CO_2 storage and CO_2-EOR simulations in OPM

OPM meeting

29 JANUARY 2019

The 4 Whys

- Why CO2 storage?
- Why CO2-EOR?
- Why CO2-EOR simulations?
- Why CO2-EOR simulations in OPM?

Figure 2.9 ▷ **World primary energy demand by fuel and energy-related CO_2 emissions by scenario**

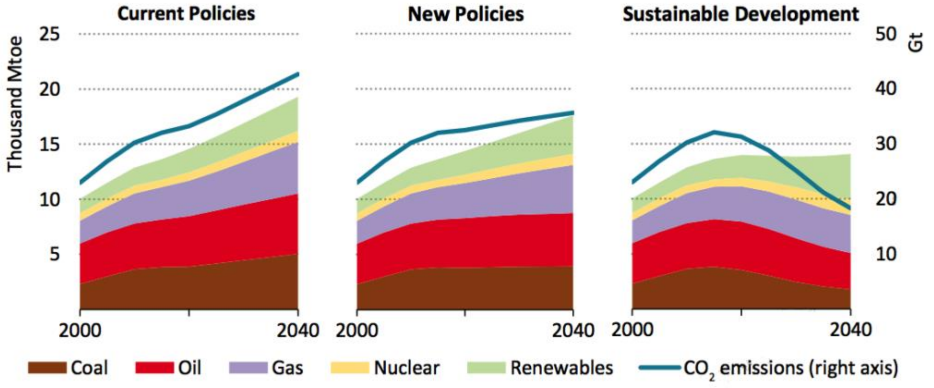
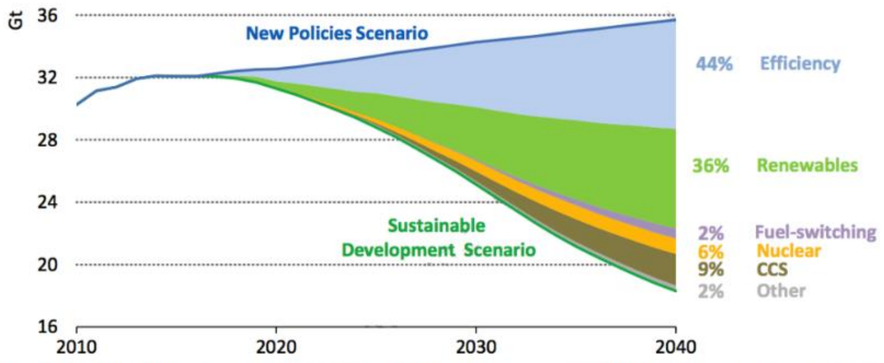


Figure 3.15 ▷ **Global CO_2 emissions reductions in the New Policies and Sustainable Development Scenarios**



Drivers of the reduction in CO2 emissions (in gigatons CO2) between the new policies and sustainable development scenarios. Figure 3.15 from the IEA's 2017 World Energy Outlook.

Current (known) CO2 storage and CO2EOR related OPM activities

- CLIMIT-DEMO: Developing simulation tools for CO_2 storage and CO_2-EOR (Sintef, Equinor, Norce)
- ENOS (TNO, Norce, ++)
- CLIMIT-DEMO: CO2 storage and CO2EOR simulation on the Brage field. (Aker-Solutions, Wintershall and Norce)

CO_2-EOR simulations in OPM

- Extended black-oil (solvent) model
- Gas and oil is represented by three-pseudo components (oil, solution gas, and injected solvent /CO_2)
- Effective hydrocarbon relative permeability, viscosity and density.

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- Use existing blackoil models.
- Computationally more efficient than compositional simulators.

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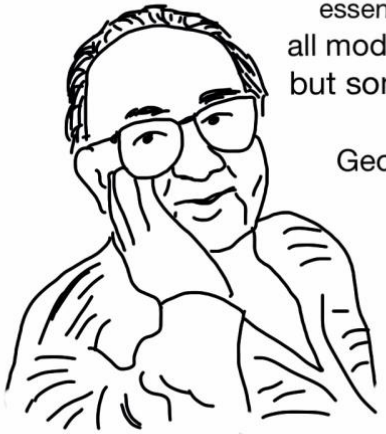
- Determining the relevant effective / upscaled quantities.
- Does it capture the important physics?

