CO$_2$ Capture Project

CO_2 Properties and Transportation

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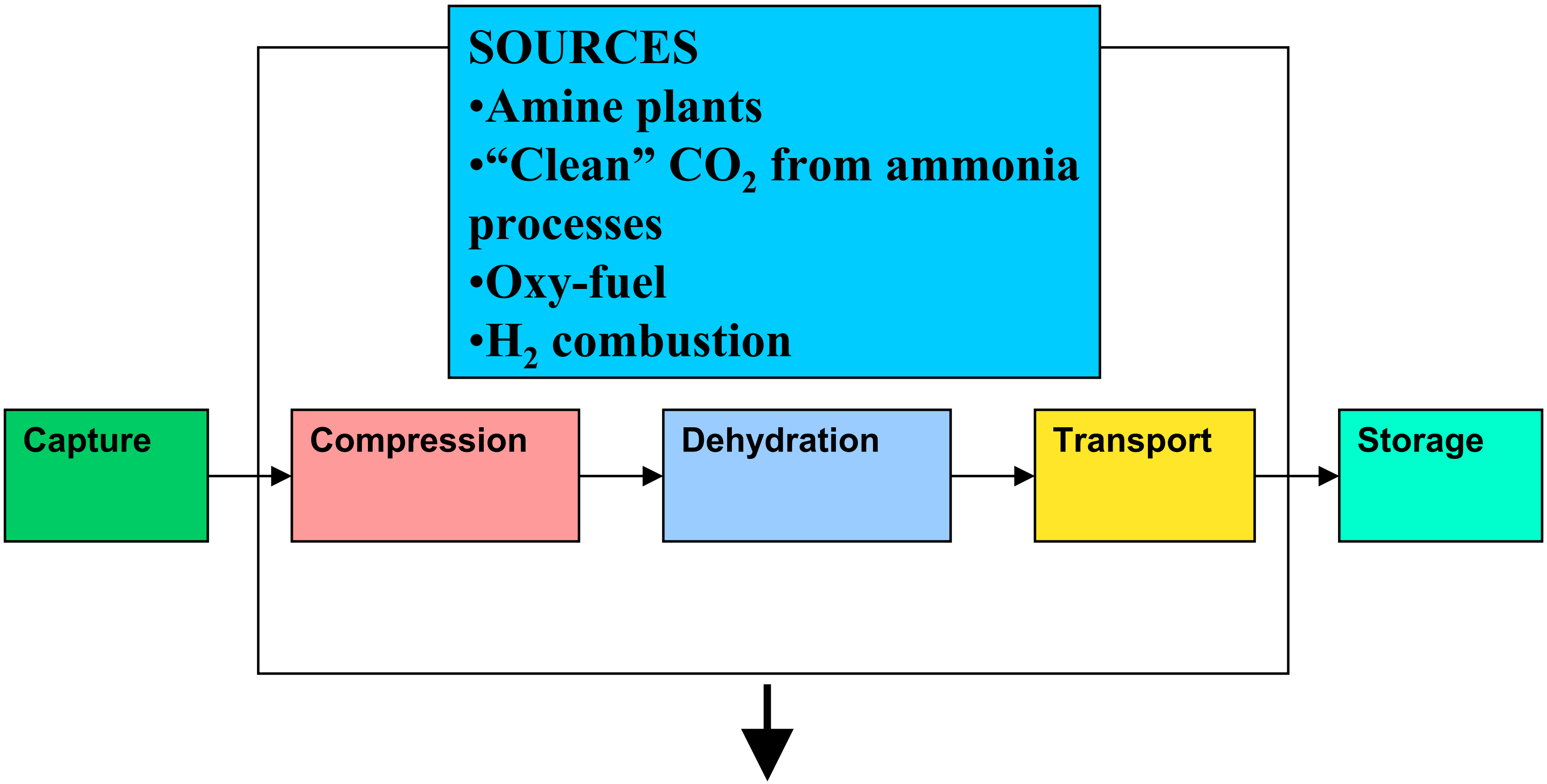
Objectives

- **Documentation of today's practice for CO_2 transportation**
- **Documentation of existing models and flowsheeting tools for CO_2 behaviour**
  - Recommendations and improvement of models based on the findings
  - Development of a wellhead pressure calculation tool
- **Challenge today's practice for CO_2 transportation**

How is CO_2 transported today?

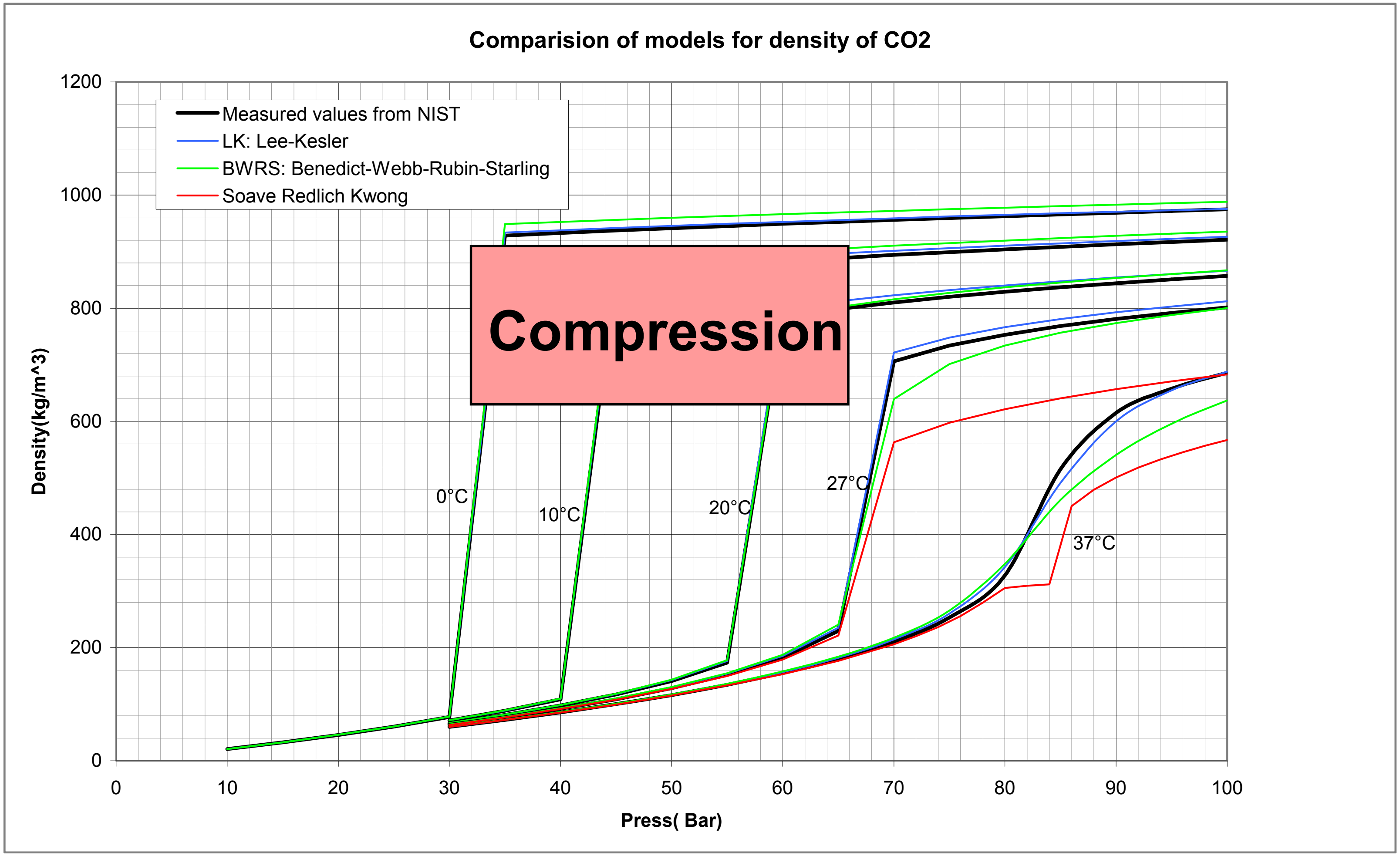
- **On-shore transportation of CO_2**
  - For Enhanced Oil Recovery (EOR). Kinder Morgan, US P
  - Acid gas (CO_2 and H_2S) removal, re-injection into wells, Canada
- **Off-shore transportation of CO_2**
  - To reduce the CO_2-content in export-gas, avoid emissions to air. Sleipner, North Sea
  - CO_2 removal from the natural gas at the Hammerfest LNG plant and reinjection into Snøhvit field

