Coal power generation technology status and future requirements

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Some of the material in this presentation is from work on the IEA CCC’s Clean Coal Roadmaps to 2030 study for the WPFF in 2009, updated.

The latter determined R, D & D and commercialisation steps in CCTs and CO$_2$ capture to 2030 for:

- Coal-fired power generation and some major industries
- OECD and non-OECD countries
BASELINE ASSESSMENTS:

- Technologies, programmes, plans and example projects in 2009 were reviewed for USA, Canada, Australia, Europe and Japan

OECD ROADMAPPING:

- Developed a view of coal technologies needed by 2030
- Developed targets for various dates to 2030
- Considering current technologies and known plans, developed the needed R,D&D and commercialisation steps

NON-OECD ROADMAPPING – other priorities and technology statuses may affect timing:

- Reviews identified cooperation areas and technology transfer needs of three example countries (China, India, S Africa)
- Information used as input in developing non-OECD roadmaps
Outline of technologies with prospects
Pulverised coal combustion

- Hundreds of GWe installed, units to ~1000 MWe
- Efficiency to upper 40s% (LHV) in best locations
- Conventional emissions control well established

How will it be in 10 or 20 years?

- Still the most deployed coal technology
- Advanced emissions control, including dry systems
- Incremental efficiency improvements
- Further efficiency gains from novel lignite drying and from jump to 35 MPa/700°C steam
- CCS as integrated technology using flue gas scrubbing or oxygen firing
Circulating fluidised bed combustion

- Hundreds of units, experience to 460MWe
- Suited to low quality coals and other fuels
- Emissions control systems well established

How will it be in 10 or 20 years?

- Still important, probably burning even more biomass and wastes
- Further incremental efficiency improvements
- Higher steam conditions (460 MWe S/C unit now operating in Poland – full load achieved Mar 2009)
- CCS using flue gas scrubbing, oxygen firing or, in new designs, chemical looping
Integrated gasification combined cycle (IGCC)

- Commercial demonstrations in USA and Europe and Japan. Shortly in China, another in USA. Others at FEED stage
- Cost and availability concerns have held back orders in past
- Efficiency ~43-45% LHV
- Very low emissions, mercury capture simple

**How will it be in 10 or 20 years?**

- More widely deployed
- Advancing performance and perhaps reducing cost differential with PCC
- Above from more advanced gas turbines and new gasifier designs, dry gas cleaning
- Polygeneration
- CCS using pre-combustion capture
Flue gas scrubbing (amines, ammonia, chilled ammonia):

- Experience to ~20 MWe
- Issues such as corrosion, solvent degradation controllable
- Efficiency penalty high but potential to decrease (~9% points)
- Scrubbing demos to 20 MWe. Larger projects upcoming, e.g. in Canada

Oxy-coal firing:

- Demonstrated at 30 MWth pilot scale in Germany
- Retrofit in progress at 30 MWe in Australia. Larger projects upcoming EU and USA
- Efficiency penalty appears similar to chemical scrubbing
- New oxygen production technology could reduce penalty if introduced
CO$_2$ capture: IGCC plants

- Physical or chemical solvent scrubbing of CO$_2$ is established in chemical industry
- 2-5 MWe pilot capture plants at EU IGCC plants (Buggenum and Puertollano)
- Lower energy penalty than for PCC
- Experience of E-class GTs on 95% H$_2$
- Other methods of separation available
- Other schemes without shift
Coverage of review of some existing OECD programmes and roadmaps in 2009

- **USA:** CCPI CCS demonstrations, Recovery and Reinvestment Act funds; FutureGen (now oxyfuel); Carbon Sequestration Technology R&D Program; CURC-EPRI Coal Roadmap
- **Canada:** Clean Coal Technology and CO$_2$ Capture and Storage Roadmaps; Clean Energy Fund May 2009, CCS research and demonstrations; Alberta fund for CCS; CCPC
- **Australia:** ACA COAL21 National Action Plan and COAL21 Fund; National Clean Coal Fund; New Clean Energy Initiative, CCS Flagships Program; Programmes of Queensland, NSW and Victoria Governments; GCCSI
- **Europe:** Funding for some CCS projects from budget surplus, others from sale of EUAs; Framework Programme with strong focus on CCS and CCTs; COST, covering basic and pre-competitive research; ZEP Technology Platform
- **Japan:** C3 Initiative CCUJ roadmap; METI Energy Technology Strategy Map and Cool Earth Innovative Energy Technology Program Technology Development Roadmap
The report described a number of then existing CCT and CCS projects, and four annexes listed many more. Example projects included:

