Opportunities and Barriers for Clean Coal & Other Clean Technologies

Annex I Expert Group Seminar
“Working Together to Respond to Climate Change”

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United States Department of Energy
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Fossil fuels are indispensable to meet demand growth

Conventional oil and natural gas supply won't meet increasing demand

Large scale alternative energy sources will be required to meet demand

Curbing carbon emissions will alter the energy mix, increase energy-related costs, and require demand reductions

Growing World Energy Demand

World Electric Power Generation by Region, 1980-2030

- Billion Kilowatthours
- History
- Projections
- OECD
- Non-OECD

World Electricity Generation by Fuel, 2004 and 2030

- Billion Kilowatthours
- 2004
- 2030
- Oil
- Nuclear
- Renewables
- Natural Gas
- Coal

U.S. Department of Energy
NPC: The Five Core Strategies

- Moderate the growing demand for energy by increasing efficiency of transportation, residential, commercial, and industrial uses
- In the U.S., expand and diversify energy supply, moderate oil and gas production decline, and increase access for new resources
- Strengthen global energy trade and investment
- Enhance science and engineering capabilities
- Develop legal / regulatory framework to enable Carbon Capture and Sequestration
Coal is expected to play a key role in growth of Emerging Economies

Global CO₂ emissions from coal: 11 GtCO₂ in 2005, 19 GtCO₂ in 2030

## Electricity Generation Capacity by Fuel Type in 2005 (%) China, India, and USA

### Operational Capacity by Fuel Type (2005)

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Capacity (MW)</th>
<th>Coal Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>116,860</td>
<td>67,296</td>
</tr>
<tr>
<td>USA</td>
<td>991,794</td>
<td>327,551</td>
</tr>
<tr>
<td>China</td>
<td>379,895</td>
<td>272,243</td>
</tr>
</tbody>
</table>

Data Source: Platts UDI, 2005
Age of Existing Coal-Fired Units in 2005 (Number of Units) in India, China, and USA

Data Source: Platts UDI, 2005
Age of Existing Coal-Fired Capacity in 2005 (MW) in India, China, and USA

Data Source: Platts UDI, 2005
Coal Power Plant Efficiencies

- Subcritical PC
- Supercritical PC
- IGCC

Projected

Efficiency

80%
60%
40%
20%

1940 1960 1980 2000 2020 2040
## Average Coal-Fired Power Plant Efficiencies
### China, India, and USA

<table>
<thead>
<tr>
<th>Country</th>
<th>Average Efficiency (HHV) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD</td>
<td>36</td>
</tr>
<tr>
<td>USA</td>
<td>33-34</td>
</tr>
<tr>
<td>China</td>
<td>~30-32</td>
</tr>
<tr>
<td>India</td>
<td>~25-34</td>
</tr>
</tbody>
</table>

- **China’s reported power efficiency is approaching OECD levels following rapid build up of new units over the last 5+ years**
- **India is improving too but not as fast as China owing to slower build up and the number of poor performing SEB stations, which represent about 2/3 of India’s electricity generation**
- **The efficiency of Indian coal plants is greatly hampered by high ash content coal, and warm weather.**
China is shifting rapidly to advanced coal technologies

- Average efficiency of coal-fired generation: 33.2% LHV
- Over 8,000 small, low-efficiency units <200 MW
- First 350 MW subcritical unit commissioned in 1982, first 600 MW subcritical unit in 1989
- Has been building mostly large (200–800 MW) subcritical units
- Focus shifted to add large supercritical and ultra-supercritical units
  - 3% of existing (30 units) and 9% of planned capacity with goal of 50% of new capacity by 2020
  - Domestic units of 600 MW under demonstration and imported 1,000-MW units under construction
- Ultra-supercritical units
  - 4 x 1000-MW units recently commissioned
India is adopting advanced technologies more slowly

