Carbon Dioxide Pipelines for CCUS
UKCCSRC Webseries, March 2021

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Safety Moment

— Golden rules (Air Products)
— Stay away from the cloud
— CO2 monitors
  — Usual industry rules apply
  — Usual pipeline rules apply
  — Very different substance
  — Different release characteristics
  — Different physical characteristics
  — Different material needs
  — Don’t necessarily apply what has been done before
What is CCS “Infrastructure”?
What is a full CCS “Chain”?
US Pipelines
c. 6000km natural and anthropogenic sources
# Existing Pipelines – a sample

<table>
<thead>
<tr>
<th>Pipeline</th>
<th>Location</th>
<th>Length, km</th>
<th>Capacity, Mt/y</th>
<th>Pressure bar / Diameter mm</th>
<th>Year Complete</th>
<th>Origin of CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortez</td>
<td>USA</td>
<td>808</td>
<td>24</td>
<td>186 / 762</td>
<td>1984</td>
<td>McElmo Dome</td>
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<td>Sheep Mountain</td>
<td>USA</td>
<td>656</td>
<td>11</td>
<td>132 / 610</td>
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<tr>
<td>Bravo</td>
<td>USA</td>
<td>350</td>
<td>7.3</td>
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<tr>
<td>SACROC</td>
<td>USA</td>
<td>225</td>
<td>5.2</td>
<td>175 / 406</td>
<td>1972</td>
<td>Gasification</td>
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<td>175 / 406</td>
<td>1998</td>
<td>Val Verde Gas Plants</td>
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<td>Bati Raman</td>
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<td>2000</td>
<td>Gasification</td>
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<tr>
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<td>24</td>
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<td></td>
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<td>Snovhit</td>
<td>Norway</td>
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<td>0.7</td>
<td>100 / 200</td>
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<td>LNG Processing</td>
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</tbody>
</table>
Where is it done

- +8000km worldwide
- Over 140 million tonnes/year
- Onshore
  - North America
    - EOR
    - Geological sources
    - Anthropogenic sources
  - Algeria
    - EOR
    - Boundary Dam
    - MASDAR
- Offshore
  - Sleipner
  - Snovhit
Phase Diagram

Critical Point
31.1°C, 7391 kPa

Melting Line

Triple Point
-56.6°C, 517.7 kPa

Saturation Line

Sublimation Line

Typical Operating Region,
4-38°C, 8619 - 17250 kPa

Solid

Vapour

Liquid

Supercritical
Typical conditions

- Transport occurs above critical pressure
- 4 – 38°C
- 86 – 172 barg

- Typical Compositions
  - New ISO standard
  - US ranges
  - 95% CO2
  - <250ppmw/w water, no free water
  - <1500ppm w/w H2S
  - <450ppm w/w Total sulphur
  - <4% Nitrogen
  - <5% mole, <-28.9°C dew point hydrocarbons
  - <10ppm w/w O2
Pipeline Compression

— Typically as dense fluid
— Requires compression from low flue gas pressure
— Existing equipment
  — Piston/Positive Displacement
  — Centrifugal
  — Integrally geared
  — Compression + pump
— Requires
  — Dehydration
  — Cooling
Compression – things to watch for

- Basis configuration depends on
  - Flexibility
  - Reliability
  - Vendor data
  - Pipeline specification
  - Parasitic load requirements

- Integration with capture plant

- Dehydration technology
  - Glycol, mol sieve absorbers

- Conditioning
  - In series with dehydration
  - Removal of “marginal” contaminants
Regulations

— US and Canada
  — 49-CFR-195 Transportation of Hazardous Liquid Pipelines
  — 49-CFR-192 Transportation of Natural and Other Gas by Pipelines
  — Z662-07 Oil and Gas Pipeline Systems

— Regulations specify the design code
— 49-CFR-192 is also applied as any release will be gaseous
Regulations UK and the EU

- Pipeline design within current regulations
- Compressors may fall under COMAH/Seveso
- EU Specs
  - EN 14161 Petroleum and Natural Gas Industries – Pipeline Transportation System
- UK
  - BS PD 8010
  - Now includes tighter controls of CO2
- ISO
  - New standards for CCS
- HSE position on Carbon Dioxide
  - Still not clear
  - Apply a precautionary approach
  - Assume a dangerous fluid and dangerous substance
Standards