CO_2 processing, transport and storage

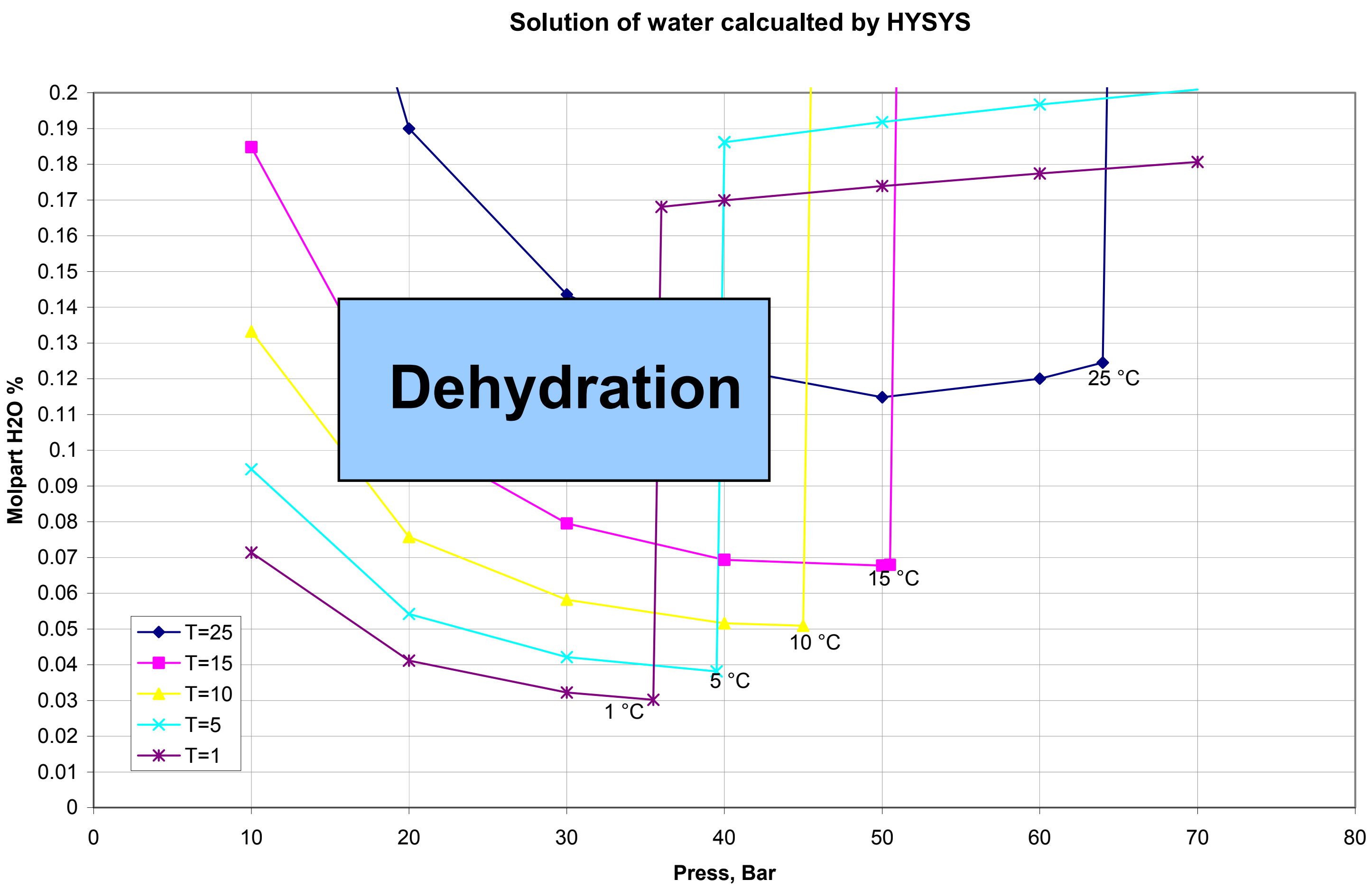


Need for reliable thermodynamic models

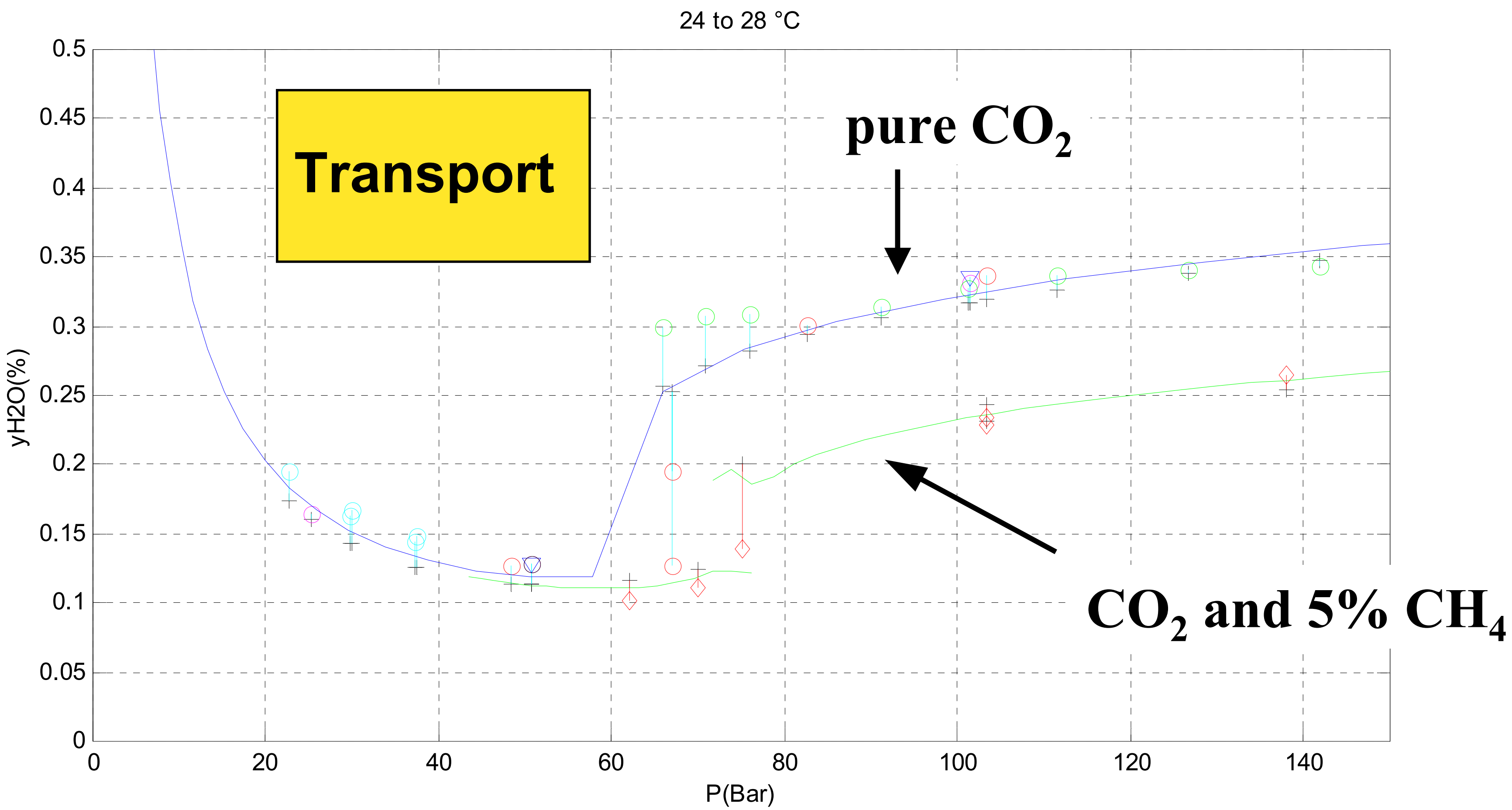
CO_2 compression, density calculation



CO_2 dehydration, precipitation of water



CO_2 transport, precipitation of water



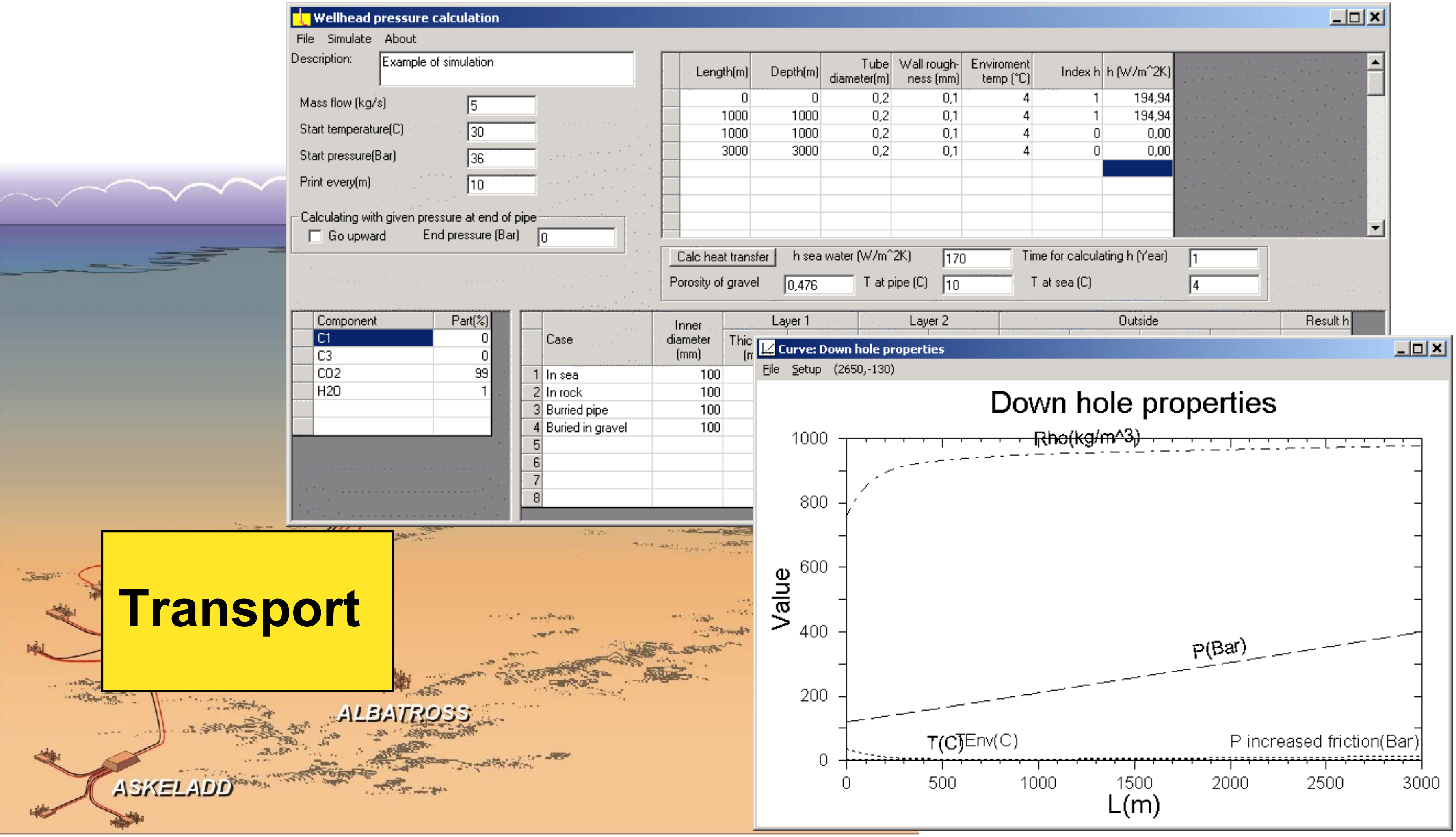
Can we rely on the Thermodynamic models?

- **CO_2 properties (density)**
  - Experimental data (NIST)
  - Acceptable performance with the Lee Kesler model
  - Flowsheeting tools can however contain bugs P
- **Water solubility in pure CO_2**
  - Some data
  - Acceptable model performance with adjusted binary coefficient (SRK) P1
- **Water solubility in mixtures of CO_2 and impurities as CH_4, N_2, H_2S and amines**
  - Little or insufficient amount of data
  - Results for 5% CH_4

Hydrate formation in CO_2

- With free water present in the system there is a possibility for hydrate formation P
- By avoiding free water in the pipeline, the hydrate problem is eliminated
- By keeping the cooling water temperature above 10º (C), hydrate formation in the cooler is prevented

