Webinars

Flow assurance and CCS

(or: you are going to be doing this for the rest of your life)

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A quick introduction

- My name is Matt Healey
- I've been doing flow assurance since the 1990s

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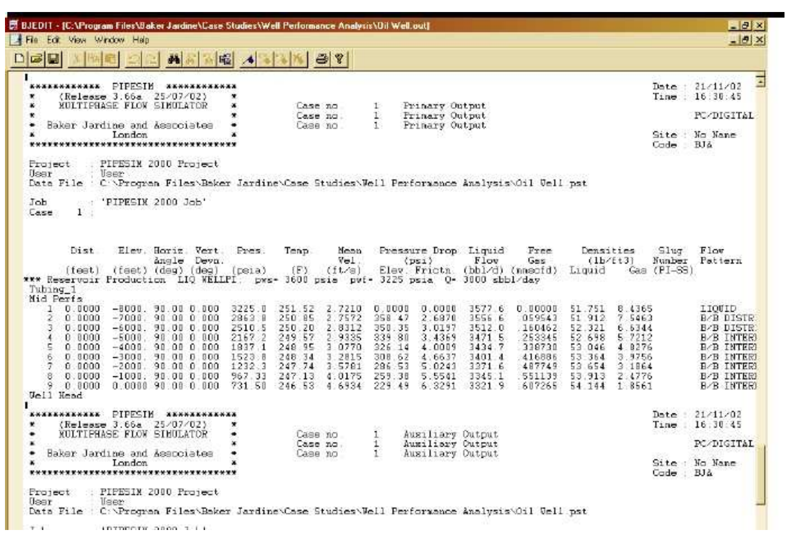
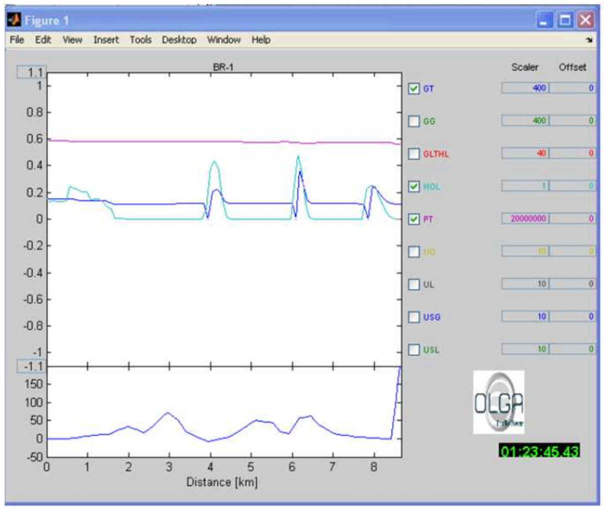
- Time for a history lesson

