Energy Crossroads: Where do we go from here?

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Dept Of Energy Science and Engineering
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Where do we go from here?

“Would you tell me, please, which way I ought to go from here?”
"That depends a good deal on where you want to get to."
"I don't much care where —"
"Then it doesn't matter which way you go."

— Lewis Carroll, Alice in Wonderland
Where do we want to get to?
Where do we want to get to?

- Energy Access – Energy for all
- Energy and Equity
- Sustainable Energy
- Energy Security
- Energy for improved quality of life
How do we get there?
How do we get there?

- Decentralised versus Centralised
- Depletable versus Renewable
- Peak Oil vs Non conventional Oil, Natural Gas
- Carbon Capture and Storage
- Nuclear
- Smart Grids
- Hydrogen Economy
History of Global Energy Use
Historical Trend in Global Energy Use
Regional Disparity Energy Use
Energy and Equity

![Graph showing cumulative percentage of global income and energy use against cumulative percentage of global population, with lines for PPP GDP in International $2005, Final energy, Electricity, and Equality line.](image)
Residential Electricity Gini (Select countries)

- Norway (0.19)
- USA (0.37)
- El Salvador (0.60)
- Thailand (0.61)
- Kenya (0.87)

Jacobsen, Energy Policy, in press 2013
Environmental, economic, and social impacts

Energy System

Energy Sector

Extraction and treatment
- Gas well
- Coal mine
- Sun
- Uranium mine

Primary energy
- Natural gas
- Coal
- Solar radiation
- Uranium

Conversion technologies
- Power plant
- Photovoltaic cell
- Power plant

Secondary energy
- Gas
- Electricity

Distribution technologies
- Gas grid
- Electricity grid

Final energy
- Gas
- Electricity

Energy End-Use

End-use technologies
- Furnace
- Computer
- Light bulb
- Air conditioner
- Aircraft
- Automobile

Useful energy
- Heat
- Electricity
- Light
- Heat/Cold
- Kinetic energy

Energy Services

Energy services
- Cooking
- Information processing
- Illumination
- Thermal comfort
- Mobility passenger-km
- Mobility tonne-km

Satisfaction of human needs

Source: GEA, 2012
ENERGY FLOW DIAGRAM

(ENERGY SERVICES)

1. PRIMARY ENERGY

2. ENERGY CONVERSION FACILITY

3. SECONDARY ENERGY

4. TRANSMISSION & DISTRN. SYSTEM

5. FINAL ENERGY

6. USEFUL ENERGY

7. END USE ACTIVITIES

DISTANCE TRAVELLED, ILLUMINATION, COOKED FOOD etc..

MOTIVE POWER RADIANT ENERGY

AUTOMOBILE, LAMP, MOTOR, STOVE

WHAT CONSUMERS BUY DELIVERED ENERGY

RAILWAYS, TRUCKS, PIPELINES

REFINED OIL, ELECTRICITY

POWER PLANT, REFINERIES

COAL, OIL, SOLAR, GAS
Global energy conversion to economic services

Cullen and Allwood, 2010

Kaya Identity

\[ \text{CO}_2 = \left( \frac{\text{CO}_2}{E} \right) \times \left( \frac{E}{\text{GDP}} \right) \times \left( \frac{\text{GDP}}{\text{Pop}} \right) \times \text{Pop} \]

E - Energy

\( \frac{\text{CO}_2}{E} \) - Carbon Intensity Of Energy

\( \frac{E}{\text{GDP}} \) – Energy Intensity

\( \frac{\text{GDP}}{\text{Pop}} \)