CO_2 transport, new developed tool

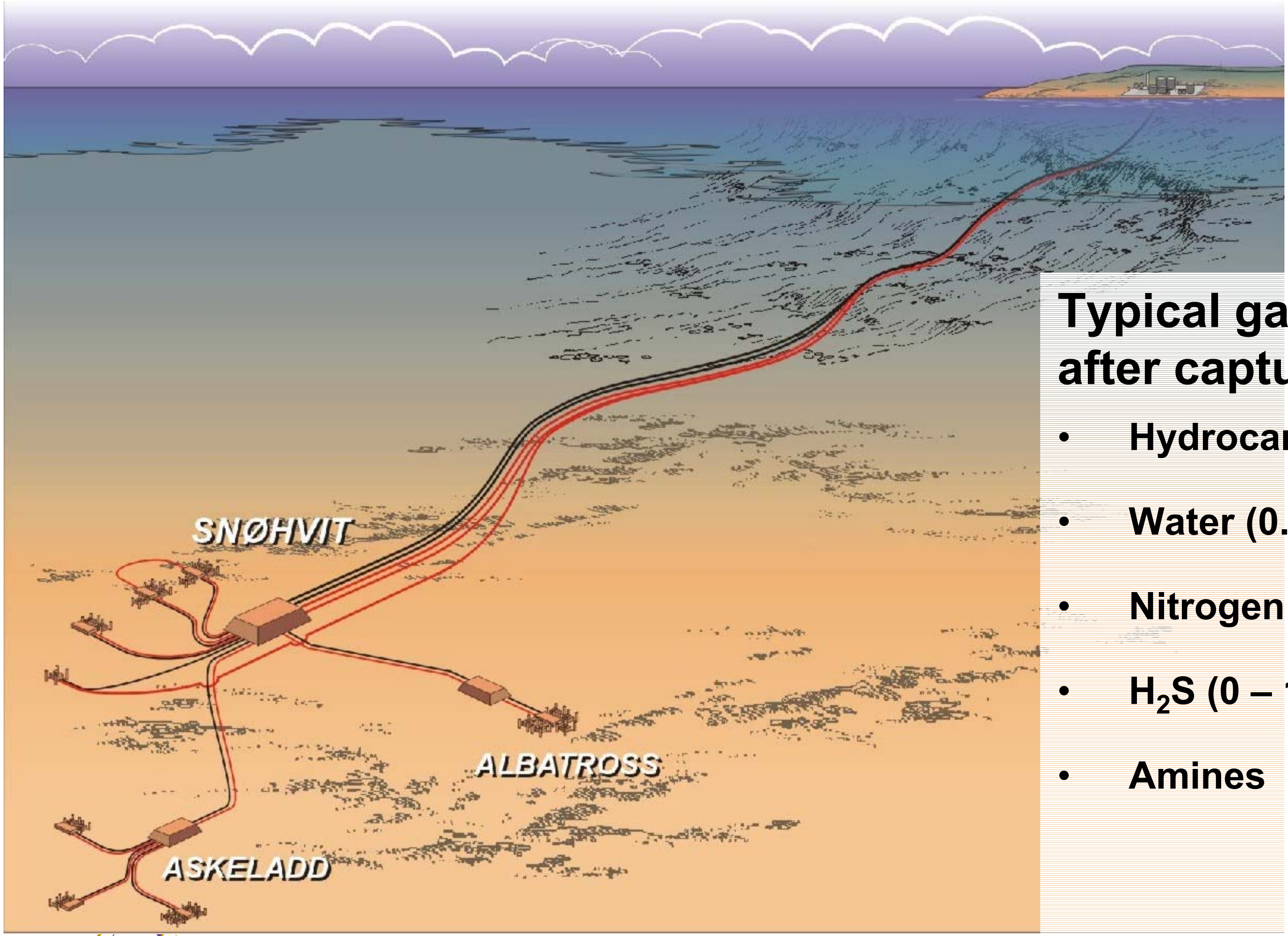


Source: Statoil/Snøhvit

Recommendations and further work

- **From comparison with data:**
  - Lee Kesler for density calculations
  - SRK with adjusted binary coefficients for calculations of solubility of water in CO_2
- **Further work is needed to provide thermodynamic data for water solubility in CO_2-mixtures with impurities**

Safe and cost effective CO_2 transport in pipelines



Typical gas composition after capture:

- Hydrocarbons (0 – 5 %)
- Water (0.15 – 0.5 %)
- Nitrogen (0 – 5 %)
- H_2S (0 – 100 ppm)
- Amines

Source: Statoil/Snøhvit

Water removal, to what level?

- **Free water gives**
  - hydrate formation
  - corrosion
- **Kinder Morgan requirements for CO_2 in pipelines used for EOR (New Mexico) is maximum 600 ppm water**
- **600ppm water content is achievable by cooling with seawater at 10ºC and free-water knockout (scrubbers)**
- **⇒ Reliable thermodynamic models are necessary for accurately prediction of solubility**

Handling composition ranges and impurities

1) Gas compression, cooling and dehydration

recommended for high contents of Hydrocarbons and Nitrogen

due to vaporisation of volatile components during condensation

2) Compression, cooling, dehydration, condensation and pumping

recommended for low contents of Hydrocarbons and Nitrogen

10% lower operational costs compared to gas compression

A selected case, compression

Simulation input:

- Seawater cooling temperature: 10°C
- Gas temperature out of cooler: 15°C
- Gas pressure at pipeline inlet: 150 bara
- Composition: 4.5 % CH_4, 0.5% H_2O in CO_2

Simulation result:

- Water content reduced to approx. 600 ppm
- by cooling and free water knock-out, only

A selected case, transportation and storage

Simulation input:

- Pipeline length: 170 km
- Water depth at injection wellhead: 320 m
- Mass flow 30 kg/s
- Reservoir depth: 2700 m
- Res. pressure: 273 bara

Simulation result:

- Minimum CO_2 temp. and pressure at injection wellhead
  - + 5°C
  - 85 bara
- Lower limit for free water precipitation approx. 1300 ppm
- ⇒ No free water in the pipeline for this case

CO_2 Pipeline Transportation

Drying

- **High cooling medium temperature**
  - e.g. air at 20 °C
- **Low pressure at injection wellhead**
  - deep reservoir
  - low reservoir pressure
- **Low ambient temperature**

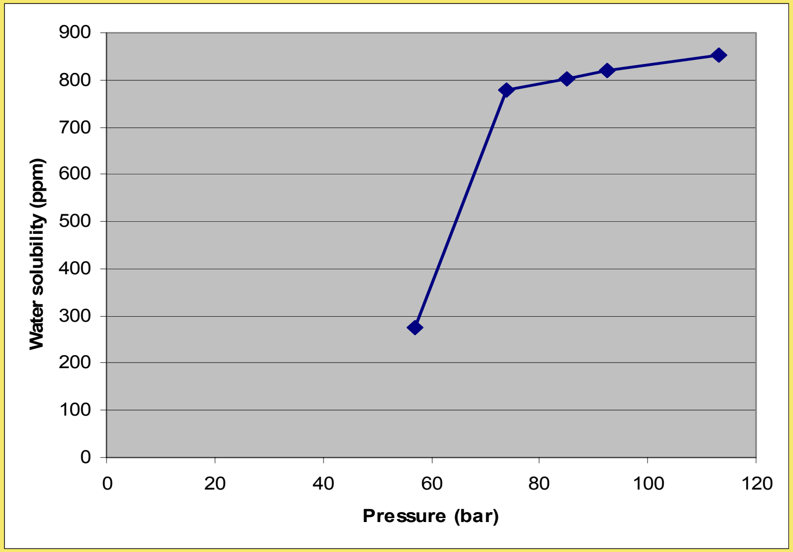
➢ **Tend to increase free water precipitation in the pipeline**

