CO₂ Capture and Storage
RD&D Priorities and Investment Needs

Jacek Podkanski, Kamel Bennaceur,

Using long term scenarios for R&D priority setting
15-16 February 2007
International Energy Agency, Paris

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Drivers for R&D in CCS

- **Capture**
  - Cost reduction to reduce cost of electricity with CCS
  - Economics of enhanced recovery
  - H2 Generation

- **Storage**
  - Risk management
  - Trapping Mechanisms/Optimization of injection
  - Monitoring & Verification
  - Long-term interaction CO₂ - Formation
**CO₂ Capture and Storage - Cost Chain**

Power & Industrial processes with CO₂ capture and injection for Geological storage in producing or depleted oil and gas fields and aquifers.

**CO₂ export terminal or shipment**

Cost:
- $30 – $80 /t
- $1 - $10 /t*
- $2 - $10/t

Cost principally distance dependant

= $33 – $100/t

Monitoring costs: $0.1-1/t

*IEA GHG*
Overview of CO2 capture processes and systems

Post combustion
- Coal
- Gas
- Biomass
- Air
- O2
- CO2
- Power & Heat
- Separation
- N2

Pre combustion
- Gasification
- Coal
- Biomass
- Gas, Oil
- Air/O2
- Steam
- Reform + CO2 Sep.
- H2
- Power & Heat
- N2O2

Oxyfuel
- Coal
- Gas
- Biomass
- Air
- O2
- CO2
- Power & Heat
- Air Separation
- N2

Industrial processes
- Coal
- Gas
- Biomass
- Air/O2
- Process + CO2 Sep.
- Raw material
- Gas, Ammonia, Steel
- CO2

IPCC – 2005 / CCP
Estimated characteristics of power plants with CCS

<table>
<thead>
<tr>
<th>Fuel &amp; Technology</th>
<th>Ref. Year</th>
<th>Invest. Cost ($/kW)</th>
<th>Effic. (%)</th>
<th>Effic. Loss (%)</th>
<th>Addit. Fuel (%)</th>
<th>Capture Effic. (%)</th>
<th>Capture Cost ($/t)</th>
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## Post-Combustion Status

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ZEP – WG1 - 2006
## Pre-Combustion Status

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<td>High Efficiency H2 Gas Turbine</td>
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ZEP – WG1 - 2006
# Oxy-Fuel Status

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<td>Water/steam cycle</td>
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ZEP – WG1 - 2006
### CO2 Capture Technologies

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<th>Separation</th>
<th>Post-Combustion</th>
<th>Oxy-Fuel</th>
<th>Pre-Combustion</th>
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<td>CO2/N2</td>
<td>O2/N2</td>
<td>CO2/H2</td>
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<td>Capture technology</td>
<td>Current</td>
<td>Emerging</td>
<td>Current</td>
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<td>Solvents (Absorption)</td>
<td>Chemical Solvents</td>
<td>Improved Solvents</td>
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<td>Polymeric</td>
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<td>Zeolites</td>
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<td>Cryogenic</td>
<td>Liquefaction</td>
<td>Hybrid processes</td>
<td>Distillation</td>
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IPCC - 2005
CO₂ Storage Phases

Pre-Operation Phase
- Certification at start
- ~ 1-2 years

Operation Phase
- ~ 10-50 years

Post-Injection Phase
- Transfer of Liabilities
- ~ 100-1000 years

Site Selection
Site Characterization
Field Design

Site Construction
Site Preparation
Injection
Monitoring
Maintenance & Well Plugging

Performance & Risk Assessment

Schlumberger - 2006

INTERNATIONAL ENERGY AGENCY
AGENCE INTERNATIONALE DE L’ENERGIE
Major R&D programs

- IEA GHG R&D Programme
- EU FP5, FP6, and FP7 projects
- Japan: Rite > 60 MEuros pa
- Australia: CO2CRC
- USA:
  - DOE funding/Regional partnerships >€50 M € pa
  - Major University-led projects: GCEP, Stanford, MIT…
- Canada: NRCan, ARC, CANMET
- Germany: Cooretec
- Other International Projects: CCP…
- China joint projects: EU, Canada, USA
- Private Sector
CCS Technology Roadmaps

- European Union ZEP 2006
- US: NETL 2006, CURC/EPRI
- Canada: CANMET Center 2006, CCTRM
- Australia: CO2CRC – 2004
- CSLF – 2004
- Japan – Clean Coal 2002
- Germany, UK …
Components of FP7

- Continued focus on Carbon Capture and Storage

- Re-introduction of Clean Coal Technology in recognition of the drive for greater efficiency whilst CCS is developed and deployed

- Technology Platform to advise on strategy and direction of these two elements
EU R&D Funding for CCS Technologies