- Average efficiency of coal-fired generation: 27.6% LHV
- Poor quality coal (>40% ash) limits performance
- Currently, 100% subcritical pulverized coal
  - 135 x 200-250 MW units since 1978 and 27 x 500 MW since 1984 commissioned by BHEL
- 1st supercritical plant (3 x 660 MW) under construction at Sipat using South Korean technology
- “Ultra-mega” projects planned using 800-MW supercritical units
## Coal Technology Status in China and India

<table>
<thead>
<tr>
<th>Technology</th>
<th>China</th>
<th>India</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGCC</td>
<td>Yantai IGCC project under consideration for past decade. Several power and polygeneration projects being developed by major utilities.</td>
<td>$2.5-M DOE/USAID/NTPC feasibility study for 100-MW unit completed. Pursuing a demo project of about 100 MW by NTPC. BHEL developed domestic technology, tested at 6-MW scale.</td>
</tr>
<tr>
<td>Gasifiers</td>
<td>37 on coal, 13 on petroleum and 1 on gas (25 Shell, 22 GE, 3 Sasol Lurgi, 1 GTI U-Gas) (35 Operating, 16 Planned)</td>
<td>6 operating on petroleum and petcoke (5 Shell, 1 GE)</td>
</tr>
<tr>
<td>CFBC</td>
<td>Many domestically built 50-200-MW units</td>
<td>Technology acquired through licensing. Four domestically built 125-MW units, including 2 firing lignite. 250-MW unit under installation at Neyveli Lignite.</td>
</tr>
<tr>
<td>CTL/ Polygeneration</td>
<td>First phase of Shenhua’s direct liquefaction plant in Inner Mongolia to start operation in 2008, producing 1.08 million tons of liquid products (diesel, LPG, and naphtha). Total production of two phases is 5 million tons. Also, developing two indirect liquefaction plants with Sasol. Polygeneration under study by others, including Hunnan International Technopolis Shenyang (HITS) using coal and waste/garbage and Datang Power (4 plants) using coal</td>
<td>Under study; on January 2007, Investment Commission said go forward, but not a near-term project</td>
</tr>
<tr>
<td>Supercritical</td>
<td>Several dozen units commissioned</td>
<td>Original license from Combustion Engineering (USA, now Alstom); scaled up by BHEL. No units constructed yet, but first plant announced by BHEL and TNEB for 2 x 800 plant at Tuticorin, Tamil Nadu. First imported unit 1980-MW (3 x 660 MW) Sipat to be commissioned in 2008 by Doosan Babcock (Korea), which will burn 43% ash coal. Three other projects already awarded to IPPs through tariff-based competitive bidding. Many more supercritical units in pipeline.</td>
</tr>
<tr>
<td>Ultra Supercritical</td>
<td>First plant commissioned early 2008 (Huaneng’s 4 x 1000-MW Yuhuan Plant)</td>
<td>Initial tie-up with Babcock Borsig. Recently, licensed Alstom boiler technology and Siemens steam turbine technology up to 660 MW. BHEL plans to develop up to 800 MW. No units constructed yet.</td>
</tr>
</tbody>
</table>
2010:
- 45-50% Efficiency (HHV)
- 99% SO₂ removal
- NOx < 0.01 lb/MM Btu
- 90% Hg removal

2012:
- 90% CO₂ capture
- <10% increase in cost of electricity (COE) with carbon sequestration

2015
- Multi-product capability (e.g., power + H₂)
- 60% efficiency (measured without carbon capture)
Thermal Power Technology R&D Priorities

- **China**
  - R&D and manufacture of >600-MW SC/USC p.c. units
  - Import state-of-the-art control technology for NO<sub>x</sub> and SO<sub>2</sub>
  - Introduce large-scale gasification and coal liquefaction
  - Polygeneration of Fuels & Power
  - Focus on Chinese manufacture to control costs by:
    - transfer foreign technologies to select equipment manufacturers via licenses and joint ventures
    - participating in international R&D projects

- **India**
  - Introduce large (660-MW) SC and USC plants
  - Promote utilization of IGCC and CFBC
  - Renovate and modernize old units
  - License foreign technology
Three elements of CCS:

- **Capture** – accounts for over 90% of the CCS cost due to high capital cost and energy penalties.