**Advanced supercritical pulverised coal plant:**
700° C Wilhelmshaven 50+ project, Germany

**Post combustion capture:**
Vattenfall demonstration project, Nordjyllandsvaerket, Denmark; Latrobe Valley Post Combustion Capture Project, Australia; Alstom chilled ammonia CO₂ capture demonstrations, USA

**Oxy-fuel:**
Vattenfall 30 MWth pilot project, Germany; CS Energy Callide A demonstration, Australia; Jamestown CFB oxy-coal combustion demonstration, NY, USA

**IGCC (with and without capture):**
HRL (Australia) demonstration; Powerfuel project, UK, GreenGen project, China, ZeroGen project, Australia
Maximising future security of electricity supply and its extension to non-supplied populations was of high priority, so reliance on coal would have to continue.

Accompanying potential CO$_2$ emissions needed to be addressed.

This required continuing assessment of development barriers and addressing the associated R, D & D to develop CCTs and CCS.

A range of coal technology options needed to be maintained, with provision for breakthrough systems to be explored.
Conclusions from 2009 survey of international roadmaps and projects ... (2)

- CCT developments needed to integrate well with CCS
- CCS needed to be proven in time for commercial deployment by the mid 2020s
- A good line-up of CCS pilot and demonstration projects was in prospect, although a greater sense of urgency was warranted
- Two-way technology cooperation between OECD and non-OECD countries was needed to ensure that the above occurred worldwide
- Dependence on future advances would not be the sole solution: major CO$_2$ emissions savings could be achieved by using current best CCT designs more widely
Although there have been some lost projects and delays, a significant number have survived.

New projects have emerged, both CCTs and CCS.

CO₂ capture has been demonstrated on coal systems at pilot (up to 20MWe) scale and FEED studies are in progress for demonstrations at 100-200 MWe for combustion technologies.

CO₂ capture is now being operated on IGCC slipstreams at 2-5 MWe pilot scale at two EU plants; a larger demonstration (about 50 MWe equivalent) is planned in the USA.
IGCC projects include new plants under construction in the USA and China, with plans for addition of at least partial CCS. One or two other new IGCC projects including CCS look fairly likely to proceed.

Unfortunately, the 50+ plant at Wilhelmshaven is indefinitely suspended.

There are possible signs of a lessening commitment to coal by some governments, prompted by adverse public reactions as well as financial tightening.
• 90% CO\textsubscript{2} capture part of standard equipment, various systems, and other emissions at virtually zero levels

• Availability >90% combustion-based systems; >85% gasification-based systems

• Efficiency of power generation approaching as far as possible that of current non-capture systems (40-45%, net, LHV)

• Substantial reduction in CO\textsubscript{2} abatement cost (40-50 US$/t predicted in 2009)
The following slides include diagrams from the 2009 report. They are simplified in the tables following them, where recent developments are also highlighted.
OECD roadmapping – PCC

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<td>COMMERCIAL USC TO 650°C+</td>
<td>COMMERCIAL CCS USC TO 35 MPa/700°C/720°C (scrubbing only for 700°C; oxy-coal to 600°C)</td>
<td>COMMERCIAL CCS USC ROUTINELY BEYOND 35MPa/700°C/720°C ALL CAPTURE SYSTEMS ALL COALS, ALL FIRING CONFIGURATIONS, EFFICIENCIES 40-45%; NET, LHV, INCL. CO2 CAPTURE, DEPENDING ON CONDITIONS AND SYSTEMS USED</td>
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<td>CCS R&amp;D, PILOTS AND DEMOS</td>
<td>ADVANCED FULL FLOW CCS DEMOS (scrubbing only for 700°C technology)</td>
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Emissions on bitum coals:
- Particulates 5-10 mg/m³
- SO₂ <20 mg/m³
- NOx 50-100 mg/m³
dry systems can give lower emissions

Full environmental controls at at least 2009 state-of-the-art emissions

Emissions on all coals:
- Particulates 1 mg/m³
- SO₂ 10 mg/m³
- NOx 10 mg/m³
- 90% mercury removal

Near-zero emissions all coals:
- Particulates <1 mg/m³
- SO₂ <10 mg/m³
- NOx <10 mg/m³
- 99% mercury removal
- 90% CO₂ capture

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Notes on PCC

- 500 MWe 700C+ PCC demonstration in Europe indefinitely suspended. Alternative demonstrations should be considered elsewhere. Sidestream CO₂ capture needs to be included.