Pop- Population
Carbon Gini

Teng et al, 2011
# Energy Services - 2005

<table>
<thead>
<tr>
<th>Energy service</th>
<th>2005 levels</th>
<th>Units</th>
<th>As a percentage of pro-rated primary energy use (including upstream conversion losses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal comfort</td>
<td>30</td>
<td>$10^{15} \text{m}^3\text{K}$ (degree-volume air)</td>
<td>19%</td>
</tr>
<tr>
<td>Sustenance (food)</td>
<td>28</td>
<td>$10^{18} \text{J}$ (food)</td>
<td>18%</td>
</tr>
<tr>
<td>Structural materials</td>
<td>15</td>
<td>$10^{9} \text{MPa}^{2/3} \text{m}^3$ (tensile strength x volume)</td>
<td>14%</td>
</tr>
<tr>
<td>Freight transport</td>
<td>46</td>
<td>$10^{12} \text{ton} \cdot \text{km}$</td>
<td>14%</td>
</tr>
<tr>
<td>Passenger transport*</td>
<td>32</td>
<td>$10^{12} \text{passenger} \cdot \text{km}$</td>
<td>14%</td>
</tr>
<tr>
<td>Hygiene</td>
<td>1.5</td>
<td>$10^{12} \text{m}^3\text{K}$ (temperature degree-volume of hot water)</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>$10^{18} \text{Nm}$ (work)</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>280</td>
<td>$10^{18} \text{bytes}$</td>
<td>6%</td>
</tr>
<tr>
<td>Illumination</td>
<td>480</td>
<td>$10^{18} \text{lumen} \cdot \text{seconds}$</td>
<td>4%</td>
</tr>
</tbody>
</table>

*Cullen and Allwood, 2010*
## Energy Supply 2005

<table>
<thead>
<tr>
<th>Energy source</th>
<th>EJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>152</td>
</tr>
<tr>
<td>Coal</td>
<td>127</td>
</tr>
<tr>
<td>Gas</td>
<td>97</td>
</tr>
<tr>
<td>Biomass</td>
<td>54</td>
</tr>
<tr>
<td>Nuclear</td>
<td>30</td>
</tr>
<tr>
<td>Renewables</td>
<td>15</td>
</tr>
<tr>
<td>Direct fuel use</td>
<td>272</td>
</tr>
<tr>
<td>Electricity</td>
<td>183</td>
</tr>
<tr>
<td>Heat</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>475</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversion device</th>
<th>EJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel engine</td>
<td>58</td>
</tr>
<tr>
<td>Electric heater</td>
<td>58</td>
</tr>
<tr>
<td>Electric motor</td>
<td>55</td>
</tr>
<tr>
<td>Biomass burner</td>
<td>49</td>
</tr>
<tr>
<td>Gas burner</td>
<td>47</td>
</tr>
<tr>
<td>Petrol engine</td>
<td>41</td>
</tr>
<tr>
<td>Cooler</td>
<td>33</td>
</tr>
<tr>
<td>Coal burner</td>
<td>31</td>
</tr>
<tr>
<td>Oil burner</td>
<td>28</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>20</td>
</tr>
<tr>
<td>Light device</td>
<td>18</td>
</tr>
<tr>
<td>Electronic</td>
<td>16</td>
</tr>
<tr>
<td>Aircraft engine</td>
<td>11</td>
</tr>
<tr>
<td>Other engine</td>
<td>10</td>
</tr>
<tr>
<td>Heat</td>
<td>233</td>
</tr>
<tr>
<td>Motion</td>
<td>175</td>
</tr>
<tr>
<td>Other</td>
<td>67</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>475</td>
</tr>
</tbody>
</table>
# Energy Supply 2005

<table>
<thead>
<tr>
<th>Passive system</th>
<th>EJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appliances/goods</td>
<td>88</td>
</tr>
<tr>
<td>Heated/cooled space</td>
<td>86</td>
</tr>
<tr>
<td>Steam system</td>
<td>67</td>
</tr>
<tr>
<td>Driven system</td>
<td>56</td>
</tr>
<tr>
<td>Car</td>
<td>40</td>
</tr>
<tr>
<td>Truck</td>
<td>38</td>
</tr>
<tr>
<td>Furnace</td>
<td>31</td>
</tr>
<tr>
<td>Hot water system</td>
<td>23</td>
</tr>
<tr>
<td>Illuminated space</td>
<td>18</td>
</tr>
<tr>
<td>Plane</td>
<td>10</td>
</tr>
<tr>
<td>Ship</td>
<td>10</td>
</tr>
<tr>
<td>Train</td>
<td>8</td>
</tr>
<tr>
<td>Buildings</td>
<td>215</td>
</tr>
<tr>
<td>Factory</td>
<td>154</td>
</tr>
<tr>
<td>Vehicle</td>
<td>106</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>475</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Final service</th>
<th>EJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal comfort</td>
<td>90</td>
</tr>
<tr>
<td>Sustenance</td>
<td>84</td>
</tr>
<tr>
<td>Structure</td>
<td>68</td>
</tr>
<tr>
<td>Freight transport</td>
<td>64</td>
</tr>
<tr>
<td>Passenger transport</td>
<td>64</td>
</tr>
<tr>
<td>Hygiene</td>
<td>56</td>
</tr>
<tr>
<td>Communication</td>
<td>29</td>
</tr>
<tr>
<td>Illumination</td>
<td>19</td>
</tr>
</tbody>
</table>
Global Share of Primary Energy mix