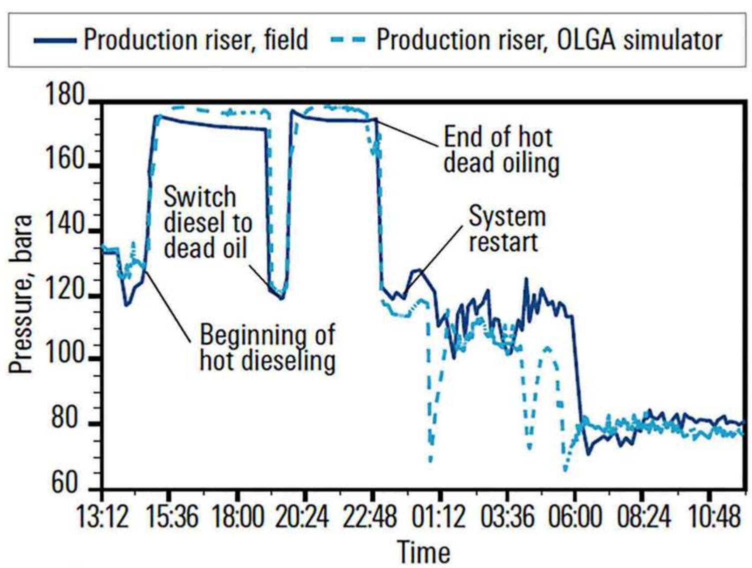
Flow assurance through the ages:1999



Flow assurance through the ages: 2005



Flow assurance through the ages: 2020



Flow assurance through the ages: 2022

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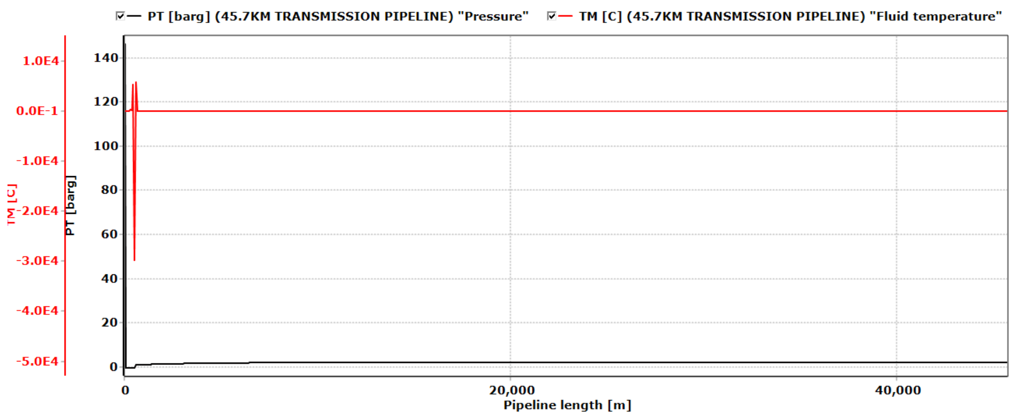

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Flow assurance is terrible again

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- We do not have appropriate tools for CCS flow assurance

Pros	Cons
Flow assurance engineers get paid by the hour	Our thermodynamic models are not suitable for CCS
	Olga is not suitable for CCS
	Ledaflow is even worse
	We don't have clear input data
	There are no tools to integrate flow assurance models with the storage reservoir (and that's really important)

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First things first: what is CCS

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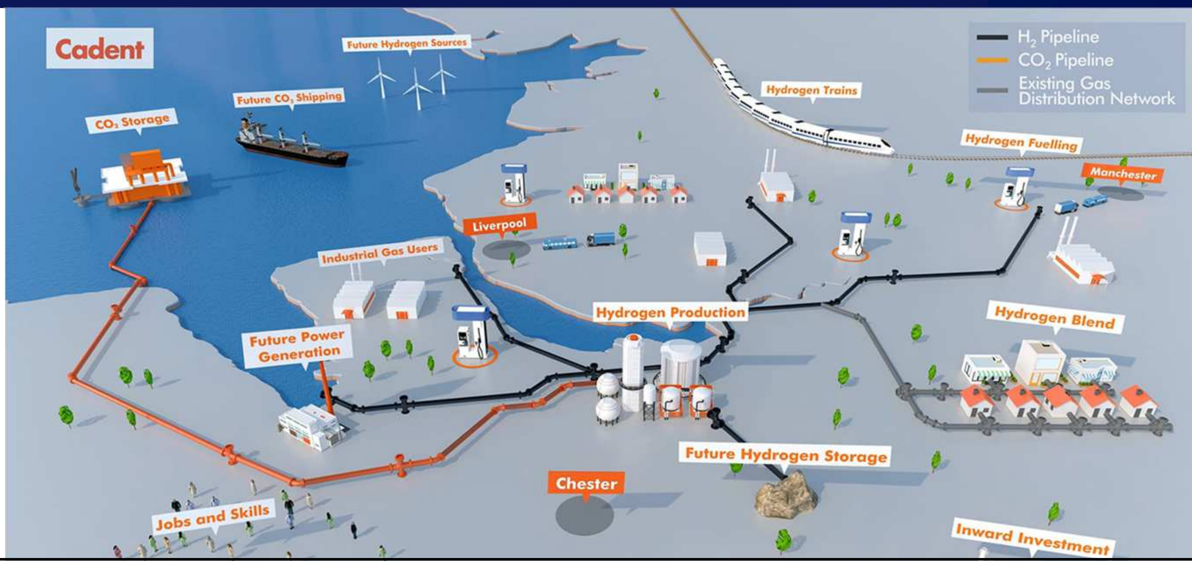