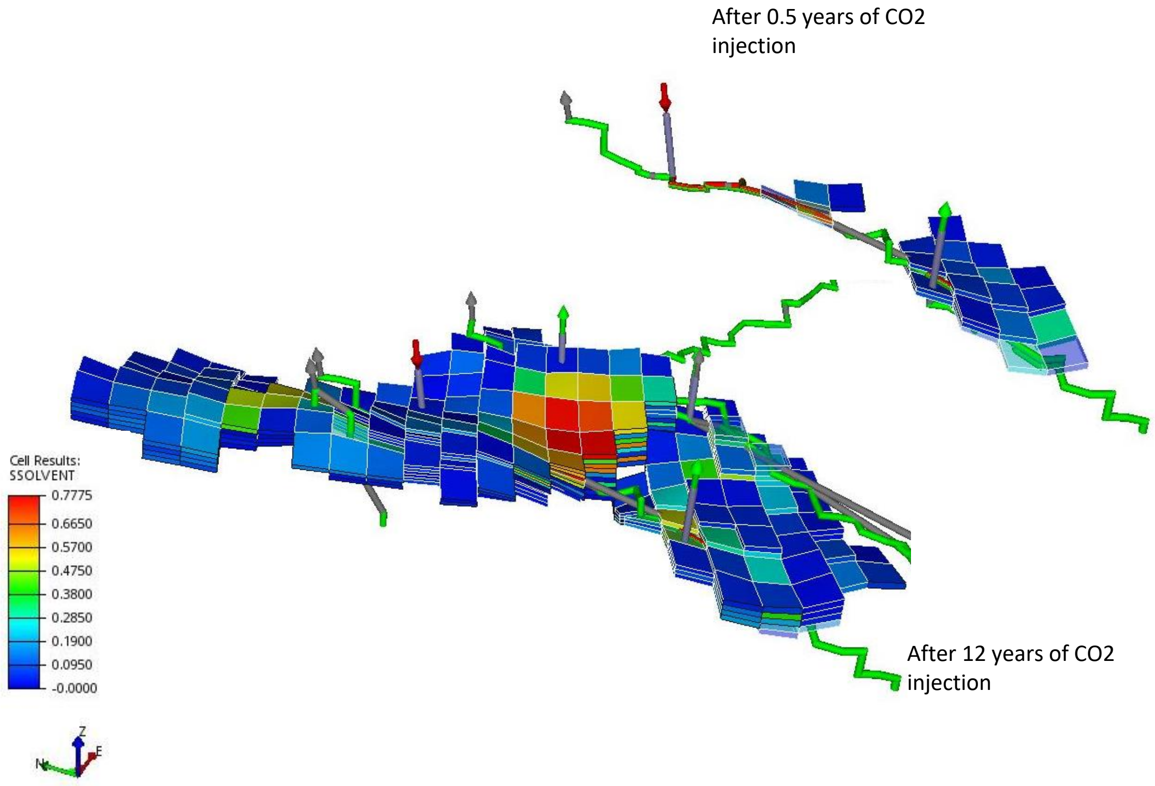


essentially,
all models are wrong,
but some are useful

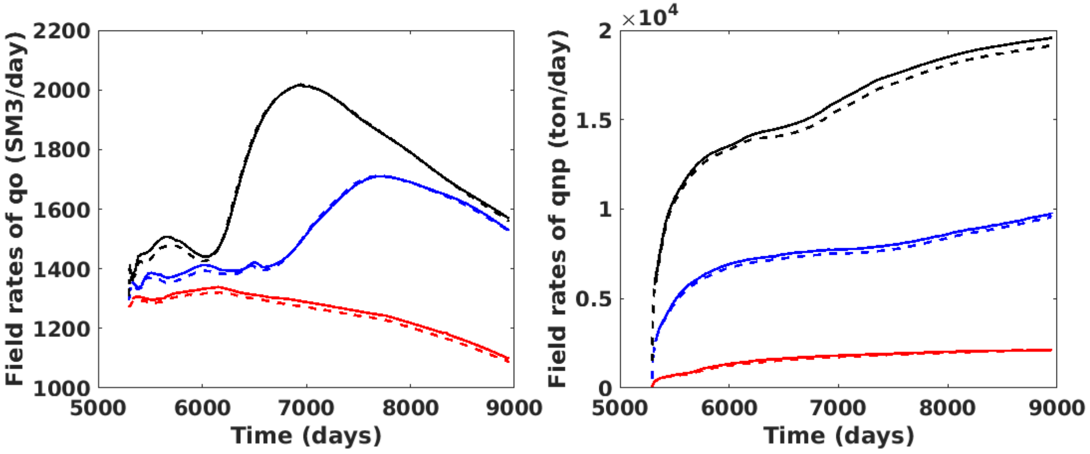
George E. P. Box

Field example 1 (Model 2)

- **Setup**
  - Run 5295 days of history.
  - LRAT controlled production wells.
  - CO2 injected from day 5479