Percent of PE (GEA standard)

1850  1875  1900  1925  1950  1975  2000

Biomass
Coal
Oil
Gas
Hydro
Nuclear
New Renewables

GEA, 2012
Cost of reducing greenhouse gas emissions by 2030
Euros per tonne of CO₂ equivalent avoided per year

Strategies sorted by cost-efficiency
- **Savings**
- **Costs**

This graphic attempts to show 'all in one': the various measures for greenhouse gas reduction with both reduction (in CO₂ equivalent) and cost (in Euros) quantified.
Read from left to right it gives the whole range of strategic options ranging from low hanging fruit, such as building insulation, in green (coming with economic savings) to the increasingly higher hanging ones, such as afforestation, wind energy, in red.

* Carbone Capture and Storage

Source: UNEP Report- Mckinsey GHG cost curve
Energy Balance for India for 2009 (in Exa Joules)

Primary Energy for Electricity Generation (10.4)

Electricity Losses (8.2)

Conversion Losses (7.2)

T&D, Auxiliary Losses (1.0)

Total Primary Energy Supply (28.3)

Total Final Consumption (18.8)
Industry Flows

Energy
- Electricity
- Fuel
- GN
- Water
- Air
- Inert Gas

Utilities

Environment

Energy conversion

Production support

Energy distribution

Processes

PUO

Waste collection

Waste treatment

Waste
- Heat losses
- Solids
- Water
- Gaseous

Products

By-Products

GEA, 2012
Thermodynamic Limits

Coal and coal products (21.5)
Crude, NGL, petroleum prod. (13.6)
Natural gas (18.1)
Renewables (7.5)
Electricity (22.3)
Heat (4.6)
Total (87.6)

Product (44.6)
Loss and waste (43.0)

Total (87.6)

Efficiency 51%

Units in ExaJoules

Coal and coal products (21.5)
Crude, NGL, petroleum prod. (13.6)
Natural gas (18.1)
Renewables (7.5)
Electricity (22.3)
Heat (1.3)
Total (84.3)

Product (25.1)
Loss and waste (59.2)
Total (84.3)

Efficiency 30%

GEA, 2012
Scenarios for Industrial Energy Use
Strength - Energy/m³

Composites

Technical ceramics

Natural materials

Non-technical ceramics

Metals

Polymers and elastomers

Guide lines for minimum energy design

Embodied energy per cubic meter, $H_m \rho$ (MJ/m³)

Strength, $\sigma_y$ (MPa)

Ashby, 2009
Standard Fan vs Efficient Fan

Standard Fan
- Power: 70 W
- Price: Rs 1300
- Life: 10 years
- Sweep: 1200 mm
- RPM: 350-400
- Similar air delivery: 230 m³/min

Efficient Fan
- Power: 35 W
- Price: Rs 2600
- BLDC motor
- Sweep: 1200 mm
- RPM: 350-400
- Similar air delivery: 230 m³/min
Cost Of Saved Energy – Efficient Fan

![Graph showing the cost of saved energy (CSE) in Rs/kWh for different discount rates and hours of usage. The graph includes lines for 1000 hours, 2000 hours, 3000 hours, and 4000 hours of usage, with corresponding CSE values.]
# CFL vs LED