➢ **Additional drying may be required**

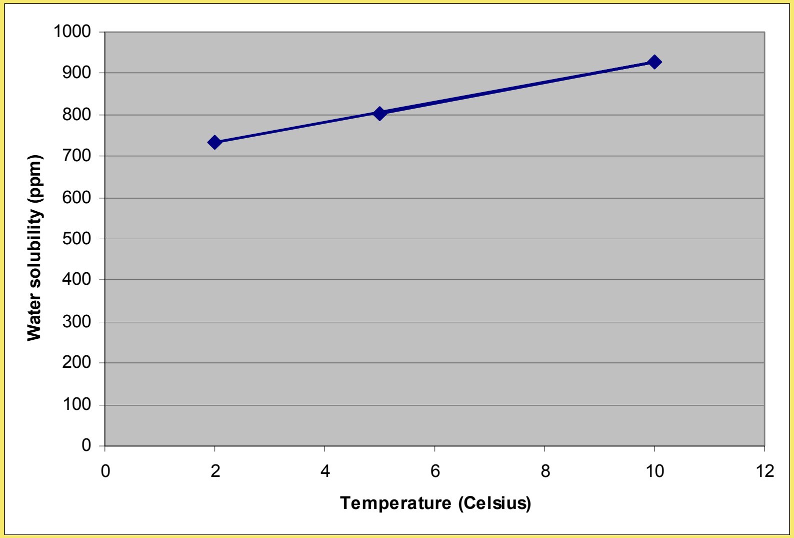
➢ **Mol sieve adsorption at 2nd stage**

Additional drying is required for

Low injection pressure



Low ambient temperature



CO_2 Pipeline Transportation

Compression

- **Long distance to injection point**
- **High reservoir pressure**
- **Low static head**
  - shallow reservoir depth
  - shallow water depth

- **High pressure requirement at pipeline inlet**
- **Increased number of compression stages**
- **Increased costs (Capex and Opex)**

Material evaluation and corrosion protection

- **Significant corrosion on carbon steel in a water phase saturated with CO_2**
- **Significant corrosion on carbon steel in a water phase containing H_2S**
- **Corrosion protection in offshore buried pipes**
  - Coating with Fusion bonded epoxy (FBE) and Polypropylene (PP)
  - Cathodic protection
- **Ordinary Carbon steel pipelines can be used for temperatures above -46 °C**

Recommendations and further work

- Cooling water temp. not below 10°C, due to risk of local hydrate formation in the coolers
- In principle, ordinary Carbon steel pipelines can be used for temperatures above -46 °C
- Further work needed wrt. minimum design temperature dry ice at atm. pressure -79°C
- Further work to establish know-how on operation of process equipment with CO_2-mixtures

CO_2 Capture Project

Thank you!

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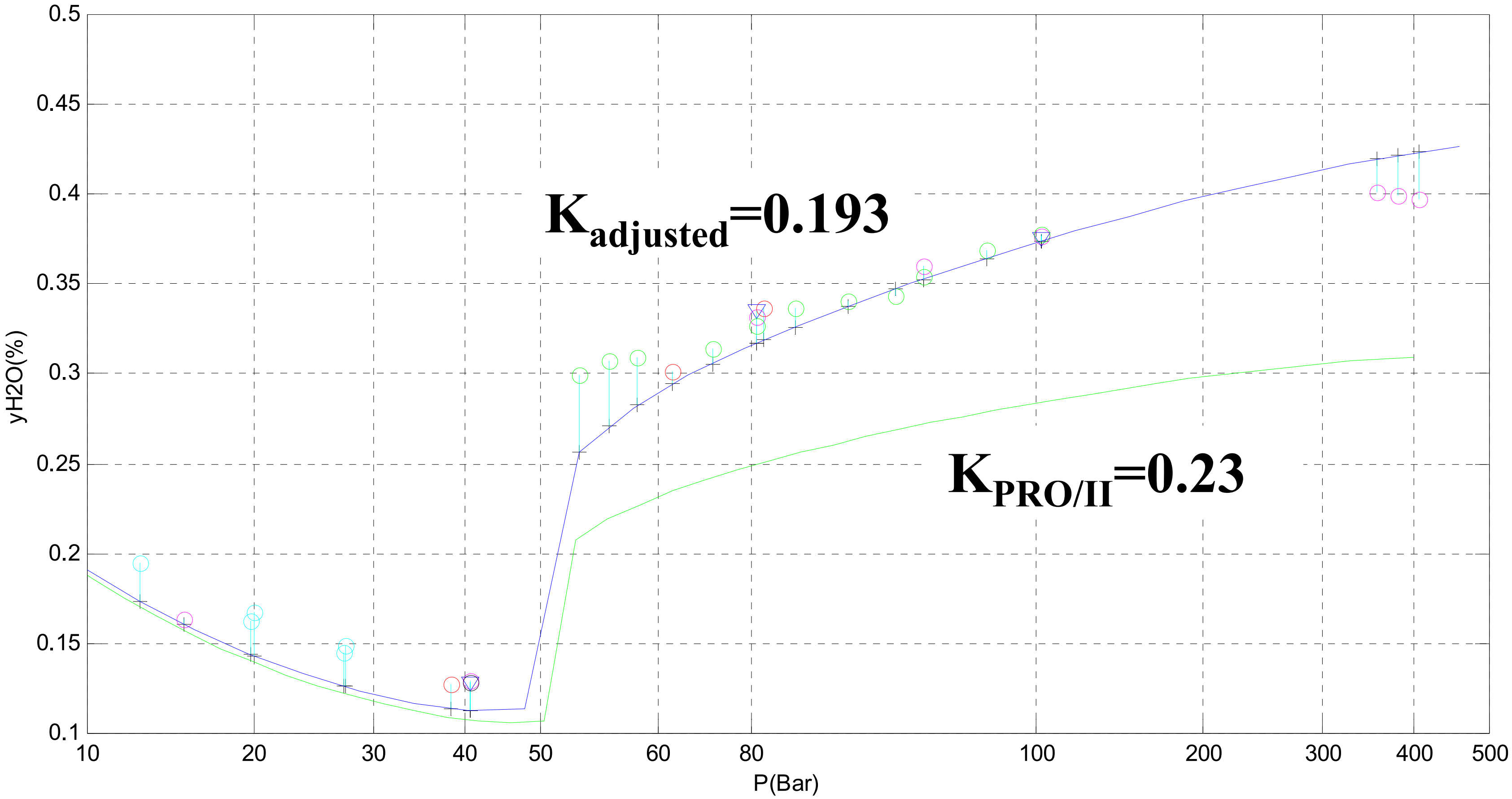
Solubility of water in CO_2 at 25ºC



