrow & \quad \downarrow & \quad \downarrow & \quad \downarrow & \quad \downarrow & \quad \downarrow & \quad \downarrow \\
\end{align*}

India’s projected energy demand\textsuperscript{1,2}

\textit{@ energy intensity of US over the years}

Savings of 21.5%

Energy Saving by 45.4%

@ 70\% of energy intensity of US over the years

\textit{Note: Energy Demand* = (Population)*(Energy Intensity)*(GDP per Capita)}

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Reduction in India</th>
<th>Reduction in China</th>
<th>Reduction in Western Europe</th>
<th>Reduction in US</th>
<th>Projected Energy Demand after Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>645.0</td>
<td>10.3</td>
<td>38.2</td>
<td>15.2</td>
<td>554.8</td>
</tr>
</tbody>
</table>

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

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Boston Analytics Research
1. Energy Information Administration (http://www.eia.doe.gov)
**Imperative 4**: Large Scale Engineering systems thinking… 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**
Engineering Systems Advanced Solid Modeling Capability

Engineering Tools Include Autocad, Solidworks, Thermal Analysis System, Fortran, C++
**Imperative 5: New Accounting for Depletion and Ecology**

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

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Cost ($cents/KWh)</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>Energy Source</th>
<th>Cost ($/KW)</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>
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<tr>
<td>Coal IGCC</td>
<td>1,842</td>
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<tr>
<td>Coal CFB</td>
<td>1,345</td>
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<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
Electricity generation dynamics

Comparison of Average Electricity Generation Cost ($cents/KWh)\(^1\)

<table>
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<tr>
<th>Energy Source</th>
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<tbody>
<tr>
<td>Coal</td>
<td>3.7</td>
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<td>Nuclear</td>
<td>4.9</td>
</tr>
<tr>
<td>Hydro</td>
<td>6.1</td>
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<td>Oil</td>
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<td>Biomass</td>
<td>7.3</td>
</tr>
<tr>
<td>Wind</td>
<td>7.9</td>
</tr>
<tr>
<td>Solar</td>
<td>51.9</td>
</tr>
</tbody>
</table>

Capital Cost ($/KW)\(^2,3,4,5,6,7\)

- Coal: $1,000
- Nuclear: $3,500
- Hydro: $1,900
- Oil: $910
- Biomass: $2,500
- Wind: $5,300
- Solar: $15,000

At US $34 per barrel

At US $100 per barrel
**Imperative 6: Not Either Or, Unification**

- **A**
  - Wind Turbine → $\text{H}_2$ → Electrolizer → $\text{H}_2$, $\text{O}_2$

- **B**
  - Sun’s Rays → $\text{H}_2$ → Electrolizer → $\text{H}_2$, $\text{O}_2$

- **C**
  - $\text{H}_2$ Cylinder, $\text{O}_2$ Cylinder

- **D**
  - $\text{CH}_4$ → Reforming → $\text{H}_2$ → Electrolizer

- **E**
  - Methanol → Biomass → Ethanol → Direct Methanol Fuel Cell

- **F**
  - Nuclear → Metal Hydride → $\text{H}_2$ → $\text{H}_2$ Tanker / Pipeline

Specialized Applications
**Imperative 7:** Collaborative Problem Solving & Synthetic Approach

### Competing Technologies and Barriers to Commercialization

- **Size**
- **Cost**
- **Heat**

### Reliability
- **Efficiency**
- **Fuel Storage**
- **Fuel Type**

### DMFC
- PEMFC
- SOFC

### MCFC
- PAFC

### Uncertain Market Opportunities

- **Automotive**
- **Oil & Gas**
- **Utility**
- **Consumer Electronics**
- **Specialty Chemical**
- **Plastics**
- **Raw Material**
- **Mining**
- **Nanotechnology**
- **“Pure Play” Fuel Cell**

- **Portable Devices**
- **Military Applications**
- **Transportation**
- **Stationary Power**

**Image:** Various companies and technologies associated with fuel cells are illustrated, including Plug Power, Dow, 3M, ChevronTexaco, Ford, GM, Shell, DuPont, Sony, ALCdA, mti micro, Ballard, and Motorola.
Shape of things to come…

Increasingly sustainable economic growth

Less capital-intensive technologies

Natural gas

Increasingly sustainable economic growth

Less capital-intensive technologies

Liquids

Petroleum oil

Non-sustainable economic growth

Capital-intensive technologies

Natural gas liquids

Oil and natural gas liquids

Gases

Hydrogen

Wood

Coal

Solids

Whale oil

Town gas

Natural gas

100%

75%

50%

25%

0%

1850 1000 1050 2000 2050 2100 2150

…beyond carbon?
Risk Management Capacity Will Need to Be Fundamentally Reviewed

Business System (Simplified)

- Discover
- Deploy
- Delivery

Degree of Uncertainty

With increasing focus on discovery of new reserves

Globalization of Capacity

With increasing global reach

Current/Past

Business System Components

With increasing focus on discovery of new reserves
Leadership Capacity? Across Nations & Across the Lines of Enquiry

Building Leadership Capacity to deal with more complex decisions and risk levels

Decision Making

Complex

Simple

Risk Level

Low

High

Coherent / Homogenous Team

Multiple Views / Objectives Debates

Leadership Capacity? Across Nations & Across the Lines of Enquiry

Building Leadership Capacity to deal with more complex decisions and risk levels
A Reminder: Navigating through Paradigm shift = Harnessing the Energy of a Tornado

Paradigm Shift

Conservation driven Growth

Extraction & Automation

Strategic Window

Resource Commitment

Economic Impact
The Journey forward . . .

Toward a New Integrated Vision for Intelligent Holistic Energy Plays
Three layers of Energy Development

**Optimize the Base**
- Develop cooperative negotiation power? Intelligent E & P and sharper slate management?
- Redefine and carve-out niche roles to build global assets
- Optimize peoples infrastructure without loosing low energy intensive

**Grow & Extend the Base**
- Grow existing paradigms in conservation and emission control mode

**Diversify Beyond the Base**
- Leverage existing capabilities and strategic assets to diversify into related businesses e.g Multi-channel energy network
Last 5,000 Years…  

Possibilities...

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

……Future

**Economics of Closed Loop Harmony**

- Agro
- Bio Mass
  - Fuel Cells
- Clean Water
- New Technologies
- Energy and Power
- Knowledge Dissemination
- Broadband
- Clean Energy

- Clean Energy and Power
- New Technologies
- Clean Water
- Fuel Cells
- Agro
.. To *Rekindle the Spirit of Enquiry*

"The Spirit of Enquiry?"

"Renewability" intensity

"Reconfigure" Socialization processes

Conservation intensity

"High"

"Low"