  - Linear ramp between 100-250 Barsa to model pressure dependency in the miscibility
  - The pressure dependency in the Todd-Longstaff parameter is neglected.



Good match with Eclipse



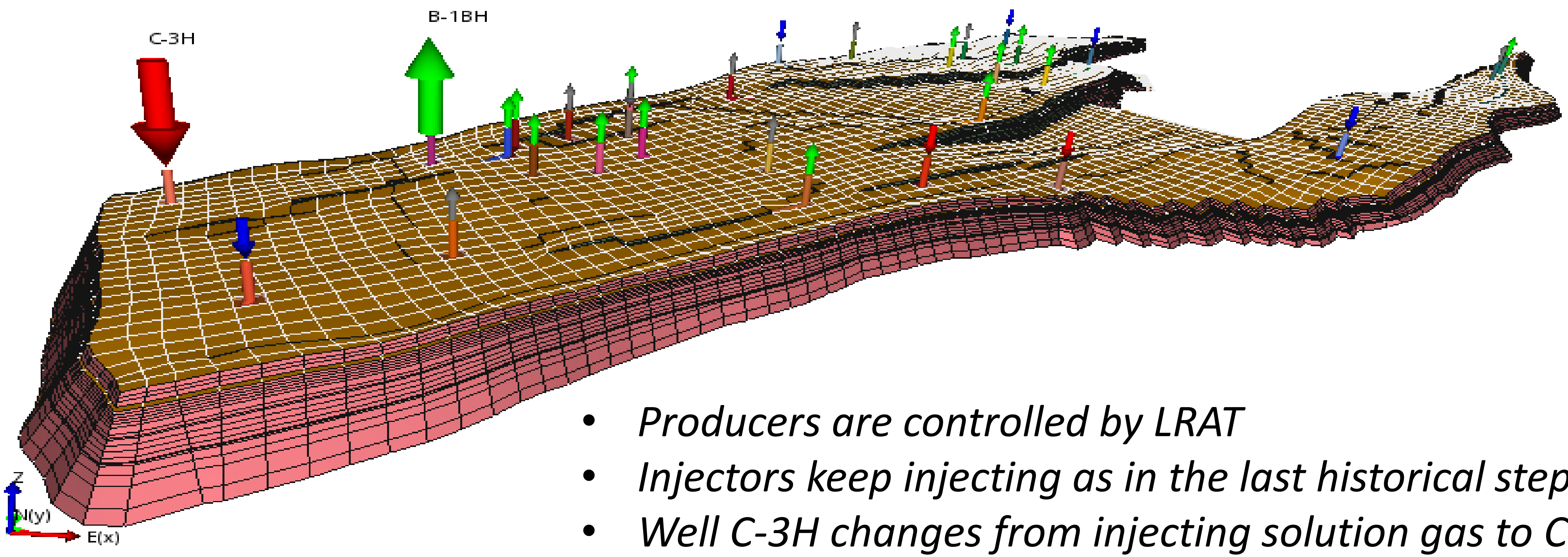
Comparison of production rates of oil and CO2 between Flow (dots) and Eclipse (solid) when injecting 0.1M (red), 0.5M (blue) and 1.0M (black) of CO2.