- The associated R&D and pilot plant work is continuing.

- By 2020, such plants need to be offered commercially, supported by continuing materials development and testing.

- Consideration should be given to including full flow CO₂ scrubbing as part of a 700C demonstration.

- Other emissions decreasing.

- Development and deployment of dry gas cleaning and novel lignite drying should probably be specifically included in roadmap; also mercury capture as normal commercial option.
# OECD roadmapping – IGCC

### Current position (2009)
- 5 DEMOS/EX-Demos Operate, 250-300 MWe
- Various Entrained Gasifiers on Various Coals

### 2009-2015
- Construct, Operate Commercial Plants with Latest F- and W-class Turbines
- Commercial OP of New Water Quench Gasifiers
- R&D: Reduce capital cost, increase availability, extend range of coals. Gas turbine developments. Dry syngas cleaning. Cryogenic air separation, e.g. ITM. Modelling to optimise IGCC blocks

### 2015-2017
- Commercial Plants with Latest F- and W-class GTs. Some with Capture
- Commercial OP of New Water Quench Gasifiers
- R&D: Reduce cost, extend range of coals, increase availability. GT developments. Dry syngas cleaning. Slipstream gas polishing for fuel cells. ITM Pilot (stand-alone)

### 2017-2020
- Commercial Plants Operating with Latest F- and W-class GTs
- Commercial OP of Various Gasifier Types

### 2020-2025
- Commercial Plants Operating with H- or J-class GTs able to burn high hydrogen. Full CO₂ Capture Available
- Commercial OP of Various Gasifier Types
- R&D: Studies supporting commercial plants. Develop CO₂ GTs

### 2025-2030
- Commercial IGCC with H- or J-class GTs with Ultra-Low NOx on Hydrogen fuel. Full CO₂ Capture
- R&D: Studies supporting commercial plants

### Post-2030
- Advanced IGCC with CO₂ capture as standard using gas separation membranes and shift membrane reactors
- Capital cost lower than PCC with CCS

### Emissions:
- Particulates <1 mg/m³
- SO₂ <20 mg/m³
- NOx <50 mg/m³; SCR will allow lower levels
- Mercury capture demonstrated

### Supporting R&D
- Full emissions controls at least 2009 state-of-the-art
- Full flow pre-comb CCS demos using scrubbing.
- Advanced CCS Demos

### Key Points:
- Particulates: 0.1 mg/m³
- Emissions of SO₂ and NOx: <10 mg/m³
- 90% mercury removal
Notes on IGCC

- Construction of commercial demos in some number, operating 2010-2017, needed to extend experience with the technology
- As many as possible should include CO₂ capture demonstrations
- 2 new IGCCs in USA, 1 in China, will be operating within the next year or two, so some progress. Other still in prospect but experience with firing IGCC syngas turbines on hydrogen, hoped for in this period, may come a little slower than hoped
- Over period to 2030, movement to higher specification gas turbines and other developments is needed to keep efficiency progressing upwards; novel systems could play a major role; decreasing emissions
- Proving that high availability is maintainable will remain very important
## OECD roadmapping – CO₂ capture