Objectives:

• Capture
  • Less than 20% increase in energy cost by 2007
  • Less than 10% by 2012
• Storage
  • Storage capacity within 30% by 2012
• MMV
  • 95% accounting

• European Technology Platform on Zero Emission Fuel Power Plants launched on December 2005
• Outreach programs (COACH …)
European Based R&D Programme

• CCS Projects
  • Enhanced Capture of CO₂ in Large Power Plant (ENCAP) Project – FP6 funded project
  • CO₂ from Capture and Storage (CASTOR) – FP6 funded project dealing with post-combustion capture
  • ISCC (In-situ CO₂ Capture Technology for Solid Fuel Gasification) – FP6 funded project
  • Vattenfall taking the initiative – 30 MW pilot plant study

• Polygeneration of Hydrogen and Electricity
  • HYPOGEN Project

• Material Development Programme
  • Component Test Facility for a 700°C Power Plant (COMTES700) – RFCS funded project – continuation of AD700 programme
USA Roadmap Development Principle

- **Short-term**: keep existing fleet in service; prepare for transition to near-zero-emission future
  - $\text{SO}_2$, $\text{NO}_x$, Hg
  - Plant optimization and control
  - Reduced carbon intensity
- **Long-term**: add near-zero emission energy plants
  - IGCCs to market
  - Advanced materials
  - Ultra-high efficiency hybrid systems
  - $\text{CO}_2$ capture and storage
USA Roadmap Development

- Global Climate Change Initiative
  - set a target of 18% GHG emission intensity reduction by 2012 (baseline year 2001)
- Future Gen – “Integrated Sequestration and Hydrogen Research Initiative”
  - US$ 1 Billion – 10 year programme
  - Target to demonstration a 275MW polygeneration plant by 2015
- Turbine of the Future Programme
  - Development of Gas Turbine firing with H\textsubscript{2} rich fuel
Gasification with Cleanup Separation

Fuel Cells

FutureGen

H₂ Production

Optimized Turbines

System Integration

Carbon Sequestration
USA Roadmap Development

- **Clean Coal Technology** –
  - “Clean Coal Power Initiative” (2001 – 2011)
    - US $ 2 Billion over 10 years
  - “Power Plant Improvement Initiative” (2001)
    - Focus on efficiency improvement and emission reduction

- **VISION 21 Programme** – “21\textsuperscript{st} Century Power Plant”

- **Material Development Programme**
  - Development of boiler material to achieve operating steam temperature greater than 750°C
Vision 21 Programme - Strategy

- Adv. Power Systems Demos, CCT, PPII
- Envir. Control (CCT, PPII)
- Emissions Control (PM, NO\textsubscript{x}, Hg)
- By-product Use
- Advanced Combustion Systems
- Water Management
- Vision 21 Technology Module and Integrated Plant Demos


- Technology Module Demos
- V21 Technology Module & Integrated Plant Demos
- Power Plants Existing and New
- V21 Plants
### Table 4.3 Performance Targets for Vision 21 Program

<table>
<thead>
<tr>
<th>Category</th>
<th>Target/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Efficiency</td>
<td>60% (LHV)</td>
</tr>
<tr>
<td>Cost competitiveness</td>
<td>Cost competitive with other energy systems</td>
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<tr>
<td>Timing</td>
<td>Major benefits by 2005; subsystems and modules by 2012; commercial plant design by 2015</td>
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<tr>
<td>NO$_x$/SO$_x$ emissions</td>
<td>&lt;4.3 µg/kJ</td>
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<tr>
<td>PM emissions</td>
<td>&lt;2.5 µg/kJ</td>
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<tr>
<td>Hg emissions</td>
<td>&lt;430 pg/kJ</td>
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<tr>
<td>CO$_2$ emissions</td>
<td>40 - 50% reduction with efficiency improvement; 100% reduction with CCS</td>
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</tbody>
</table>

(Source: IEA, 2003)
German: COORETEC Programme
UK: CAT Options are complementary

- Increased Efficiency
- Zero Emissions

Key issue will be value of CO₂

Zero emissions will need the most efficient plant

Carbon Reduction

Near-term | Mid-term | Long-term | Time
# Australia – Coal21 Action Plan

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*www.ieagreen.org.uk*
Australian R&D Programme

- Oxy-Combustion Development
  - Japanese-Australian cooperation
  - Pilot Scale study for PC Boiler Retrofit (25 MWe) – Callide A Project
- IGCC Demonstration Plant Programme
  - Demonstration of IGCC with carbon capture programme
  - Pilot plant study (16 MW and 65 MW)
  - 200 MW will be commissioned at Stanwell Power Station by 2010 - depending on the outcome of the feasibility study
- IDGCC for brown coal
  - Target to commission 800 MWe IDGCC by 2010
  - 100 MW IDGCC demonstration project is currently at site selection and costing stage. Decision to proceed will be made by mid-2006
- Ultra Clean Coal Development Programme
  - International cooperation with the Japanese (Hyper Coal Project)
  - A relationship was developed with the Chinese power utilities
### Japanese Vision - Development for 21st Century