Why is flow assurance so important

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- The CCS operating range is huge
  – Turndown of 1% is not uncommon
  – Reservoir pressure often starts very low and end up very high
- CO2 phase behaviour is challenging
  – Operating pressures usually start where CO2 is a gas, and end where CO2 is a liquid
  – We are usually operating very close to the critical point
  – We have no useful information on CO2 two-phase flow
- CO2 has a very high Joule Thomson coefficient
- Availability of a CCS network needs to be very high, usually >99%

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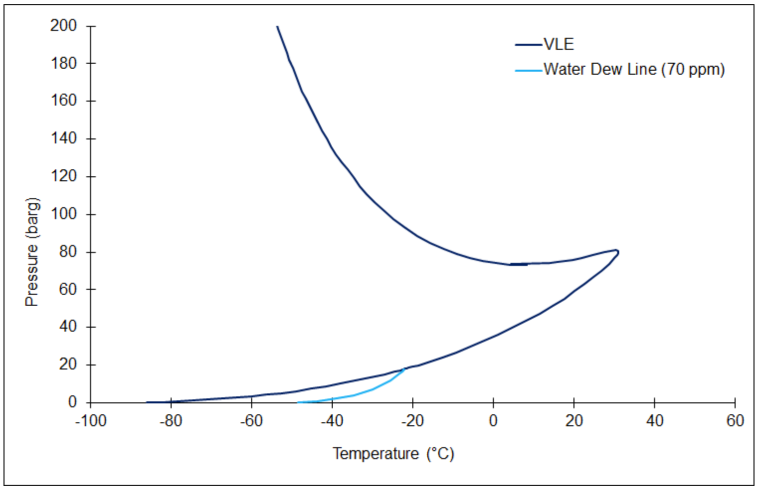
A phase envelope



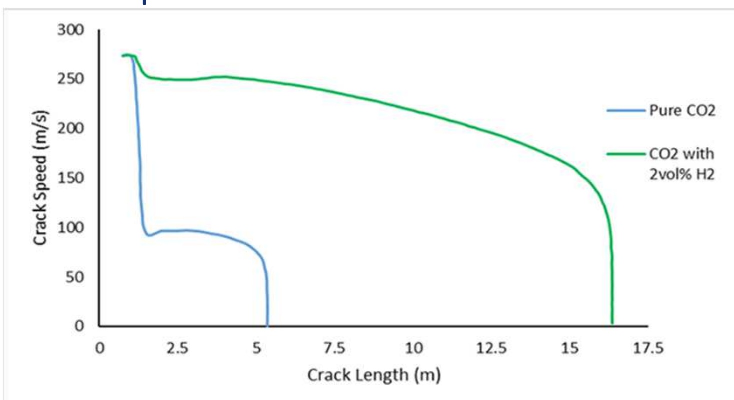
Why is flow assurance so important

- The flow assurance design integrates the entire system
  - CO2 industrial emitters will provide CO2 intermittently, but require fixed operating conditions
  - The reservoir pressure is not fixed
  - How to design a system that meets both needs?

