UKCCS RESEARCH CENTRE

Operating flexibility in future low carbon energy systems

IES conference

12th September 2017

Thomas Spitz[1,*], Francisco Ascui[2], Hannah Chalmers[1], Mathieu Lucquiaud[1]

[1]School of Engineering, University of Edinburgh, The King's Buildings, Edinburgh, EH9 3JL, UK

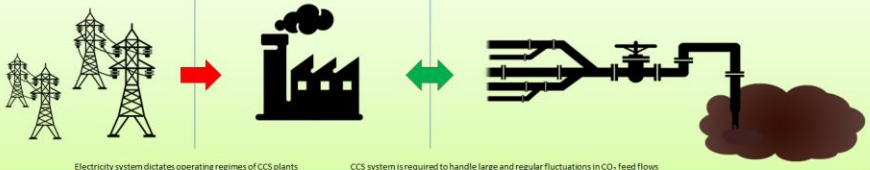
[2]Business School, University of Edinburgh, 29 Buccleuch Pl, Edinburgh, EH8 9JS, UK

Operating Flexibility of CO_2 Injection Wells

T. Spitz[a]*, H. Chalmers[b], F. Ascui[c], M. Lucquiaud[a].

[a] *Institute for Materials and Processes, School of Engineering, University of Edinburgh, Mayfield Road, Edinburgh, EH9 3JL, UK*
[b] *Institute for Energy Systems, School of Engineering, University of Edinburgh, Mayfield Road, Edinburgh, EH9 3JL, UK.*
[c] *Business School, University of Edinburgh, 29 Buccleuch Place, Edinburgh, EH8 9JS, UK.*

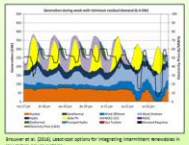
Overview

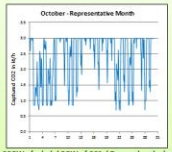


Electricity system dictates operating regimes of CCS plants

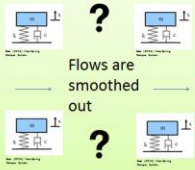
CCS system is required to handle large and regular fluctuations in CO_2 feed flows

Profiles





30GW of wind / 9GW of CCS / Demand and wind data from 2004 ('average windy year')



What are the risk and issues associated with variable flows for transportation, injection and storage networks?

How much variability can injection and storage system handle over the short and long term?

Electricity system dictates operating regimes of CCS plants

CCS system is required to handle large and regular fluctuations in CO_2 feed flows

Risks & Issues for Injection Wells

Hydrate formation

- Forms under high pressure and low temperatures
- Solid and ice-like appearance
- Consists of CO_2 trapped in a water lattice
- **Can plug flow and interrupt operation**
- **Difficult and time consuming to remove once they have formed**

Cracking of cement & wellbore materials

- Thermal load and temperature variations have large effect on casing, cement and formation stresses
- Steel, cement and rock will repeatedly expand and contract in volume and relative to each other due to different thermal expansion coefficients
- **Repeated cycling can create and enlarge fractures, fissures and radial cracking in cement sheath**

Hydrogen induced embrittlement

- Generally only a risk when there is H_2 or H_2S present in the flow
- Due to volatility of the gases their concentrations in the gas phase when flashing are increased
- Atomic **hydrogen can penetrate the well material which makes the material brittle**
- **It can also make the material more susceptible to fatigue failure**

Oscillations & Vibrations

- Vibrations can be classified into steady-state and dynamic transient vibrations
- Dynamic transient vibrations are usually more severe
- **Increased requirement for ramping amplifies risk associated with transient vibrations and oscillations**
- This is particularly the case when flashing happens across the well-head choke valve

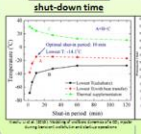
Reduced lifetime

- **The above effects can lead to reduced lifetimes of injection wells**
- No data yet available regarding lifetime reductions
- **Reduced lifetime leads to additional costs**
- Higher maintenance / work-over costs
- Need for drilling more wells
- These costs need to be compared against the cost of mitigating lifetime hampering processes and effects
- CO_2 flow balancing options
- Enable wells to cope better with CO_2 flow variability

Exaggerated by JT-effect at low loads when flashing is taking place across the wellhead choke valve

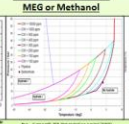
Operational & Design options → *Enabling CO_2 injection wells to cope better with fluctuating flow rates*