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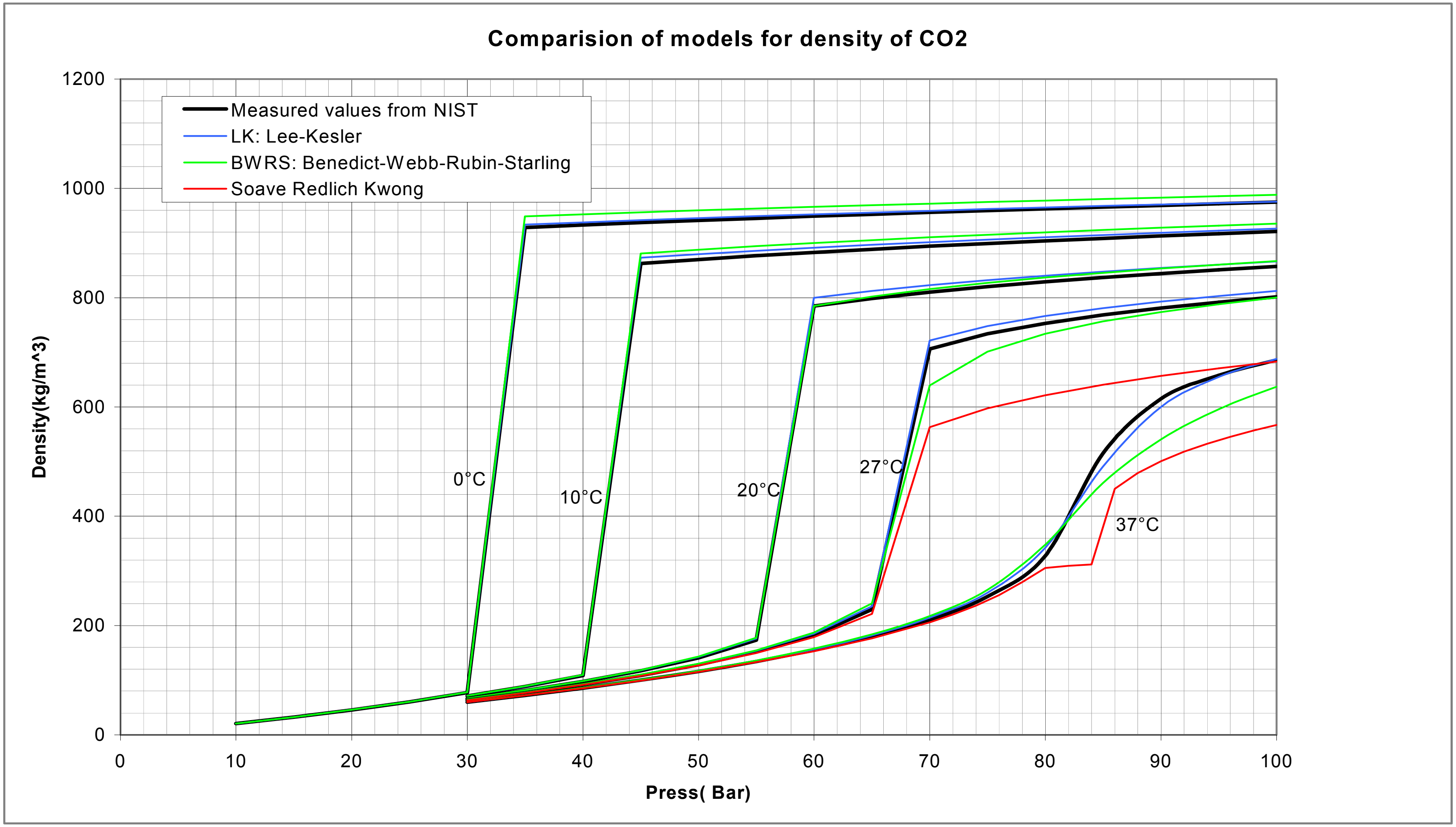
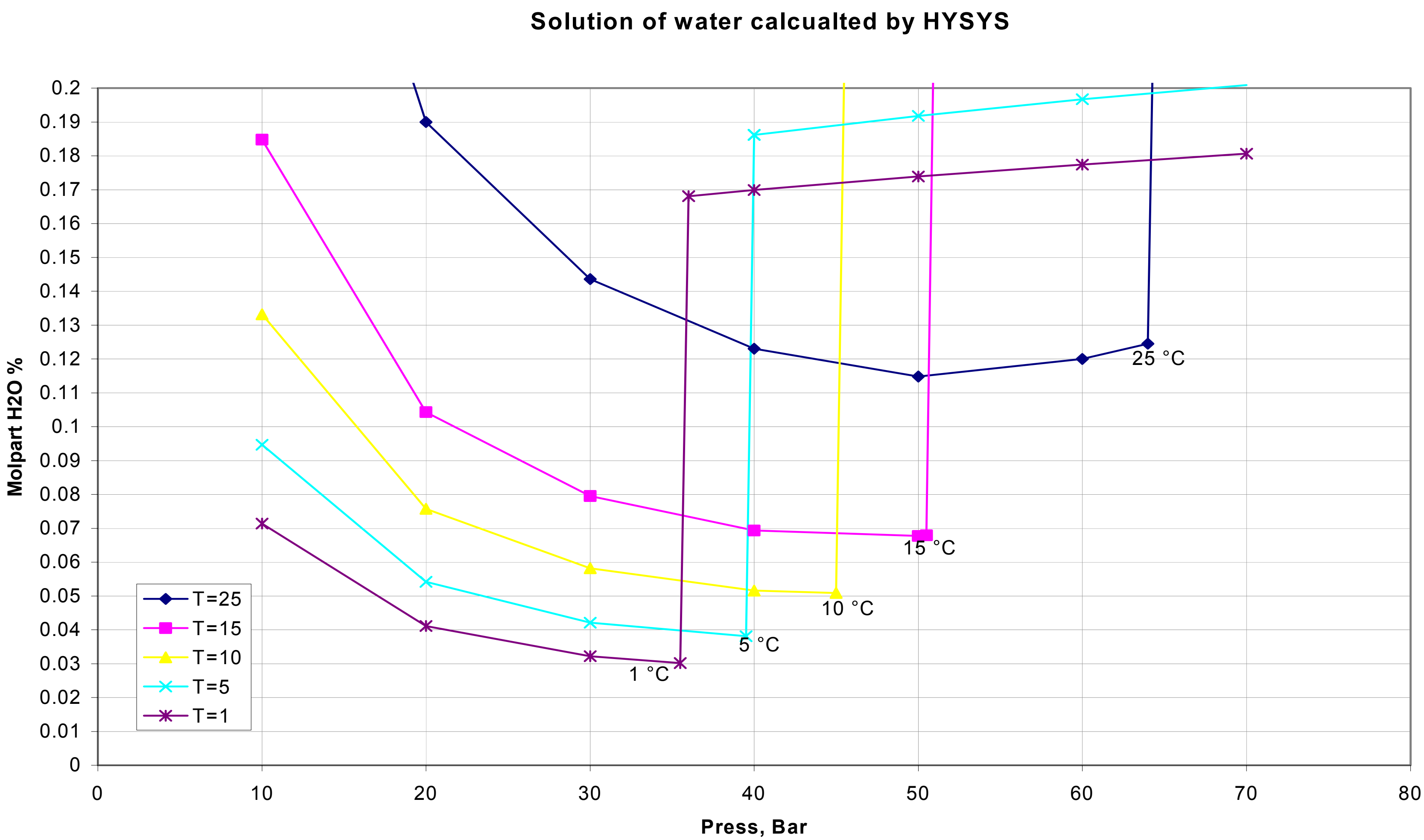
Density of pure CO_2