- Bonus problem: there is essentially zero operating experience

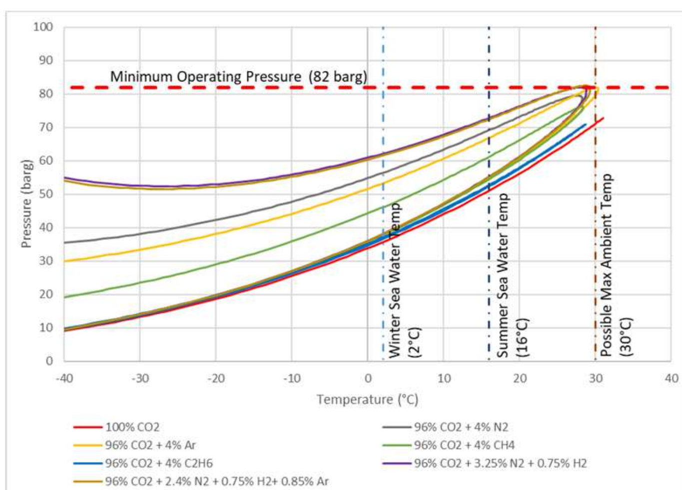
Flow assurance challenges

- First challenge: the CO_2 contains impurities
- Impurities are important



Flow assurance challenges

- There are dozens of impurities to consider.
- Some of them affect the bubble point and critical point…



Flow assurance challenges

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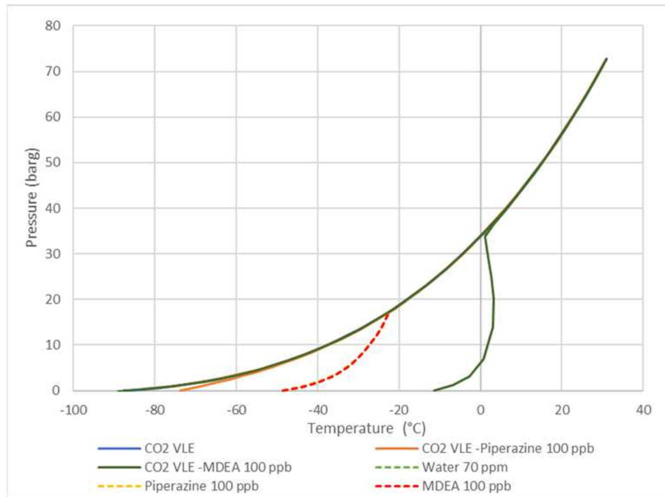
- ...and others affect the dew point.
- But we can't look at both at the same time: our thermodynamic models can't handle it.



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Flow assurance challenges

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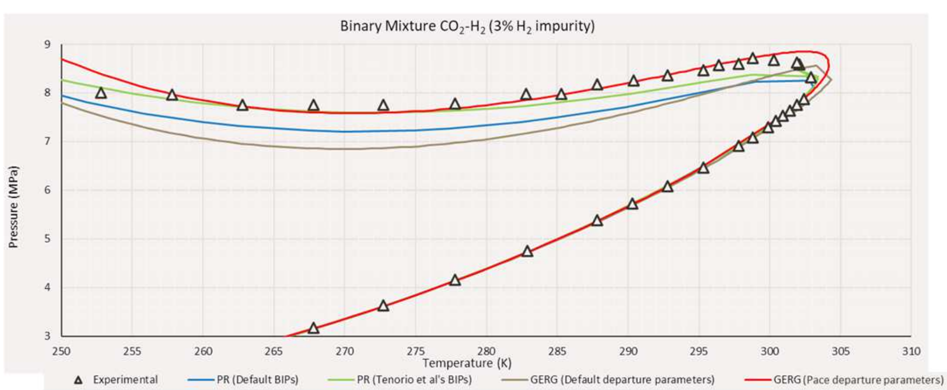
- Our thermodynamic models are also poor...