<table>
<thead>
<tr>
<th></th>
<th>Compact Fluorescent Lamp</th>
<th>Light Emitting Diode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power:</strong></td>
<td>14 W</td>
<td>6W</td>
</tr>
<tr>
<td><strong>Price:</strong></td>
<td>Rs. 150</td>
<td>Rs. 1200</td>
</tr>
<tr>
<td><strong>Life:</strong></td>
<td>8000 hours</td>
<td>30,000 hours</td>
</tr>
<tr>
<td><strong>Lumens/ W</strong></td>
<td>50</td>
<td>120</td>
</tr>
<tr>
<td><strong>Lumen output:</strong></td>
<td>700 lumens</td>
<td></td>
</tr>
</tbody>
</table>
Cost of Saved Energy – CFL vs LED

![Graph showing the cost of saved energy for CFL and LED bulbs over different discount rates and hours of usage. The graph includes lines for 1000, 2000, 3000, and 4000 hours of usage.]
DSM at Micro Level – Case study of Main Building IIT Bombay

Main Building IIT Bombay – Office-type commercial load

1 – Main Electrical Distribution Panel (sub-ground level PCC)
2 – Director’s office
3 – Dean IR and Dean Faculty office
4 – Dean SA and Deputy Director’s Office
5 – Account Section and Registrar Office
6 – Administration
Effect of various DSM options on MB load curve
Integration of DSM with PV

100 Households
Residential loads:
Incandescent bulb
Ceiling Fan, Television
Radio/Music load,
Agricultural pumpset
Isolated system
PV- Battery
PV-Battery-DSM
Daily Load Curve - Summer

- Total load
- Average
- Load(DSM)
- Average(DSM)
Annual Load Duration Curve

LDC-no DSM

LDC- DSM
Comparison of PV rating and cost
Zero Energy Buildings

www.passiv.de
(Germany/Sweden)

ECBC, Teri GRIHA – Building rating schemes
Dependent on climatic zone, share of AC space

Bayer Innovation Centre Noida
Zero Emissions Building
45 kWh/m²/year, solar PV
http://www.bayer.com/
Solar decathlon - Research Areas

- Structural Analysis
- Materials
- Prefab construction
- Passive Architecture & Simulation

MUTLIPLE FACETS OF CONSTRUCTING A GREEN

- Solar Potential & PV
- HVAC Design
- MEP System Design
- Instrumentation & Control Systems
Collaboration

Inter-disciplinary research – Team has students from 13 different disciplines

Diverse team consisting of students from all major programmes – PhD, M.Tech, Undergraduate (2nd, 3rd, 4th, 5th Years)

Collaboration and interfacing with industry experts
Efficiency and DSM

- Rebound Effect
- Transaction Costs
- Level Playing Field
- Needed a Paradigm Change – Focus on Energy Services
- Shortage of Supply to Longage of Demand
Case Study: Capacitor Leasing

Source: Taylor et al., 2008
BLY Schematic

- **Buyer in Annex I Country**
- **PoA - Manager**
  - Technically develops BLY scheme methodology and documents
  - CDM EB Communication
  - Validation / Verification
  - PoA approval

- **CFL INVESTOR**
  - Returns fused CFLs
  - Safe disposal of returned CFL
  - Safe keeping of replaced ICL lamp for inspection
  - Payment for CERs
  - CERs sold
  - Procures long-life CFLs and distributes to households
  - Day-to-day monitoring; Verification survey to assess lamp failure rate

- **HOUSEHOLD**
  - Pays Rs 15 for new CFL

- **DISCOM**
  - Provides access to the households for installing CFLs
  - Each BLY project ~ 600,000 CFLs, up to 4 CFLs per household
  - 400 million ICLs / annum replaceable, annually saving ~ 6000 MW

Source: BEE web site
Summing Up

- Need to re-orient energy sector – focus on energy services
- Energy Access and Energy Equity critical
- Energy Efficiency, Demand Side Management – Significant Potential
- Nowhere near fundamental thermodynamic limits – scope for technology, systems development
- Need for Innovation
- Water, Material, Land, Employment impacts
End- Note

“The future depends on what you do today.”

Mahatma Gandhi
Acknowledgements

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rangan@iitb.ac.in

Thank You
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