Solubility of water in CO_2 calculated by HYSYS



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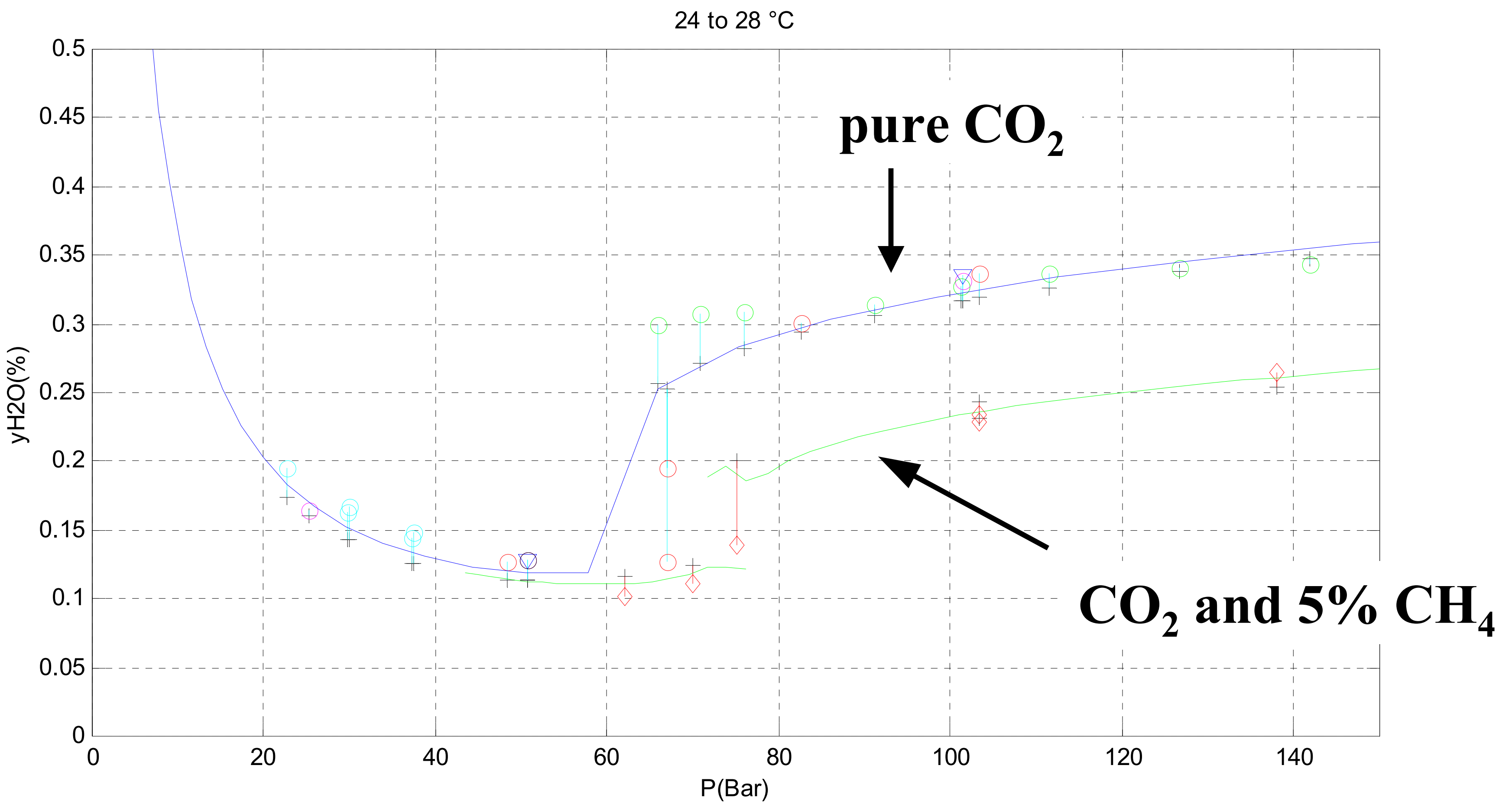
Water solubility in CO_2



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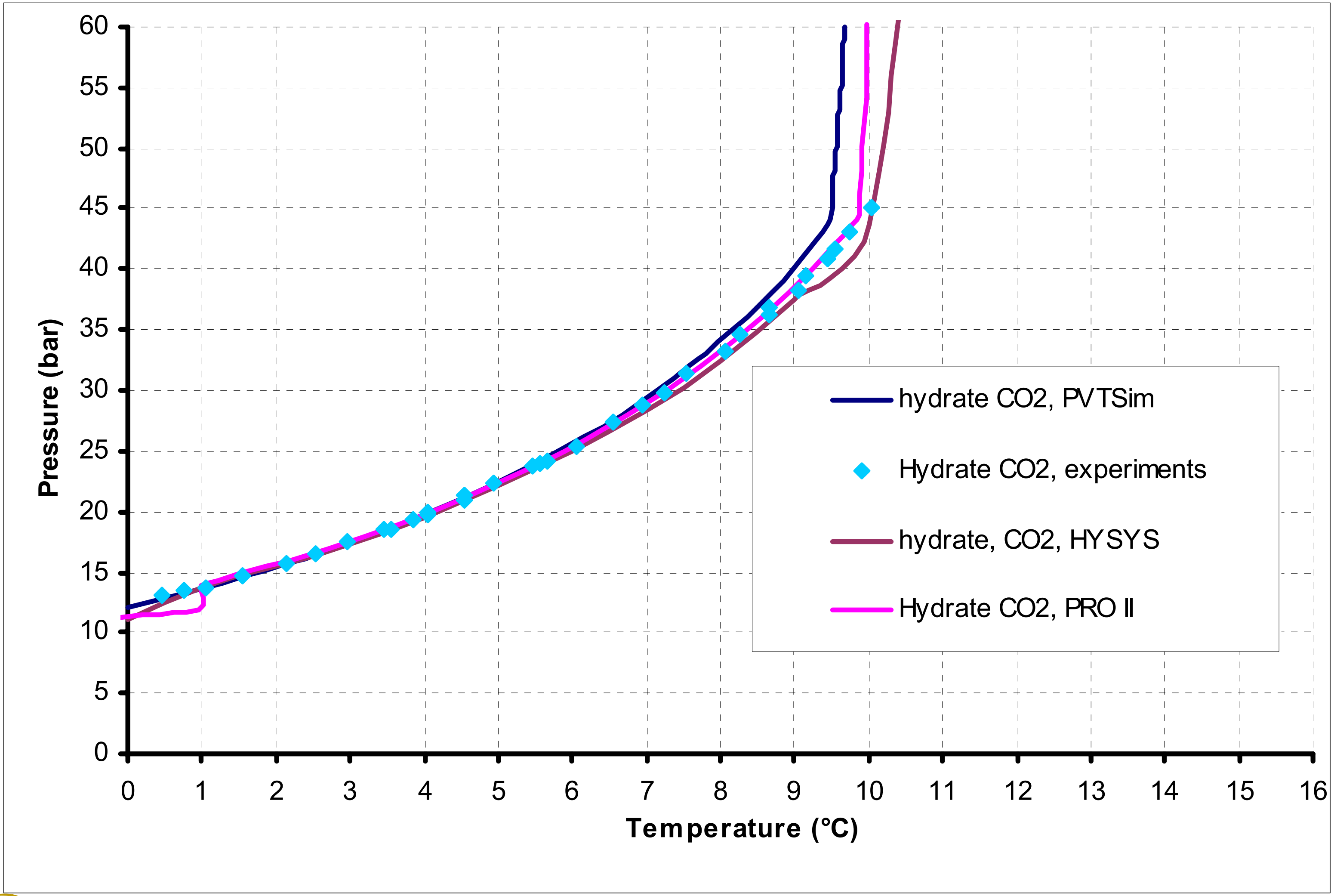
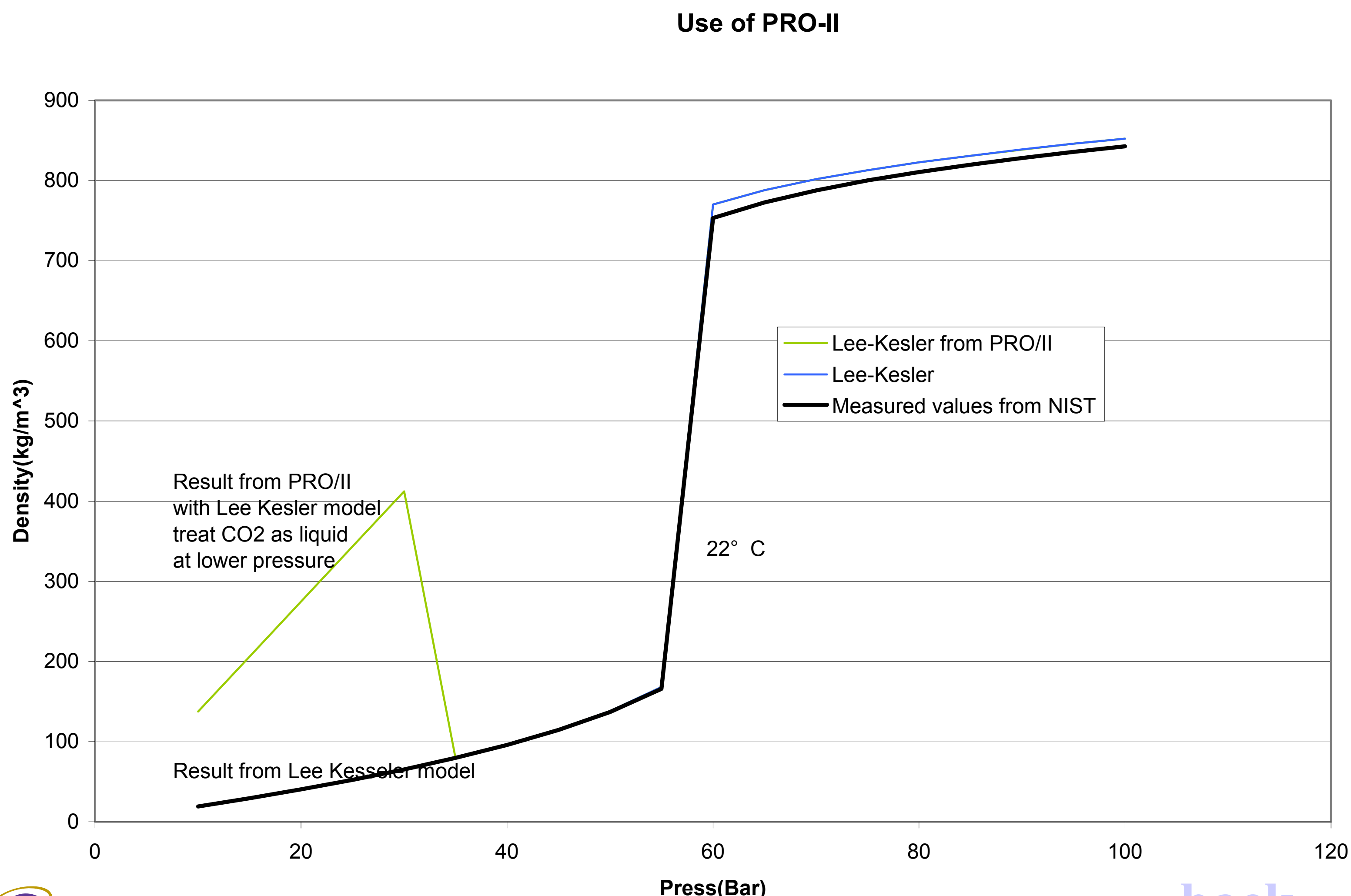
Hydrate formation in CO_2