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Flow assurance challenges

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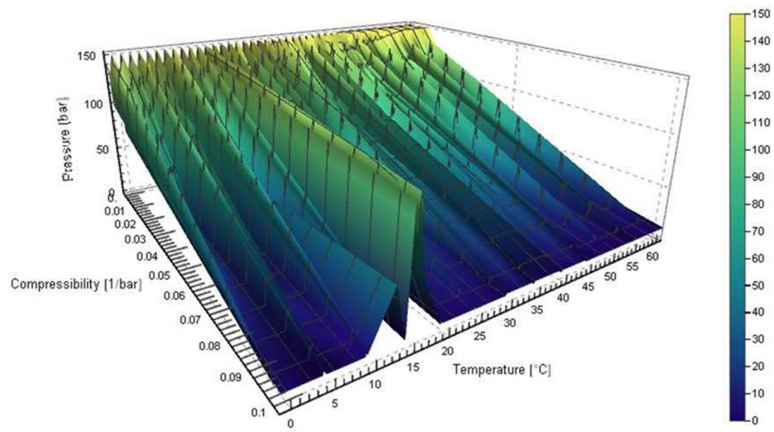
- ...and sometimes they deliver error-strewn results.



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Flow assurance challenges

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- But the biggest challenge is with our flow assurance software.
- Problems include:
  - poor thermodynamic predictions
  - discontinuous thermodynamic data, which can cause Olga to crash, or (worse) simply report incorrect results
  - poor stability around key areas, especially the bubble point, the critical point and the Widom line

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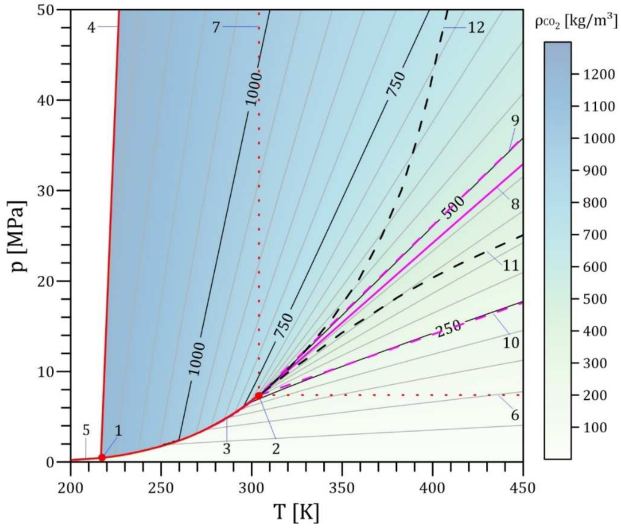
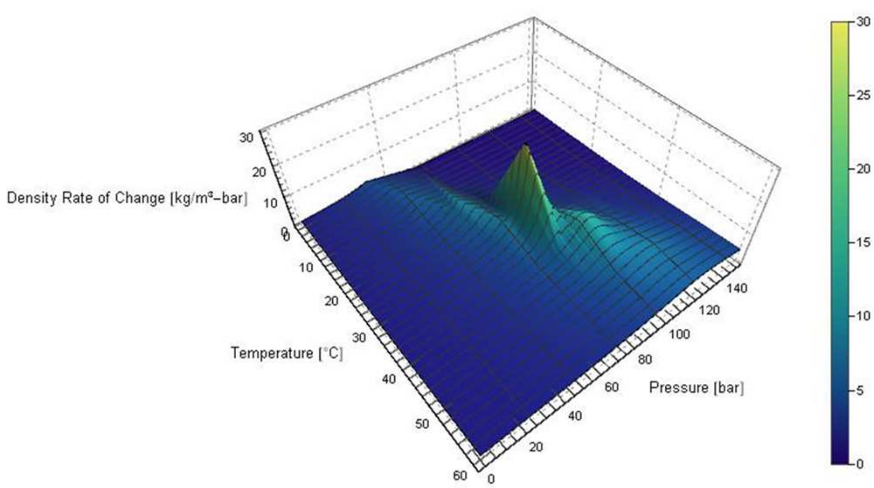
The Widom Line



The Widom Line



Flow assurance challenges

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- There are several software options, all have compromises

