High Efficiency Low Emissions: positive impacts of achieving coal power efficiency gains

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IEA Clean Coal Centre
mission statement

The IEA CCC will disseminate to a wide community objective analysis and information on the efficient, low emissions use of coal worldwide according to a programme agreed by the Membership: In order to achieve this objective, the focus of the IEA CCC activities comprises three broad categories:

- Towards zero emissions – including carbon abatement, emissions and effects, pollution control technology, residues.
- Coal utilisation and analysis – including coal properties, fuel handling, power generation technologies, coal conversion technologies, and industrial uses of coal.
- Economics and markets – including supply, transport and markets development, country studies, capital and operating cost reviews of current and new build technologies, including comparisons with non-coal options.

Services will be delivered through direct advice, review reports, workshops and conferences, facilitation of R&D, provision of networks and web based instruments.
Membership status of the IEA Clean Coal Centre at October 2014

The foremost centre of excellence for all aspects of clean coal knowledge transfer

Member countries:
- Austria
- Canada
- Germany
- Italy
- Japan
- Poland
- S Africa
- UK
- USA
- Australia
- CEC
- Beijing Research Institute of Coal Chemistry
- Electric Power Planning & Engineering Institute of China
- Banpu
- BHEL
- Anglo American Thermal Coal
- Suek
- Coal Association NZ
- BHEL
- AngloAmerican

International organizations:
- Anglo American
- Suek
- CEC
- BRICC
- BHEL
- Banpu
- Electric Power Planning & Engineering Institute of China
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- Coal Association NZ
- S Africa
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- Italy
- Japan
- Poland
- S Africa
- USA
- UK
Scope of the presentation

• Drivers for technology advancement
• Historical improvements in coal power generation technology
• Getting larger and introducing higher efficiency steam cycles
• HELE concept both for CO$_2$ and non-GHG emissions mitigation
• Current examples of HELE coal power plant
• Advanced HELE developments
• Scope to maximise HELE plants in major coal using economies
• Future work for IEACCC
Coal can ensure energy security and economic competitiveness. There are environmental challenges but technologies are available to deal with these.
Role of clean coal technology

• High efficiency low emissions technologies are critical to maintain coal based energy security and as a precursor to the longer term deployment of CCS

• Essential to assist developing countries in making this choice as part of their efforts to escape from poverty through access to reliable sources of power

• Lending criteria by multi-lateral donors not overly helpful
Historical improvements to power cycle efficiencies

- Economies of scale leading to larger units
- Higher temperature steam cycles
- Better integrated operating procedures

Electricity Produced per tonne of Coal (kWh/t)
Recent plant state of the art conditions

Max SH Steam Temperature, °C

- **Ultrasupercritical**
- **Supercritical**

### Data Points

- **Studstrup (DK)** 540/540
- **Maatsura 1 (J)** 538/566
- **Esbjerg (DK)** 560/560
- **Schwarze Pumpe (D)** 547/565
- **Maatsura 2 (J)** 593/593
- **Haramachi 2 (J)** 600/600
- **Nordjylland (DK)** 580/580/580
- **Boxberg (D)** 545/581
- **Tachibanawan 1 (J)** 600/610
- **Avedore (DK)** 580/600
- **Niederaussem (D)** 580/600
- **Hekinan (J)** 568/593
- **Isogo (J)** 600/610
- **Yunghung 566/576
- **Genesee 3 580/570
- **Hitachinaka (J)** 600/600
- **Torrevaldaliga (I)** 600/610
- **Huyan (China)**
Application of sc and usc steam cycles
Focus on technologies to reduce both GHG and non-GHG (NOx, SO2, PM) emissions.

Technologies for cleaner coal generation

(1) Reducing coal consumption
- Mill
- Coal
- Water
- Condenser
- Turbine
- Generator
- Steam
- Boiler
- De-NOx
- Flue gas
- EP
- De-S

(2) Reducing non-GHG emissions
- Pollutants to be reduced:
  • SO2, NOx,
  • Particulate matter

(3) Carbon Capture and Storage
- CO2 Storage
- CO2 Capture
- N2, H2O

Technologies for cleaner coal generation

HELE Technologies

HELE Technologies

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(3) Carbon Capture and Storage
- CO2 Storage
- CO2 Capture
- N2, H2O
Waigaoqiao No. 3 power plant in Shanghai is one of the cleanest in the world