Qualifying the tools



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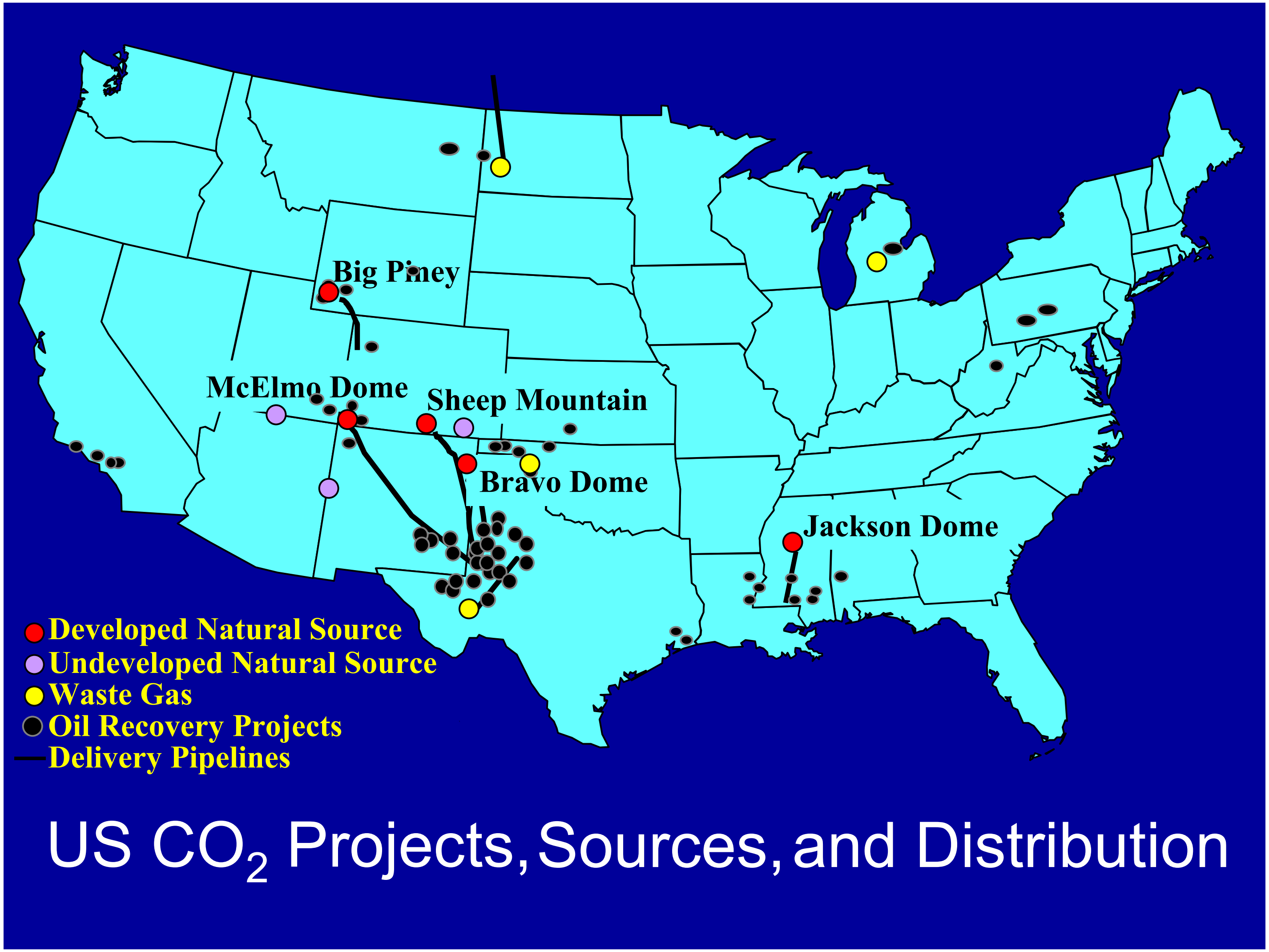
US CO_2 Projects, Sources, and Distribution



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