EN 14161
API 620, 650
ASME B16.9, B31.3
Section VIII Division 1
MSS SP-44-1996
ASTM A193/A193M, A194/A194M

BS 3293, 3518, 3974, 4515-1, 4515-2, 4882, 6651, 7361-1, 4515-2, 4882, 6651, 7361-1, 7910
EN 287, 288, 10204, 10208, 10224, 13480, 60079-10, 60079-14, ISO 3183-3, PD 5500

IEC 60079-10, 60079-14
ISO 3183-3
PD 5500

API 5L, 6A, RP 5L2
ASME B16.5, B16.9, B16.11, B16.20, B16.21, B16.47, B31.3, B31.8, Section VIII Division 1

MSS SP-44
NACE MR-0175
NFPA 30
BS PD 8010:1
General Pipeline Design

- Fluid properties
- Environment
- Effects of Temperature and Pressure
- Design conditions
- Supply and demand magnitude/locations
- Codes and standards
- Route, topography and access
- Environmental impact
- Economics
- Hydrological impact
- Seismic and volcanic impacts
- Material
- Construction
- Commissioning
- Operation
- Protection
- Integrity
Chemical Properties

- Carbon Dioxide + water
  - Carbonic acid
  - Weak acid
  - Acidity increases with temperature and pressure
- Clathrates (hydrates) can form at ambient temperatures and relatively low pressures.

- REMOVE THE WATER!
- Reactions with other treatment process chemicals
Entry Specification

- Specifies
  - What is in the pipeline
  - What is allowed in the pipeline

- Typical concerns around
  - Physical properties
  - Changes in critical point/phase transitions
  - HSE issues of contaminants on release
  - Geologic storage requirements
  - Corrosion
  - Integrity/pipeline design

- Provides reduced variability of fluids in a network
  - Sets part of the design basis for capture plants

- ISO 27913:2016
Constraints of contaminants

- Regulation
- Venting must be safe
- Default position
  - No contaminant may be present at a level that changes the safety and risk parameters of the host carbon dioxide stream
- Chemical
  - Reactions
  - Phase changes
  - Impact on fluid properties (water solubility etc)
- Mechanical issues
  - Corrosion
  - Decompression speed – changes may make integrity more of a challenge.
Flow Assurance

- Pipelines are static equipment
- Operational behaviour driven by outside influences
- Fluid flow must be controlled to avoid damage to storage sites
- Surge flow is not desirable
- Water content must be controlled
- Transient behavior, temps/press need to be understood
- EoS need to be defined and validated
Line pipe

— Steel
   — Stainless for wet service
   — Carbon steel for dry
   — Low temperature carbon steel for venting/blowdown

— Mechanical specification
   — Fracture control
     — Thick wall
     — Fracture (crack) arrestors

— Entry specification
   — Corrosion control
   — Decompression speed
Non Metallic Components

- CO2 penetrates into materials
- Depressuring can result in damage
- Trapped CO2 expands in situ causing;
  - Extrusion
  - Blistering
  - Rapid Gas (Explosive)
  - Decompression
- Affects
  - Valves
  - Seals
  - Gaskets
  - PIGS!
- Industry view of dispersion of CO2
- Sets the risk envelope of the pipeline
- Not like other gases, CO2 is heavy and will slump
Re-using existing infrastructure
Not always new pipelines

- Existing Natural Gas network
  - 30 – 94 bar
  - Not suitable for dense phase
  - Transport of gas is low

- Offshore pipelines are higher design pressures

- Distance offshore is a factor
  - Onshore booster stations can be fitted
  - Offshore boosters would require a platform

- Existing pipelines are aging

- Re-classify a pipeline
  - Re-do all calculations to appropriate standard
  - Inspection and repair
  - Apply new regulations and standards
Re-use of infrastructure

- Can we re-use the existing?
- Consider in projects
  - Longannet – NG NTS Feeder 10
  - Shell Peterhead – Goldeneye
  - ACORN – NG NTS Feeder 10
- Considerations
  - Materials of construction
  - Method of construction
  - Design conditions, particularly the design pressure
  - Routing and its suitability to new fluid
  - Safety and Environmental cases
  - Mitigation measures
  - Age issues, corrosion, inspection
  - System pressure
SUMMARY

- Pipelines a mature part of the chain
- Compression and pumping also proven
- Still some work to do in the context of CCS
Thank you!

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