Optimal start-up & shut-down time



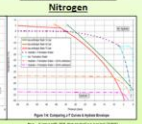
Mitigating low temperatures

Additional Injection of MEG or Methanol



Avoiding hydrate formation

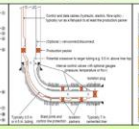
Additional Injection of Nitrogen



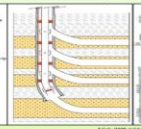
Increasing backpressure to reduce JT-effect

Ball Valves

Sliding Sleeves



Multilateral Wells



Multiple Tubing Strings

Increasing backpressure in the injection well to reduce JT-effect

Alternative Options → *Mitigating fluctuations of CO_2 flows to the injection wells*

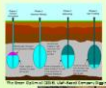
Energy Storage

Power Plant level

- Pre-combustion: H_2 storage
- PCC: Solvent storage
- Oxy-fuel: LOx storage

→ Balances CO2 feed flows to T&S system in order to mitigate flow fluctuations in injection wells

T&S Network level



Interim Storage:

- In Buffer Tanks
- Underground

What is the cheapest option?

*Corresponding author: T.Spitz@ed.ac.uk +44 (0)131 6507444

Rationale behind PhD project

- Most research focuses at CCS technology at steady state and on individual components along CCS process chain

vs.

- Increasing penetrations of intermittent renewable power on the grid mean CCS power stations (and downstream infrastructure) will need to operate more flexibly (part load/ramping)

Research Question:

- How do CCS power stations operate in future low carbon electricity systems?
- What are the flow rates feeding into CO2 T&S systems and will their variability cause issues?

PhD Research project

1) Requirement of CCS power stations in future low carbon power systems to operate flexibly

→ **Electricity system modelling**

2) Constraints to flexible operation along CCS process chain

→ **Search for constraints**

3) Options along CCS chain to balance variations in CO2 flow rates

→ **Power plant process modelling**

→ **Pipeline linepacking modelling**

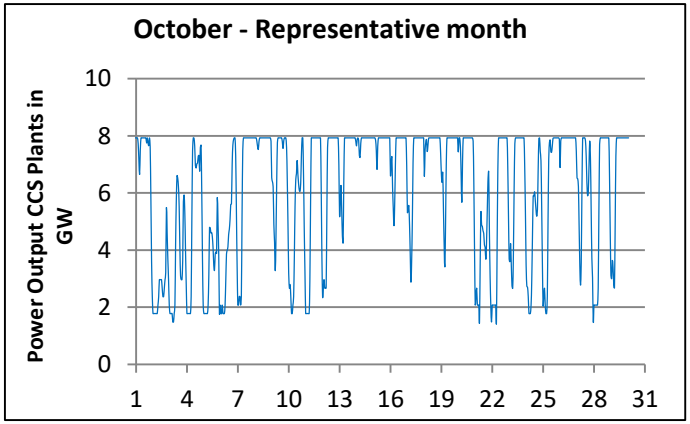
Operating profiles of CCS power stations in future low carbon electricity systems

UCED dispatch model

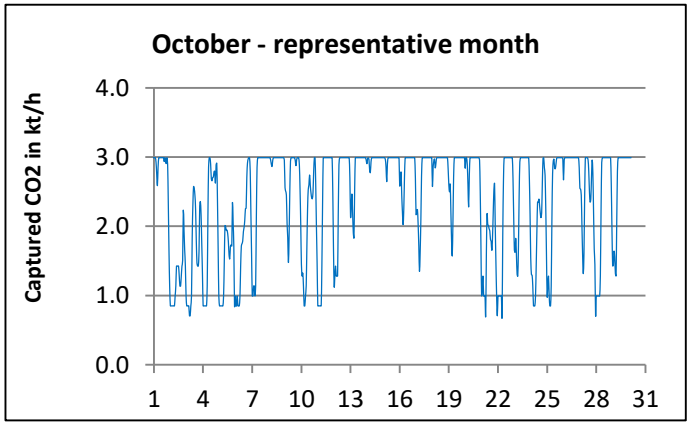
- GB power system (developed by Bruce 2015)
- High resolution historical wind data from 2002-2010 embedded (Hawkins 2012)
- Historical demand data (matching years)
- Nuclear power generation capacity 17.1GW (BEIS 2016)
- Wind fleet: Varied: 15-45GW installed capacity
- CCS (Gas) capacity: Varied: for reaching emission intensity targets (50,100,150g/kWh)
- Additional CCGT, OCGT, DSR capacity to satisfy de-rated capacity margin

Presented scenario

- 30GW available wind power generation capacity
- 100g/kWh CO2 emission intensity
- Wind and demand data from 2004 as 'average wind speed year'



