Operational Flexibility of CCS

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Carbon Capture and Storage:
How is it Working and What Next?
IMechE, London, 13th-14th October 2010
IEA Greenhouse Gas Programme

- An Implementing Agreement established in 1991 by the International Energy Agency
- Aim is to:
  
  Provide members with definitive information on the role that technology can play in reducing greenhouse gas emissions
- Emphasis on CO$_2$ Capture and Storage (CCS)
- About 20 country members and 20 industrial sponsors
- Based at Cheltenham, UK
Outline of Presentation

- Why will power plants with CCS need to operate flexibly?
- How to achieve flexibility in CCS power generation
- Costs and emissions of flexible CCS in an electricity system
The Need for Flexibility

UK electricity demand, 2009
Electricity Demand

Do we need to decarbonise this electricity?

- **Base load**
  - 60% of total generation
  - Hours: 0-8000

- **Intermediate/peak load**
  - 40% of total generation
  - Hours: 8000-10000

Electricity generation, GW

Hours
CO₂ Emission Projections

- <100g/kWh by 2030
- UK Committee on Climate Change, 2009
The Role of CCS

- Power companies and national governments prefer diverse energy supplies to reduce risks
- CCS will operate in grids with other technologies
- Power plants are usually operated according to a merit order based on marginal operating costs

- Wind / solar / marine energy
- Nuclear
- Fossil fuels with CCS / Biomass
- Fossil fuels without CCS

Lower marginal cost - operate whenever available
Higher marginal cost - operate at lower load factor

Note: Renewable plants rather than nuclear plants may be turned down to cope with short term demand variations because they incur lower costs for changing load.
Impact of Renewables/Nuclear on Fossil Fuel Plant Operation

35% wind, 25% nuclear

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<tr>
<th>Electricity generation, GW</th>
<th>Hours</th>
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- Blue line: Fossil fuel + nuclear + wind generation
- Green line: Fossil fuel + nuclear generation
- Pink line: Fossil fuel generation
Plant Load Factors

Load factor of fossil fuel plants: % of plant availability
35% wind, 25% nuclear
Rate of Change of Load for Fossil Fuel Power Plants

Assuming 35% of generation from wind, 25% nuclear
Based on 2009 UK power demand (half-hourly periods)
Wind power output scaled from 2009 NETA data
How to Achieve Flexibility

• Integrated power generation and CCS plants
  • CCS needs to operate flexibly
• Non-integrated CCS and power generation plants
  • Avoids the need for CCS flexibility
Integrated CCS Power Plant

IGCC

- Fuel
- Gasification and shift conversion
- CO₂ capture and compression
- CO₂ transport and storage
- Hydrogen-rich gas

Power plant (combined cycle)

- CO₂

Post combustion / Oxy-combustion

- Fuel
- Boiler or gas turbine
- CO₂ capture / purification and compression
- CO₂ transport and storage
- Flue gas
- Steam

Power plant (steam cycle)

- Low-CO₂ flue gas

- CCS operates at the same load factor as the power plant
- Utilisation of CCS plant is low at low power plant load factors
- Flexible CO₂ capture, transport and storage is needed
Flexibility of Integrated CCS

- Potential constraints on flexible operation of capture plants
  - Thermal cycling of equipment
  - Liquid distribution in columns
  - Process materials reaching steady state
  - Constraints imposed by energy integration for improved efficiency
  - CO₂ compressor turndown
- Process developers are working on flexibility
- Little information in the public domain
- CASTOR/CESAR pilot plant experience:
  - “The capture plant will be as flexible as the power plant”
  - Small scale: 1t/h CO₂
- Further work needed to demonstrate flexible operation
- Some constraints may be overcome by accepting lower percentage capture of CO₂ during load changes
  - Impact on overall annual emissions needs to be assessed
  - Regulations need to allow it
CO₂ Transport and Storage

• Potential constraints on flexible operation
  • CO₂ pipeline operation
    o CO₂ normally piped in the dense phase – different to natural gas
  • CO₂ underground storage reservoirs
    o Encouraging experience of flexibility at In Salah
    o Experience at more storage sites is needed
    o Some concerns about impact of intermittent operation on long term storage capacity

• Little information in the public domain
Flexibility of CO\textsubscript{2} Storage
Information from In Salah

J Forsyth, BP. CCS operating experience from InSalah, IEAGHG report 2010/1, January 2010
Non-Integrated CCS

- Only the power plant has to operate flexibly
- CCS can operate continuously, no need for flexibility
- High utilisation of CCS equipment
Non-Integrated CCS
emissions: 98.5-99% capture

Gasification and capture
- full load operation

Coal → Gasification and shift conversion → CO₂ capture and compression → CO₂ transport and storage

Hydrogen-rich gas → PSA → On-site power → Post combustion capture

Tail gas → CO₂ capture and compression

Power plant - flexible operation

Underground hydrogen storage (salt cavern) → Power plant (combined or open cycle) → Flue gas

Power

Hydrogen for other consumers (optional)
Hydrogen Storage

- Solution mined salt caverns, widely used for natural gas storage
- Commercial experience of hydrogen storage in salt caverns
  - UK
    - Former ICI chemical complex, Teesside
    - Caverns now operated by SABIC
    - 3 caverns, 200-300 tonnes H₂ each
    - Operated for many years, no discernable leakage
  - USA
    - Air Liquide, Texas
    - Cavern 250 feet diameter, 1500 feet long
    - 93 million Nm³ working capacity (8,000 tonne)
    - No scale up required for CCS
Hydrogen Storage

Modelling of UK electricity system with 35% wind and 25% nuclear

Total storage volume to enable gasification/CCS plants to operate at full load is equivalent to 27 days of UK natural gas consumption
Non-Integrated CCS

- Issues to be considered for flexible operation
  - Hydrogen combustion in gas turbines
  - Availability of salt strata suitable for hydrogen storage
  - Hydrogen storage in geological structures other than salt caverns
Costs of Electricity with CCS (Individual plants)

Coal: €2/GJ, Gas: €6-8/GJ, Discount rate: 8%, Plant life: 25 years, O+M cost: 4%/y of capital, CO₂ transport and storage: €5/tonne
Electricity costs for fossil fuel plants in an overall system:

- Fraction of fossil fuel plants with CCS is increased to reduce emissions.
- CCS plants operate at the highest load factors.
- Open cycle gas turbines used for lowest load factors.

€6/GJ natural gas cost
Electricity costs
Fossil fuel plants in an overall system

€8/GJ natural gas cost
Conclusions

- CCS operational flexibility requirement depends on:
  - The variability of power demand
  - The amount of renewables and nuclear in the grid
  - The overall CO₂ emissions target
- Two approaches for flexible fossil fuel power generation:
  - Integrated power generation with CCS
    - CCS has to operate flexibly
  - Non-integrated CCS and power generation
    - CCS flexibility is not necessary
- Further work is need to demonstrate flexible operation of CCS plants
- Optimum combination of flexible CCS power plants depends strongly on fuel prices and emission limits
Thank you

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