<table>
<tr><th colspan="2">Base software</th><th>Olga Comp Tracking</th></tr>
<tr><th>Olga</th><th>Ledaflow</th><td rowspan="4">• PH formulation
• Constrained to limited equations of state (which means big bubble point prediction errors)
• Long runtimes
• Numerical stability still an issue</td></tr>
<tr><td>• PH formulation (new!)
• Look-up table
• Poor numerical stability</td><td>• PH formulation
• Needs diffusion coefficients
• Poor numerical stability</td></tr>
<tr><th colspan="2">Single-component module</th></tr>
<tr><td colspan="2">• Pure CO_2 only
• Not useful for anything</td></tr>
</table>

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Problems have solutions

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- Our thermodynamic models are poor
  - But we can tune them against laboratory data, and add margins for uncertainty
- Our flow assurance software is poor
  - We worked around them in the 1990s, and we can work around them now
- Flow assurance is the cornerstone of CCS design
  - Communication is at the heart of good engineering
  - We need to be creative in how we present our results

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Improving thermodynamic modelling

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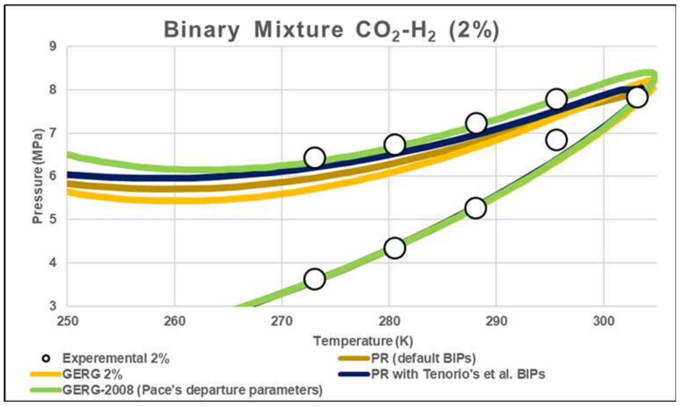
- Find published laboratory data on bubble point and density and optimise your model: base it on GERG-2008 or on CPA with Peneloux volume shift



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Improving thermodynamic modelling

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- Sources for an overview of all this, and for recommended Binary Interaction Parameters
  - Luna-Ortiz, E., Healey, M., et. al. (2022) Development Of A CO2 Specification For Industrial CCS Transport Networks: Methodology, Limitations And Opportunities, OTC Houston, USA
  - Luna-Ortiz, E. (2021) 'CO2cktails in a pipeline': The Phase Behaviour of CO2 With >20 Impurities, Trondheim CCS Conference, June 2021, Norway
  - Luna-Ortiz, E., Szklarczyk-Marshall, K., Winter, M., & McAllister-Fognini, E. (2021) Impact of Hydrogen as Impurity in the Physical and Transport Properties of CO2 Streams in CCS/CCUS Transport Systems: A Technical Discussion, 15th International Conference on Greenhouse Gas Control Technologies, GHGT-15, March 2021, Abu Dhabi, UAE
  - Li & Yan (2009) Evaluating cubic EoS for calculation of VLE of CO2 and CO2- mixtures for CO2 capture and storage processes, Applied Energy, 86, 826-836 (Ar, H2S, CH4, O2, SO2)
  - Gomez Perez et al. (2017) Comparative study of vapour-liquid equilibrium and density modelling of mixtures related to carbon capture and storage with the SRK, PR, PC- SAFT and SAFT-VR Mie equations of state for industrial uses, Fluid Phase Equil., 440, 19-35 (CO)
  - Knapp, et al. (1982) Vapor-Liquid Equilibria for Mixtures of Low Boiling Substances DECHEMA Chemistry Data Series Vol. VI (NH3)
  - Amines? Good luck. VMGSim has some data.

