Drivers and challenges for flexible operation of pulverised coal power plants with CCS

Hannah Chalmers, Matt Leach and Jon Gibbins
hannah.chalmers02@imperial.ac.uk
h.chalmers@surrey.ac.uk

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Outline

• Electricity system and policy considerations

• Short run marginal cost sensitivities

• CO$_2$ capture bypass: importance within a day?

• Solvent storage as an alternative
Coal-fired plant roles in electricity systems

- Most studies focus on providing electrical energy
- Role of coal can vary
- More flexibility required to complement nuclear and/or renewables?

- Ancillary service categories indicate range of network support
- System needs depend on range of factors (e.g. hydro availability)
- Range of different procurement options used

Top: Demand profiles based on UK SCAR report and peak assumed to be >80% of peak load
Policy context and possible constraints

Overall effort also important to maintain continuity

e.g. 20 plants committed by 2010 globally?

FIRST TRANCHE Demonstration

SECOND TRANCHE Commercial & Regulatory Drivers

CCS ROLLOUT STARTS

GLOBAL CCS ROLLOUT
Big prize is getting two learning cycles from two tranches of CCS projects before global rollout

PLANTS COMING INTO SERVICE

2015 DEMO PROJECTS IN PLACE

2020 CCS STANDARD IN DEVELOPED COUNTRIES?

2025 GLOBAL CCS ROLLOUT

Semi-commercial plants with additional support mechanisms more likely? But then need to decide what form the additional mechanism should take. Market based approaches likely in some jurisdictions...

May have selection criteria as in UK/Europe. Rules for operation will then depend on contract between funder and project consortium.

Figure based on Gibbins and Chalmers (2008), Energy Policy
SRMC variation ($2.2/GJ coal, $7.8/GJ gas)

Coal with CCS (36-44% LHV with 9% point energy penalty)
NGCC with CCS (55.5-60% LHV with 7% point energy penalty)
Coal without CCS (36-44% LHV)
NGCC without CCS (55.5-60% LHV)

Short run marginal cost ($/MWh)

CO₂ price ($/tCO₂)

Base case plant technical performance generally following IEAGHG studies from 2004/5
Base case plant technical performance generally following IEAGHG studies from 2004/5
Change in supercrit with CCS SRMC for other factors ($2.2/GJ coal, $7.8/GJ gas)

- Lower base plant efficiency (40% LHV)
- Higher base plant efficiency (50% LHV)
- Lower energy penalty (7%)
- Higher energy penalty (11%)
- Lower %CO2 captured (85%)
- Higher %CO2 capture (95%)
- Lower CO2 capture opex ($8/tCO2)
- Higher CO2 capture opex ($24/tCO2)
Basic post-combustion liquid solvent system

- **FLUE GAS**
- **CONDENSATE FROM CO2**
- **SOLVENT SOLUTION**
- **CO2**
- **BOILER FEED WATER**
- **COOLING WATER**

**Diagram Elements**:
- **SCRUBBER**
- **STRIPPER**
- **LEAN/RICH HEAT EXCHANGER**
- **REFLUX CONDENSERS**
- **REBOILER**
- **STEAM FOR CO2 RELEASE**
- **ALSO REQUIRE POWER FOR CO2 COMPRESSION**

** Processes**:
- **CLEANED FLUE GAS FROM POWER PLANT**
- **FLUE GAS COOLER**
- **BLOWER**
- **GAS TO STACK**
- **OPTION FOR VOLUNTARY BYPASS (HIGH ELECTRICITY PRICE AND/OR LOW CO2 PRICE)**

**Additional Notes**:
- **ALSO REQUIRE POWER FOR CO2 COMPRESSION**
Basic post-combustion liquid solvent system

• Bypass likely to be added for reliability/availability/maintainability (operability?)
  - Additional output to network only possible if balance-of-plant capacity big enough (e.g. generator)
  - Could open options for providing ancillary services (e.g. fast ramp when steam diverted back to power plant)
• Economic case affected by relative CO₂ and electricity prices
• Possibilities will depend on policy as well as on economics/technology
Hourly short run revenue for supercrit with CCS SRMC ($2.2/GJ coal, $7.8/GJ gas)

'high' daytime price
max of NGCC or subcrit
(both without CCS)
setting the electricity price

- $2.2/GJ coal, $7.8/GJ gas, no bypass
- $4.4/GJ coal, $7.8/GJ gas, no bypass
- $2.2/GJ coal, £15.6/GJ gas, no bypass
- $4.4/GJ coal, £15.6/GJ gas, no bypass
- $2.2/GJ coal, $7.8/GJ gas, with bypass
- $4.4/GJ coal, $7.8/GJ gas, with bypass
- $2.2/GJ coal, £15.6/GJ gas, with bypass
- $4.4/GJ coal, £15.6/GJ gas, with bypass
Hourly short run revenue for supercrit with CCS SRMC ($2.2/GJ coal, $7.8/GJ gas)