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<tr>
<td><strong>4 LARGE SCALE CAPTURE DEMONSTRATIONS ON NON-POWER PLANTS</strong></td>
<td>POST-COMB CAPTURE: LARGE DEMOS 85% CAPTURE INCLUDING RETROFFITS USING SCRUBBING R&amp;D &amp; PILOTS ON PCC AND CFBC: develop/improve chemical solvents; laboratory work on post comb capture using dry systems</td>
<td>POST-COMB CAPTURE: LARGE DEMOS 85% CAPTURE INCLUDING RETROFFITS USING SCRUBBING R&amp;D &amp; PILOTS: test advanced solvents, dry systems. Capture slipstream on 35MPa/700°C/720°C unit.</td>
<td>POST-COMB CAPTURE: ADVANCED DEMOS &gt;85% CAPTURE INC RETROFFITS. R&amp;D: advanced solvents membrane contactors dry absorption, adsorption</td>
<td>FIRST COMMERCIAL SYSTEMS, &gt;85% CAPTURE. ALL 3 MAIN METHODS OF CAPTURE. NEW PLANTS AND RETROFITS</td>
<td>COMMERCIAL SYSTEMS 90%+ CAPTURE. POST-COMB CAPTURE: NEW SOLVENTS; MEMB CONTACTING; SOLID ABSORBENTS, ADSORBENTS</td>
<td>COMMERCIALY AVAILABLE SYSTEMS, 90%+ CO₂ CAPTURE, EFFICIENCIES 40-45%, NET, LHV, POST COMBUSTION CAPTURE: GREATLY REDUCED WATER CONSUMPTION FROM VARIOUS SYSTEMS.</td>
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<td><strong>NUMBER OF PILOT CAPTURE PLANTS</strong></td>
<td>PRE-COMB CAPTURE: LARGE DEMOS 85% CAPTURE PHYSICAL AND CHEMICAL SCRUBBING R&amp;D: H₂ combusting GTs, slipstream tests on memb separation, lab test membranes and membrane reactors, advanced gasifiers</td>
<td>PRE-COMB CAPTURE: LARGE DEMOS 85% CAPTURE PHYSICAL AND CHEMICAL SCRUBBING R&amp;D: air-extracting GTs for hydrogen, shift with low steam req’t, pilot membranes, membrane reactors, gasification fuel cell cycles, advanced gasifiers, novel IGCC cycles</td>
<td>PRE-COMB CAPTURE: ADVANCED DEMOS &gt;85% CAPTURE FULL FLOW DEMOS R&amp;D: H-class GTs for high H₂ fuels, pilot shift membrane reactors, novel IGCC cycles, pilot ITM IGCC</td>
<td>PRE-COMB CAPTURE: DEMO SHIFT MEMBRANE REACTORS; DEMO GASIFICATION FUEL CELL CYCLES FOR CCS; DEMO NOVEL GASIFICATION-BASED CYCLES; DEMO ITM IGCC CCS Supportive R&amp;D</td>
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Notes on CO₂ capture with update

- CO₂ capture technologies need rapid demonstration at 100 MWe plus to become commercially deployable in the 2020s
- All 3 main types of CO₂ capture need pursuing: a number of North American and EU publicly funded demonstration projects are likely to construct soon, with FEED studies begun
- Later demonstrations will allow performance and cost to be improved so that first commercial systems, from 2020, would use such systems
- During the 2020s, breakthrough systems need to be demonstrated (e.g. chemical looping, integrated ITM oxy-coal, membrane reactors, fuel cells) to provide bases of advanced post 2030 plants
- Supporting R&D will be needed throughout
Non-OECD roadmaps

- Other priorities and technology statuses may affect timing of R,D&D and commercialisation

- Reviews carried out to identify cooperation areas and technology transfer needs of three example countries (China, India, S Africa)

- Information used as input in developing non-OECD roadmaps
Coal use in China, India and South Africa
Power generation

Sipat power plant, India

Shanghai, 900 MW SC units

Fuyang Huaren, 660 MW SC units
### China power technologies roadmap including CO₂ capture

#### Current position (2009)
- **PCC**: SUBCRIT, SC AND USC
- **End 2009**: 24% PLANTS SC/USC UP TO 600°C
- **Numerous FBC units**

#### 2009-2015
- **Close small subcrit**
- **Deploy more SC and USC**
- **Knowledge sharing**: Emissions control systems SC CFBC
- **Post-comb CO₂ capture pilots**

#### 2009-2015
- **Knowledge sharing and technology transfer**: Gasification, gas turbines
- **GREENGEN IGCC stage II**: 25% flow pre-comb CCS Demo

#### 2015-2020
- **Close small subcrit**
- **Deploy more SC and USC**
- **Knowledge sharing and technology transfer**: Post-comb CO₂ capture
- **OXY-coal CO₂ capture**

#### 2015-2020
- **Post-comb CO₂ capture demos**
- **OXY-coal pilots and first demos**

#### 2020-2030
- **Deploy USC to 700°C**
- **First commercial CCS plants**
- **Knowledge sharing**: Advanced emissions control
- **Advanced post-comb CO₂ capture**
- **OXY-coal CO₂ capture**

#### 2020-2030
- **Advanced post-comb CO₂ capture demos**
- **OXY-coal demos**

#### Post-2030
- **Commercial CCS USC PCC and CFBC routinely beyond 35MPa/700°C/720°C**
- **All capture systems**
- **All coals, all firing configurations**
- **Efficiencies 40-45%, Net, LHV, inc CO₂ capture, depending on conditions and systems used**