- **Transport** - requires infrastructure, pipeline, right of ways, limited by economics of transport distance.

- **Storage** - safety, long-term storage, liability, land and mineral access rights for geologic storage.

Research focuses on cost and energy penalty reductions and providing a scientific and operational basis for safe and effective injection and long-term storage.
Examples of CO₂ Capture Technologies

**Plant Type**
- Combustion Plants (new construction)
- Gasification-Based Plants (new construction)

**Current State of the Capture Technology**
- Commercial/Near Commercial
- Advanced

**CO₂ Capture Technologies**
- Amine Wet-Scrubber
  - $110-130/ton Carbon
- Advanced Amine
  - $90-120/ton Carbon
- Advanced Rectisol
  - $150-170/ton Carbon
- Advanced Selexol w/ Hydrogen Co-production
  - $45-60/ton Carbon
- Hydrogen Membranes
  - $40-50/ton Carbon
- Ionic Liquids
  - $30-60/ton Carbon
- FutureGen w/ Carbon Capture and Storage
  - $0-10/ton Carbon (net) Potential
- Chilled Ammonia
  - $100-140/ton Carbon
- Aqua Ammonia w/ Byproduct Sales
  - $70-80/ton Carbon
- Oxyfuel Combustion
  - $70-80/ton Carbon
- Adv. Oxyfuel Comb.
  - $55-70/ton Carbon

Note: These costs have not been rigorously updated but represent estimates based on cost escalations since original costs were constructed in 2006
Capturing CO₂ with Today’s Technology Significantly Reduces Plant Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Gasification</th>
<th>Pulverized Coal Combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg IGCC</td>
<td>39.5</td>
<td>39.1</td>
</tr>
<tr>
<td>Avg IGCC w/ CO2 Capture</td>
<td>32.1</td>
<td>27.2</td>
</tr>
<tr>
<td>PC-Sub</td>
<td>36.8</td>
<td>24.9</td>
</tr>
<tr>
<td>PC-Sub w/ CO2 Capture</td>
<td>-32%</td>
<td>-30%</td>
</tr>
<tr>
<td>PC-Super</td>
<td>39.1</td>
<td>27.2</td>
</tr>
<tr>
<td>PC-Super w/ CO2 Capture</td>
<td>-30%</td>
<td>-30%</td>
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Capturing CO₂ with Today’s Technology is Expensive

Cost of Electricity Comparison

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<tr>
<th></th>
<th>January 2007 Dollars, Coal cost $1.80/10⁶ Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg IGCC</td>
<td>7.79 cents/kWh</td>
</tr>
<tr>
<td>Avg IGCC w/ CO₂ Capture</td>
<td>10.63 cents/kWh, +36%</td>
</tr>
<tr>
<td>PC-Sub</td>
<td>6.40 cents/kWh</td>
</tr>
<tr>
<td>PC-Sub w/ CO₂ Capture</td>
<td>11.88 cents/kWh, +86%</td>
</tr>
<tr>
<td>PC-Super</td>
<td>6.33 cents/kWh</td>
</tr>
<tr>
<td>PC-Super w/ CO₂ Capture</td>
<td>11.48 cents/kWh, +81%</td>
</tr>
</tbody>
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Impediments to IGCC & CCS

- Higher cost of IGCC over conventional PC
- IGCC is less mature than PC
  - Absence of warranties on IGCC hardware
  - Lack of industry confidence
  - Difficulties in obtaining financing
- High cost of CCS
  - Reluctance of regulated utility commission to adjust rate base for costlier plants
- Long-term CO₂ storage liability to utilities
Cost Reduction Goals of IGCC R&D