‘mid’ daytime price
min of NGCC (no CCS) or subcrit (may have CCS) setting the electricity price

- $2.2/GJ coal, $7.8/GJ gas, no bypass
- $4.4/GJ coal, $7.8/GJ gas, no bypass
- $2.2/GJ coal, £15.6/GJ gas, no bypass
- $4.4/GJ coal, £15.6/GJ gas, no bypass
- $2.2/GJ coal, $7.8/GJ gas, with bypass
- $4.4/GJ coal, $7.8/GJ gas, with bypass
- $2.2/GJ coal, $15.6/GJ gas, with bypass
- $4.4/GJ coal, $15.6/GJ gas, with bypass
Does bypass matter within a day?

- Likely that night profits insignificant
- 14hr daytime with NGCC (no CCS) as the marginal plant
- 2hr peak
- Need low CO$_2$ price or high peak revenue for bypass to make sense
Solvent storage - additional operating option?

- FLUE GAS
- CONDENSATE FROM CO2
- SOLVENT SOLUTION
- CO2
- BOILER FEED WATER
- COOLING WATER

Optional Lean Solvent Storage

Leak/Rich Heat Exchanger

Reflux Condensers

Also require power for CO2 compression

Cleaned Flue Gas from Power Plant

Flue Gas Cooler

BLOWER

Optional Rich Solvent Storage

Reboiler

Steam for CO2 Release
Solvent storage - additional operating option?

- Allows flexibility, but avoids CO$_2$ emissions
- Potential synergies with renewables – rapid additional supply and lower minimum output during solvent regeneration
- Further work needed on engineering details
- Additional capital required to install extra facilities
- Need to consider balance-of-plant (as partial cap.)
- Different operating modes to consider -> need to learn from pumped storage hydro operations?
Initial illustrative analysis of short run value of solvent storage for supercrit with CCS

- Numbers not real, but some trends may be robust
- Short run benefit expected, but also need to consider capex etc
- Ancillary service value neglected (as in other examples)

Source: Chalmers et al, submitted to IJG GC
Assumptions for previous slide

- Net plant output with CCS (at full load): 750MW
- No balance of plant constraints for increased output with capture plant bypass (which incurs no energy penalty)
- Fuel prices: $2.2/GJ coal and $7.8/GJ
- Marginal costs for CO₂ capture, transport and storage: $16/t CO₂
- Other marginal operating costs: negligible
- Daytime electricity price: short run marginal cost of maximum of subcritical coal or NGCC (both without CO₂ capture)
- Night electricity price: short run marginal cost of minimum of subcritical coal or NGCC (both without CO₂ capture)
- Peak electricity price: 2x or 4x day electricity price
- Solvent storage cycle: 2hr storage with energy penalty = 1% of fuel LHV and 8hr of additional regeneration at 125% of normal flow with energy penalty = 125% of normal penalty
Conclusions

• A range of operating options could be valuable to coal-fired CCS power plants
• Potential policy constraints also important so need to contribute to ongoing debate
• Fuel price is a dominant factor in SRMC analysis
• Bypass could be economically valuable with high peaks (or low CO$_2$ price)
• Solvent storage could be important to allow flexibility without increasing plant CO$_2$ costs
• Initial economic analysis can help to highlight priorities for technical analysis (and demo tests)
Imperial College Centre for Carbon Capture and Storage

“Towards carbon-neutral energy and beyond”

www.imperial.ac.uk/ccs
Factors for describing plant operation

- Start-up/shutdown times (min or hr)
- Ramp rate when changing load (MW/min)
- Part load efficiency (%)
- Grid rated capacity and maximum output (MW)
- Minimum stable generation (MW)
- Variety of products
- Variety of fuels
  - Biomass + CCS potentially important since potential for negative emissions
Improving flexibility for oxyfuel

- Some utilities prefer oxyfuel, maybe partly since fewer steam cycle changes.
- Need to bypass CO\(_2\) compression and ASU to avoid majority of energy penalty.
- LOX storage likely to be critical:
  - ASU start-up
  - Supercrit fast response?

Source: IEAGHG R&D Programme, Report 2005/9
Different approaches for IGCC

• Very limited literature
• General conclusion is that it is preferable to avoid flexible operation of gasifiers

• Possibilities for H₂ and/or syngas storage
• Co-production, but check implications for meeting climate change goals for some products
• Part-load with gasifier output and add (probably expensive) natural gas for peaks only?