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Improving thermodynamic modelling

- Sources for lab data

  - Verma S, Oakes CS, Chugunov N, Ramakrishnan TS. Effect of contaminant on the thermodynamic properties of CO_2-rich fluids and ramifications in the design of surface and injection facilities for geological CO_2 sequestration. Energy Proc 2011;4:2340-7.
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  - Brown S, Beck J, Mahgerefteh H, Fraga S. Global sensitivity analysis of the impact of impurities on CO_2 pipeline failure. Reliab Eng Syst Safe 2013;115:43-54.
  - Halseid M, Dugstad A, Morland, B. Corrosion and bulk phase reactions in CO_2 transport pipelines with impurities: Review of recent published studies. Energy Proc 2014;63:2257-69.
  - Wetenhall B, Race JM, Downie MJ. The Effect of CO_2 Purity on the Development of Pipeline Networks for Carbon Capture and Storage Schemes. Intl J Greenh Gas Con 2014;30:197-211.
  - Wang J, Wang Z, Ryan D, Lan C. A study of the effect of impurities on CO_2 storage capacity in geological formations. Intl. J Greenh Gas Con 2015;42:132-7.
  - Skaugen G, Roussanaly S, Jakobsen J, Brunsvold A. Techno-economic evaluation of the effects of impurities on conditioning and transport of CO_2 by pipeline. Intl J Greenh Gas Con 2016;54:627-39.
  - Healey M, Mistry K, Jones T, Luna-Ortiz E. Understanding gas-phase breakout with high H_2 content in CCS pipeline gathering networks. Intl J Greenh Gas Con 2019;90:102816.
  - Farkas A. Orthohydrogen, Parahydrogen and Heavy Hydrogen. Cambridge University Press; 1935.
  - Fandiño O, Trusler MJP, Vega-Maza D. Phase behavior of (CO_2+H_2) and (CO_2+N_2) at temperatures between (218.15 and 303.15) K at pressures up to 15 MPa. Intl. J Greenh Con. 2015;36:78-92.
  - Peletiri SP, Rahmanian N, Mujtaba IM. Grading the impact of Impurities in Rich CO_2 Pipeline Fluids. Chem Eng Trans. 2018;70:175-80.
  - Al-Siyabi I. Effect of Impurities on CO_2 Stream Properties. PhD Thesis. Heriot-Watt University; 2013.
  - Reid RC, Prausnitz JM and Poling BE. The Properties of Gases and Liquids. 4th ed. McGraw-Hill; 1987.
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  - Oldenburg CM. Joule–Thomson cooling due to CO_2 injection into natural gas reservoirs. Energy Convers. Manage 2007;48:1808-15.
  - Botros KK, Geerligs J, Rothwell B, Robinson T. Measurements of Decompression Wave Speed in Simulated Anthropogenic Carbon Dioxide Mixtures Containing Hydrogen. J Press Vessel Technol. 2017;139:021201-7.
  - Martynov SB, Talemi RH, Brown S, Mahgerefteh H. Assessment of Fracture Propagation in Pipelines Transporting Impure CO_2 Streams. Energy Proc. 2017;114:6685-97.
  - Li H, Jakobsen JP, Wilhelmsen Ø, Yan J. PVTxy properties of CO_2 mixtures relevant for CO_2 capture, transport and storage: Review of available experimental data and theoretical models. Appl Energy. 2011;88:3567-79.
  - Aursand P, Hammer M, Munkejord ST, Wilhelmsen O. Pipeline transport of CO_2 mixtures: Models for transient simulation. Intl J Greenh Gas Con. 2013;15:174-85.
  - Shin BS, Rho WG, You SS, Kang JW. Evaluation of Thermodynamic Models for predicting equilibria of CO_2 + impurity binary mixture. Intl. J Thermophys. 2018, 39:44.
  - Kunz O, Wagner W. The GERG-2008 Wide-Range Equation of State for Natural Gases and Other Mixtures: An Expansion of GERG-2004. J Chem Eng Data. 2012;57:3032-91.
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  - Ke J, Suleiman N, Sanchez-Vicente Y, Murphy TS, Rodriguez J, Ramos A, Poliakoff M, George MW. The phase equilibrium and density studies of the ternary mixtures of CO_2 + Ar + N_2 and CO_2 + Ar + H_2, systems relevance to CCS technology. Intl J Greenh Gas Con. 2017;56:55- 66.