Power generation operating profile for representative month (demand and wind data from October 2004)



Time profile of captured CO2 over representative month (demand and wind data from October 2004)

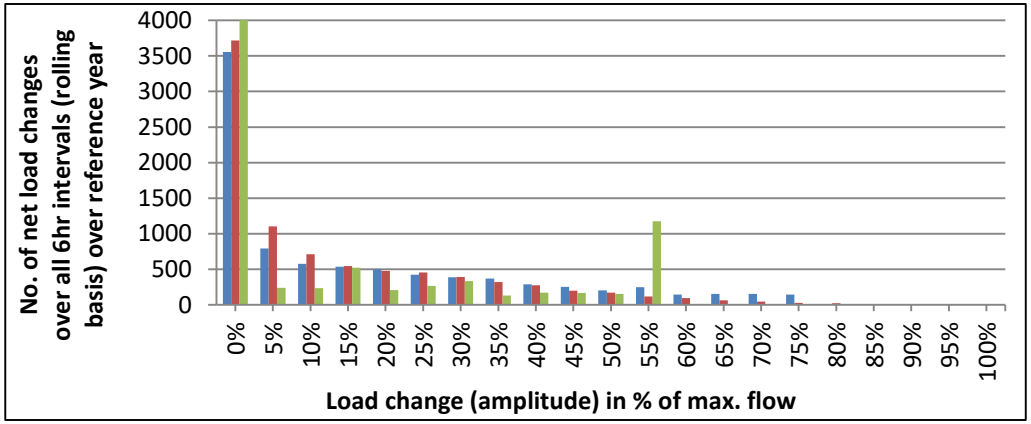
Captured CO_2 flows - Variability

Analysed variations in amount of CO2 that is produced:

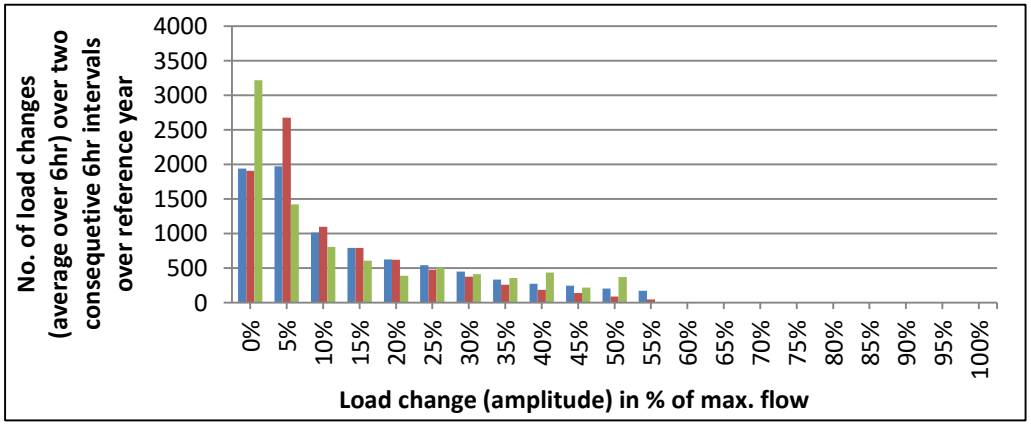
- Net CO2 flow rate variations over 6hr intervals (rolling basis over base year)
- **32%** of net load changes are **greater than 25%** of nominal flow and **18%** are **greater than 40%** of nominal flow

---

- Average CO2 changes over two consecutive 6h blocks (rolling basis over base year)
- **25%** of average changes are **greater than 25%** of nominal flow and **10%** are **greater than 40%** of nominal flow



Number and amplitude of net load changes over 6hr time periods over base year (rolling basis)



Number and amplitude of average load changes over two consecutive 6hr time blocks over base year (rolling basis)

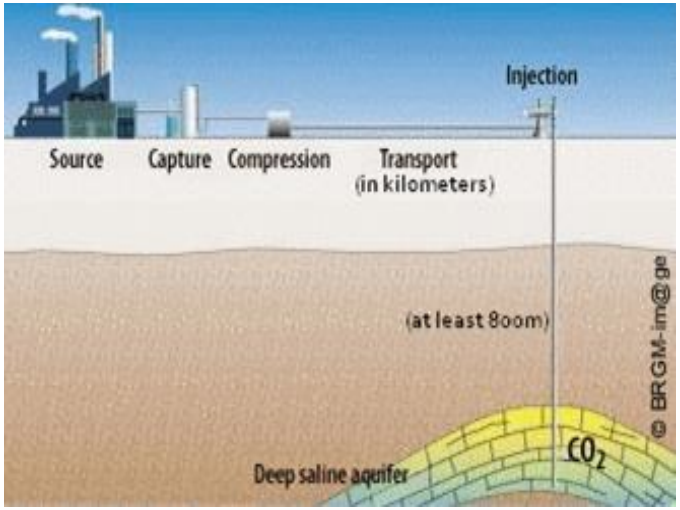
Constraints to flexible operation of CO2 T&S system