Significant speedup

Case	Flow	Eclipse	
1	1380	5000	0,28
2	1710	8950	0,19
3	1800	8600	0,21

*Intel Core i7-6700, 4(8) @ 3.4 GHz, 8M
** The run-time comparison is approximate.
Different tuning may change the run time of both the simulators.

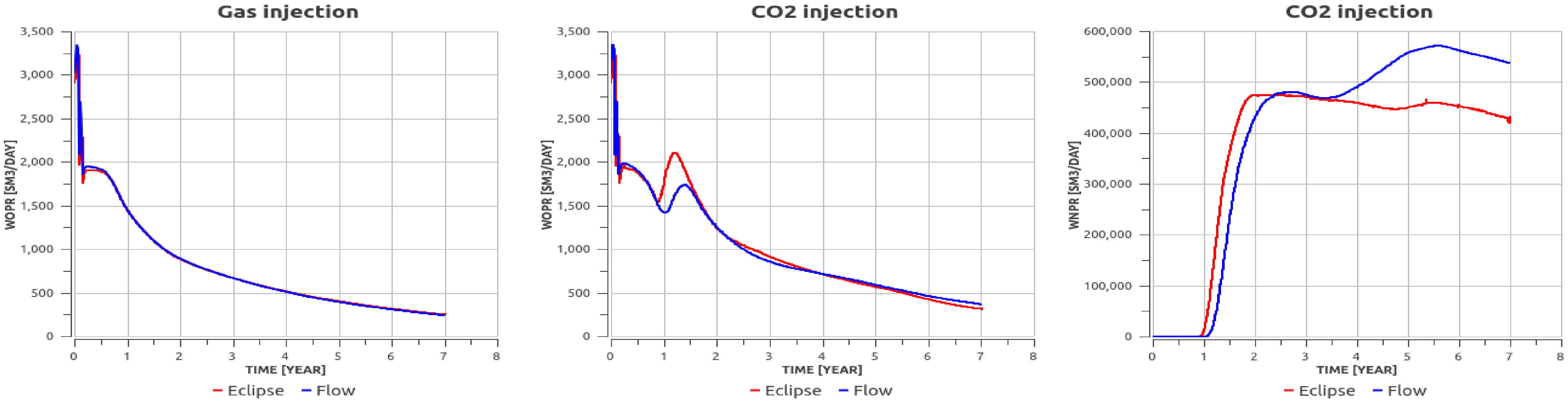
A field case example of CO_2 injection on the Norne field.



- *Producers are controlled by LRAT*
- *Injectors keep injecting as in the last historical step*
- *Well C-3H changes from injecting solution gas to CO_2 (approx. 2000 Tonn of CO_2 pr day)*
- *All details are available in …/opm-publications/ghgt14/*

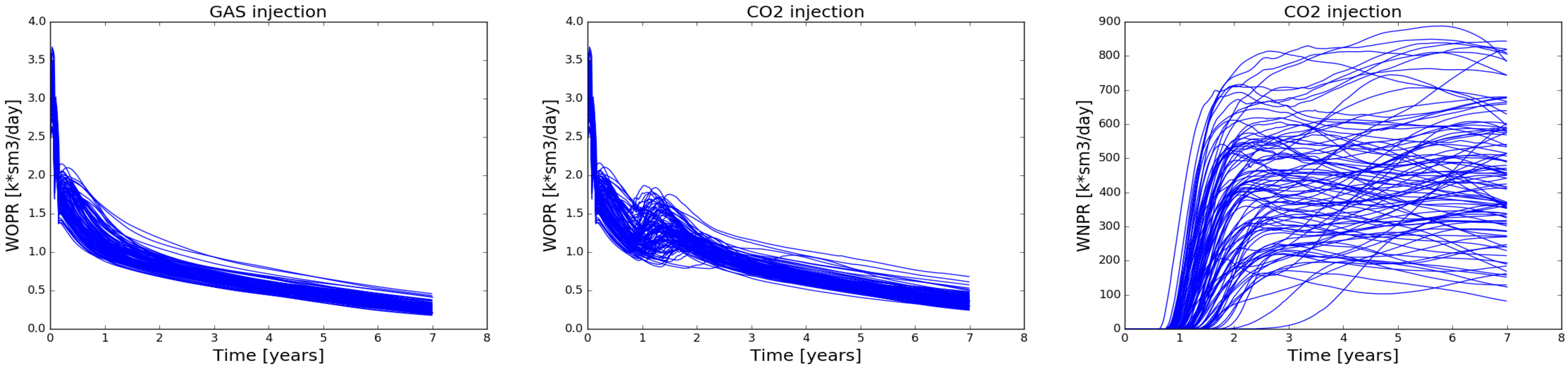
Comparison with Eclipse

*Comparison of well rates in Well B-1BH between Eclipse (red) and **FLOW** (blue)*