Seeing is believing
### Waigaoqiao no. 3 power plant

#### Emissions (mg/m³)
- Dust: 11.63
- SO₂: 17.71
- NOx: 27.25

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net efficiency (%)</td>
<td>42.73</td>
<td>43.53</td>
<td>43.97</td>
<td>44.50</td>
<td>44.40</td>
</tr>
<tr>
<td>Specific coal consumption (gce/kWh)</td>
<td>287.4</td>
<td>282.2</td>
<td>279.4</td>
<td>276.0</td>
<td>276.1</td>
</tr>
<tr>
<td>Annual load rate (%)</td>
<td>75</td>
<td>75</td>
<td>74</td>
<td>81</td>
<td>77</td>
</tr>
</tbody>
</table>
Need to limit capital costs as well as increase steam cycle efficiency

**Yesterday**

Vertical or spiral wound furnace
- 250 bar, 540° /560° C
- $\eta < 40\%$ (Net, LHV)

**Today**

600 MW reference design
- 300 bar, 600° /620° C
- Achievable $\eta = 45 ÷ 47\%$ (Net, LHV)

**2010-2015 Soon**

Thermie AD700
- 325 bar, 700° C/700° C
- $\eta = 50 ÷ 55\%$ (Net, LHV)

COST 522
- 300 bar, 630° /650° C

Reduced capital costs
- Novel layouts

**Soon**

Need to limit capital costs as well as increase steam cycle efficiency.
Towards ≥50% cycle efficiency with advanced USC technology

<table>
<thead>
<tr>
<th>National programme</th>
<th>Steam temperature</th>
<th>Efficiency (LHV, net)</th>
<th>Programme start date</th>
<th>Demonstration plant operational by (size)</th>
<th>Also includes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>700°C</td>
<td>&gt;50%</td>
<td>1998</td>
<td>2021 (500 MWe)</td>
<td>Coatings, biomass co-firing, cycling</td>
</tr>
<tr>
<td>USA</td>
<td>760°C</td>
<td>45-47% (HHV, net)</td>
<td>2000</td>
<td>2021 (600 MWe)</td>
<td>Oxyfuel, coatings, high sulphur coal</td>
</tr>
<tr>
<td>Japan</td>
<td>700°C</td>
<td>&gt;50%</td>
<td>2008</td>
<td>2021 (600 MW)</td>
<td>Biomass co-firing</td>
</tr>
<tr>
<td>China</td>
<td>700°C</td>
<td>46-50%</td>
<td>2011</td>
<td>2021 (660 MWe)</td>
<td>-</td>
</tr>
<tr>
<td>India</td>
<td>700°C</td>
<td>&gt;50%</td>
<td>2011</td>
<td>2017 (800 MWe)</td>
<td>-</td>
</tr>
</tbody>
</table>

Metals used in boiler and turbine hot spots:
- Steels well proven in USC at 600°C
- Nickel based alloys proving capable in A-USC at 700°C
Raising efficiency significantly reduces the CO₂/kWh emitted (source: IEA HELE Roadmap, Dec 2012)
IEACCC HELE assessment study

- Country specific study on the prospects for implementing High Efficiency Low Emissions (HELE) technologies
- Impact of HELE implementation on emissions of CO2
- Look at Australia, China, Germany, India, Japan, Poland, Russia, S Africa, S Korea, USA
- Determine outline costs of deployment, where possible
- Identification of significant trends
HELE upgrade path through phased plant retirement

**Base Case**
Existing coal fleet with additional USC to meet demand (if required)

**50 year retirement scenario**
Review in 2020, 2030 and 2040. Retire capacity over 50 years old and replace with USC

**25 year retirement scenario**
Review in 2020, 2030 and 2040. Retire capacity over 25 years old and replace with USC in 2020, AUSC in 2030 and 2040
China – 25 year retirement scenario, 2015 - 2040

Benefitting from an actively pursued HELE upgrade policy which avoids significant quantities of CO₂. If continued with AUSC, will see emissions level out by 2040.
India – 25 year retirement scenario, 2015 – 2040 CCS emissions trendline

Fastest growing coal fleet after China. If HELE technology is implemented, significant savings can be made, but current policies on technology may not go far enough.
Lower potential savings as coal fleet is already highly efficient and future electricity demand prospects modest. Energy policy under review but high efficiency coal plant an important priority.
Highly dependent on coal and significant emissions savings possible from HELE. Recent and planned new capacity is supercritical not USC. Uncertainties on coal’s place in the future energy mix.
Russia – 25 year retirement scenario, 2015 - 2040

An inefficient coal fleet that would yield significant savings through HELE upgrades. The Russian situation is difficult to research and warrants further study to better quantify the benefits.
This study has provided a valuable insight into country-specific HELE possibilities but deeper analysis for all countries is recommended.

Priority areas for further study are considered to be: India, South Africa, Poland and Russia.

Other coal users need to be researched to complete the world view. A further overview study on HELE prospects is recommended for the “Asian Tiger” economies as a first step.

Plant improvements are significant to achieving efficiency gains and a review of the current best practices is recommended leading to knowledge transfer opportunities.