Transportation Pipeline	**Booster Station**
- Pressure boundaries to maintain single phase - Max. speed (erosional velocity) - (Ramp rates: 'Hammer effects')	- Ramp rates - Maximum and minimum flow
Injection well	**Reservoir**
- Hydrate formation (JT-cooling) - Cracking of cement and wellbore materials (JT-cooling) - Reduced lifetime due to cyclic thermal stresses (JT-cooling) - Hydrogen induced embrittlement of well material (Phase change) - Oscillations and vibrations (exaggerated by phase change) - (Ramp rates: 'Hammer effects')	- Maximum pressure levels - Halite build up (saline aquifers) - (Temperature variations to limit thermal stresses on rock)

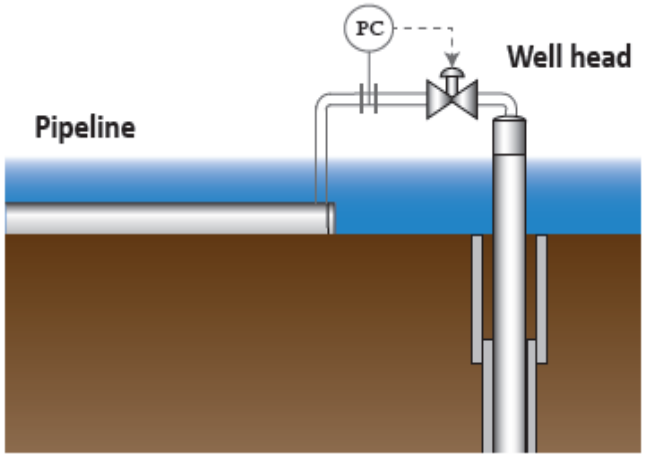
*Based on secondment to FEED study team of National Grid Carbon Ltd. for White Rose project in the UK. Information is sole responsibility of the authors.

Constraints to flexible operation of CO2 T&S system

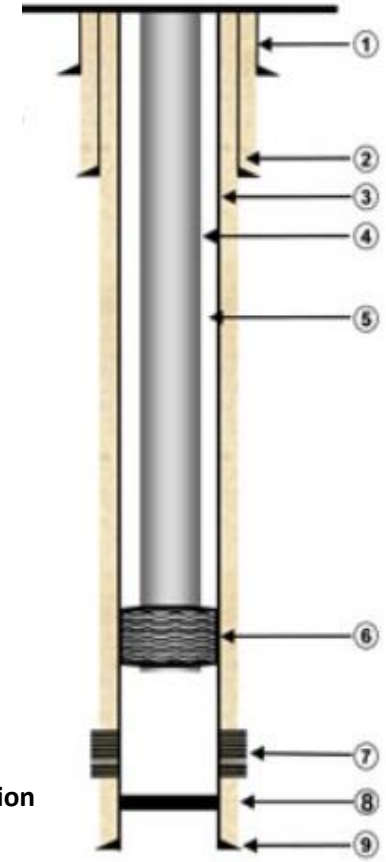
When does flashing happen? → Wellhead choke valve is crucial



Schematic illustration of carbon capture, transport, injection and storage chain (Club CO_2 2011)



Schematic illustration of the wellhead choke valve (Ogink 2015)



Schematic illustration of injection well (Koperna et al. 2012)

→ low reservoir pressures
→ Deep reservoirs
→ low flow-rates

Options to mitigate issues associated with variable flow rates

- **Balancing options on power plant level**
  - Solvent storage at PCC power plants
  - Liquid oxygen storage at oxy-fuel power plants
  - Hydrogen storage at pre-combustion power plants

- **Balancing options in CO2 T&S system**
  - Storage tanks
  - Interim storage in geological formation
  - Line-packing

- **Other options/Enable wells to operate more flexibly**
  - Sophisticated well design options
  - Intelligent wells

→ **What is the cheapest option?**

Which of these options do I consider in more detail

- Solvent storage in post combustion capture power plants
- Line-packing

→ Process modelling required

Thank you for your attention!!