Improving flow assurance modelling

- Flow assurance modelling is tricky
  - Expect lots of manual intervention
  - There are no useful error message that will help debug a case that is crashing
  - Limit design cases and use engineering judgement
- Trickiest cases
  - Depressurization
  - Shutdown of trapped volumes and elevation change
  - Shutdown of dense phase pipeline & cooldown to bubble point
  - Really any case where impurities are important

Presenting results

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- The behaviour of CO_2 is unintuitive to those of us from the hydrocarbon world.
- The major flow assurance challenge on most CCS projects is low temperatures: it gets very cold very quickly any time there is boiling, or expansion of gaseous/supercritical CO_2.
- The flow assurance will (probably) drive the design of the CCS network.
- The flow assurance will (certainly) determine the operation of the CCS network.

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Presenting results

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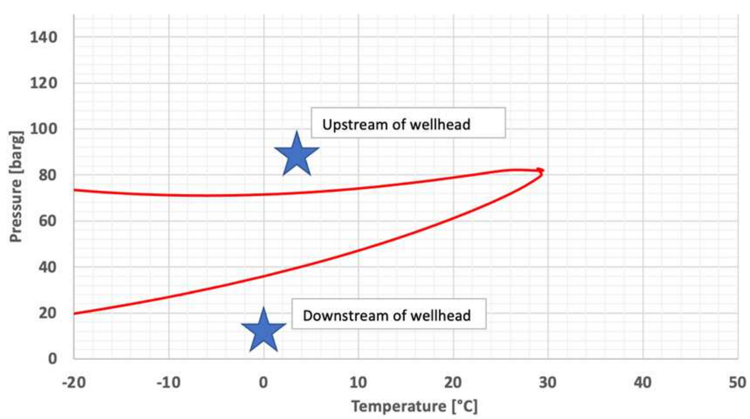
- This is a “typical” problem, from a real project. Choking flow at an injection wellhead.



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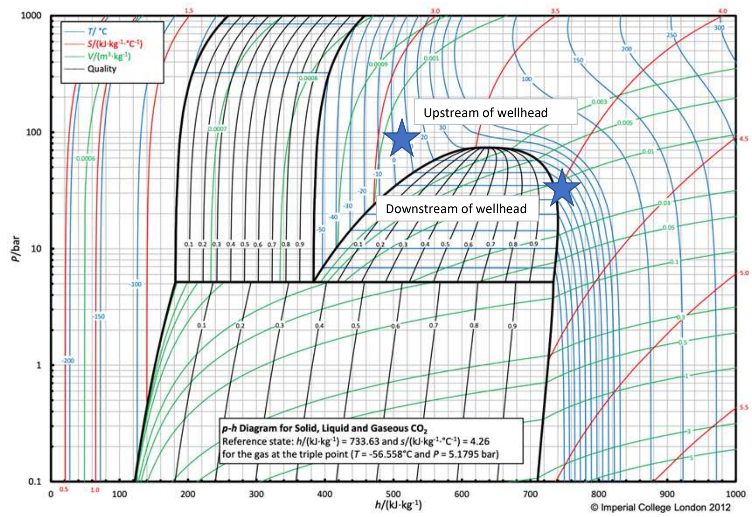
Presenting results

- Follow the enthalpy, not the temperature.
- Somewhere in this system, the fluid enthalpy has to increase 250 kJ/kg or the well gets too cold.
- That's 100 MW for this particular project.
- This is the main driver behind the design.



Flow assurance

- By 2030, we at Pace predict there will be about 2000 CCS projects in design or operation.
- We need this industry to succeed. It is the only route to keep global warming to below 2 °C.
  – (Unless nuclear power gets really popular, really quickly.)
- The flow assurance team on about 1950 of those CCS projects will deliver the work that defines the design, and defines the system operability.
- Flow assurance engineers are CCS engineers.

Thanks for your time

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