#### IGCC Demos under construction
- **Commercial IGCC**
- **Commercial IGCC with CO₂ capture**
- **Technology transfer and knowledge sharing**: Advanced gas turbines
- **Dry gas cleaning**
- **Dry CO₂ capture**

#### IGCC CO₂ capture as standard
- **Some using membranes**
- **Efficiency 40-45%, LHV, inc CO₂ capture, depending on technology, coal type, conditions**
- **ITM oxygen as option with ITM-optimised H₂ GT**
- **Dry gas CK incl. mercury**
- **Fuel cells in some plants**
- **Eventually other systems with CO₂ GTs CO₂/H₂O GTs**

#### Emissions from comb plants:
- **Wide range but some plants have effective dust, SO₂, NOx controls**

#### Near-zero emissions, all coals:
- **Particulates 0.1 mg/m³**
- **SO₂ <10 mg/m³**
- **NOx <10 mg/m³**
- **99% mercury removal**
Non-OECD roadmapping: notes on power technologies with update

• In China, USC parameters reach close to world highest now

• Generation plants in India and South Africa now reaching supercritical – need to move quickly toward higher conditions through continuing external collaborations

• In 2009, there were two IGCC projects in China with timescales close to many OECD projects, and technology collaboration projects with overseas gas turbine manufacturers were in place. The GreenGen project is the only one currently under construction
China has many initiatives and activities on CO\textsubscript{2} capture, e.g. GreenGen IGCC project, post-combustion CO\textsubscript{2} capture plants of Huaneng, EOR using CO\textsubscript{2} from Shenhua CTL plant planned.

CCS activities have started in South Africa and a demonstration is planned. India interested in CCS for future but currently focused on efficiency improvement.

Non-OECD roadmapping: notes on CO\textsubscript{2} capture
Finally ...

Two general conclusions slides, followed by two more giving suggested pointers to discussion items
CCTs need further development to improve efficiencies and reduce emissions to near zero by 2030. Current application of best coal technologies needs to spread much further.

Demonstration of PCC at very high parameters has stalled but needs to be revived and if possible include CO$_2$ capture.

Commercial demonstrations of novel lignite drying systems are needed for higher efficiency with such fuel on PCC and IGCC.

IGCC orders are still disappointing.

CO$_2$ capture technologies on coal systems, now at up to 20 MWe, needs larger demonstrations to achieve commercial CCS in the 2020s. This process is occurring, with FEED studies and finance...
Conclusions ... (2)

- All 3 main types of CO₂ capture need progressing rapidly as well as potential breakthrough capture technologies
- Rapidly rising countries such as Brazil and Indonesia need to be encouraged through co-operations to use best available technology
- *Two-way* knowledge sharing between OECD and non-OECD will be increasingly important for CCT and CCS deployment
- CCS is beginning to worry some of the public: this perceptual issue needs solving before it becomes a real limitation on projects
Some initial pointers for this discussion ...

- Need to fit with IEA CCS roadmap
- **Need to look forward to 2050** – breakthrough technologies may be important
- **Metrics for roadmap to feature in report need to be agreed** – e.g. Extent of deployment of different types of plant, efficiency/heat rate, specific CO₂ emissions; other emissions; plant flexibility, water consumption, capital requirements, cost per MWh, cost per tonne of CO₂ avoided/captured
- **Targets for selected metrics need to be agreed**
- **Is a target date for no further non-capture plants needed?**
- **Growing interest in use of low rank coals** – what are the best technologies for maximum efficiency?
- **Dry cooling and reduced water usage for CO₂ capture need to be accommodated while keeping CO₂ emissions low**
• **Technical development gaps identification** – e.g. proving commercial scale demonstration 700C PCC; establishing low energy consuming lignite drying; proving commercial scale IGCC with CCS and low NOx; achieving G and H-class gas turbines in a commercial IGCC, and gas turbine optimised for ITM oxygen; dry gas cleaning for PCC and IGCC; reducing costs and speeding development of breakthrough technologies such as chemical looping ...

• **IGCC still slow to take off but CCS was supposed to improve the relative prospects for IGCC because of a lower capture cost**: is cost now increasing compared with PCC-CCS? Cost of some IGCC-CCS projects has caused deferments/cancellations

• **Many IGCC-CCS projects are starting as NGCC for declared economic reasons. Is this the best way? Will they proceed beyond gas?**

• **Support for stable carbon price needed everywhere**