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<th>Year</th>
<th>Environment Limitation</th>
<th>Resource Limitation</th>
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<tbody>
<tr>
<td>1990</td>
<td>CO₂ reduction rate: 10%</td>
<td>Efficiency increase: 1st generation - PFBC - PC (USC)</td>
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<tr>
<td>2000</td>
<td>10 - 20 %</td>
<td>Efficiency increase: 2nd generation - coal combustion &amp; gasification combined cycle power generation (IGCC, etc.) - DIOS, SCOPE21 - Reduction of emissions: 3 Tens</td>
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<tr>
<td>2010</td>
<td>20 - 30 %</td>
<td>Efficiency increase: Hybrid Generation - fuel cell power generation based on coal gasification - simultaneous power generation &amp; chemical feedstock gas production - hydrogen production from coal (CO₂ recovery and fixation) - elimination of emissions</td>
</tr>
<tr>
<td>2020</td>
<td>30 - 40%</td>
<td>Zero-emission generation - hydrogen from coal: fuel cell &amp; hydrogen turbine combined cycle power generation, hydrogen driven automobiles - concept of new coal industries: energy, iron and steel, and chemicals unified centre - CO₂ conversion and utilization</td>
</tr>
</tbody>
</table>

Note: Reduction rates are on an intensity basis
(Source: Michiaki, 2002)
Japanese C3 Initiative toward ZET Coal Utilisation

- **Coal gasification technology**
  - Air-blowing gasification
  - Oxygen-blowing gasification
  - High-grade coal gasification

- **Fixing technology**
  - CO2 separation/recovery
  - CO2 fixing

**Timeline**
- **2004**: Demstration test
- **2005**: Improvement of heat efficiency
- **2010**: Assimilation with separation/fixing technologies
- **2015**: Realization of zero-emission
- **2020**: Gasification furnace for industrial use
- **2025**: Commercial facility of IGFC
- **2030**: A-IGCC/A-IGFC

**Key Points**
- CO2 separation/recovery technologies
- CO2 fixing technologies
- Performance metrics: 46-48% (Transmission-end efficiency)

**Economic Considerations**
- On the assumption that the amount is the same as the current unit price of coal-fired power generation ($5.9/kWh as calculated on a trial basis by the Federation of Electric Power Companies of Japan)

**Economic Outcomes**
- $6/kWh
- $6-7/kWh

**Environmental Impact**
- Zero-emmission
Japanese R&D Programme

- IGCC Demonstration Project
  - Demonstration of 250 MW IGCC (based on oxygen enriched air blown gasifier) to be operational by 2007
  - Target efficiency (LHV basis) ~ 48%
- Energy Application for Gas, Liquid and Electricity (EAGLE) Programme
  - Target to deploy 50 MWe IGFC by 2010 (for distributed electricity)
  - Target to deploy 600 MWe IGFC by 2020
- Oxy-Combustion Development
  - International cooperation with Australia
- Hyper-Coal Project (Ultra Clean Coal Project)
  - International cooperation with Australia
  - Target to produce coal processed to remove ash and other undesirable components which will be fired directly in a turbine.
Commercial Scale Capture Projects

- Denmark: Ejsberg
- Norway: Hydro 400 MW by 2011
- StatOil: Mongstad 300 MW by 2014
- UK: Progress Energy
  - 800 MW by 2011
  - Eon, RWE
  - Powerfuels
  - BP
- Germany
  - RWE 400 MW by 2014
  - Vattenfall 30 MW in 2008
- 250 MW in 2020
- China
  - NZECA
- Japan:
  - HI Callide
  - ZeroGen
  - 100 MW by 2010
- Callide
- SaskPower
  - 300 MW by 2012
- FutureGen
  - 275 MW by 2012
- Lockwood IGCC
  - 1200 MW by ??
- Warrior Run
Storage Projects

- 50 Acid Gas Injection in North America
- 4 New CO2-EOR Pilots in Canada
- 70 CO2-EOR projects in U.S.A.

Key:
- ECBM projects
- EOR projects
- Gas production field
- Saline Aquifer

www.co2captureandstorage.info
Summary

- Drivers for R&D in CCS
  - Capture cost
  - Storage: Optimization and MMV
- Several technology roadmaps from North America, Europe, Japan and Australia
- International and regional coordination networks
- Announced commercial-scale projects are far from an emission-reduction “wedge” by 2020