- Current IGCC costs are approximately 20% higher than conventional coal plants.
- Our US DOE program goal is to develop technology that would reduce IGCC costs, increase reliability and efficiency, and have the features for accommodating CCS, and when combined with CCS will result in a nominal increase in the cost of electricity (~10% premium).
- Cost reductions will result from improved gasifier designs (more reliable and maintainable), cheaper air separation technologies (e.g. membranes), improved gas clean-up technologies, and utilization of advanced low-emission hydrogen turbines, and reduction in CCS costs and energy penalties.
<table>
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<th>Research Area</th>
<th>Research Technologies</th>
<th>Cost of Electricity</th>
<th>Net Power Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier Island</td>
<td>-O₂ Membranes&lt;br&gt;-Advanced Transport Reactor&lt;br&gt;- Raw Gas Shift Reactor</td>
<td>6-15% Reduction</td>
<td>4-11% Increase</td>
</tr>
<tr>
<td>Power Island</td>
<td>-Low NOₓ Hydrogen Turbines&lt;br&gt;-SECA Fuel Cells ($400/kW)</td>
<td>7-25% Reduction</td>
<td>10-20% Increase</td>
</tr>
<tr>
<td>CCS</td>
<td>-H₂ Membranes&lt;br&gt;-Advanced Selexol&lt;br&gt;-Novel Chemistry</td>
<td>Can Reduce COE Penalty from 60-80% for Amine to less than 10%</td>
<td>Can Reduce Energy Penalty from 30% for Amine to 5% range</td>
</tr>
</tbody>
</table>
**Benchmark: $30/tCO₂**

Carbon emission charges in the neighborhood of $30/tCO₂ can enable scale-up of most of technologies, if supplemented with sectoral policy to facilitate transition.

<table>
<thead>
<tr>
<th>Form of Energy</th>
<th>Equivalent to $30/tCO₂ (≈ $100/tC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>$1.60/1000 scf</td>
</tr>
<tr>
<td>Crude oil</td>
<td>$13/barrel</td>
</tr>
<tr>
<td>Coal</td>
<td>$70/U.S. ton</td>
</tr>
<tr>
<td>Gasoline</td>
<td>25¢/gallon (ethanol subsidy: 50¢/gallon)</td>
</tr>
<tr>
<td>Electricity from coal</td>
<td>2.4¢/kWh (wind and nuclear subsidies: 1.8 ¢/kWh)</td>
</tr>
<tr>
<td>Electricity from natural gas</td>
<td>1.1¢/kWh</td>
</tr>
</tbody>
</table>

$30/tCO₂ is the current European Trading System price for 2008 emissions. At this price, current global emissions (30 GtCO₂/yr) cost $900 billion/yr, 2% of GWP.

Slide Source: Professor Socolow, Princeton University
Partners: Australia, Canada, China, Japan, India, Republic of Korea, United States

Objectives: “Meet goals for energy security, national air pollution reduction, and climate change in ways that promote sustainable economic growth and poverty reduction.”
Asia Pacific Partnership
The CSLF is an international climate change initiative that is focused on development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage. The purpose of the CSLF is to make these technologies broadly available internationally; and to identify and address wider issues relating to carbon capture and storage. This could include promoting the appropriate technical, political, and regulatory environments for the development of such technology. The CSLF is currently comprised of 22 members, including 21 countries and the European Commission.
Final Observations

- Fossil Fuels will continue to be a large part of the world’s energy mix.

- Technology is available today for carbon capture from new and retrofitted coal-fired IGCC and PC power plants, however:
  - It is very expensive
  - Parasitic load is very high
  - Reliability needs to be proven

- Sequestration needs to be adequately demonstrated, especially in deep saline reservoirs with large-volume CO$_2$ injection

- DOE RD&D program is targeting the key issues of lowering system costs, increasing efficiencies, and proving sequestration.

- International cooperation, through many diverse mechanisms, will be necessary to ensure success.
For Additional Information

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