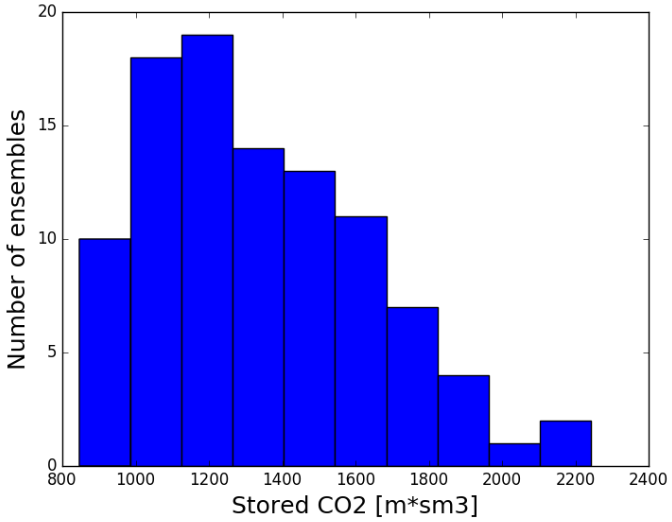
Ensemble robustness

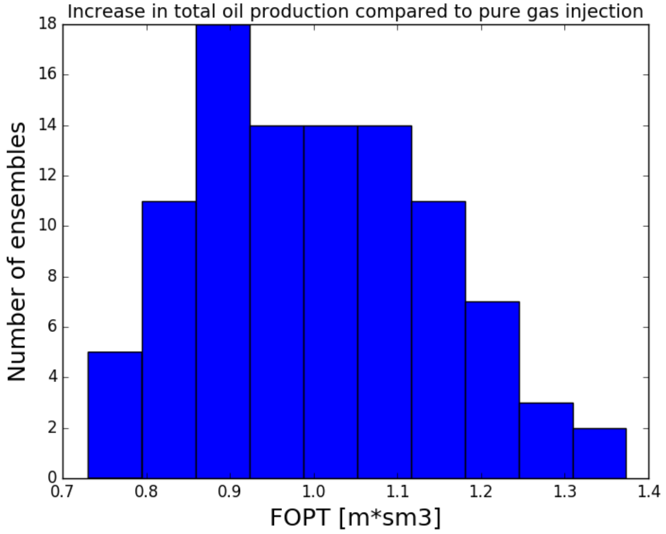
Simulation results for the ensemble members



Ensemble robustness

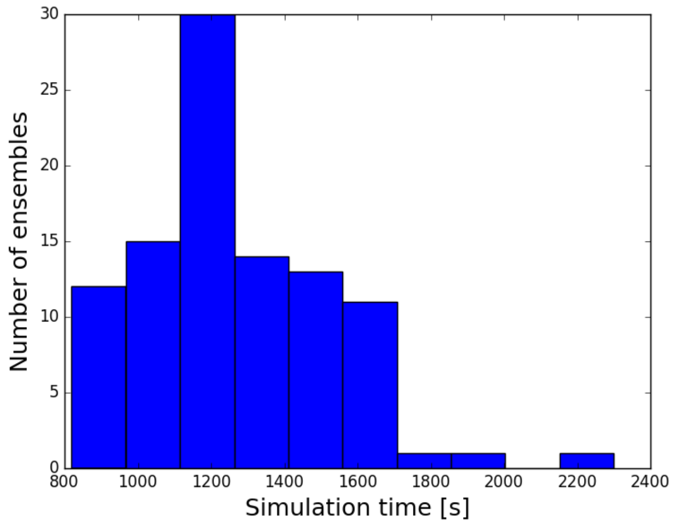
Simulation results for the ensemble members

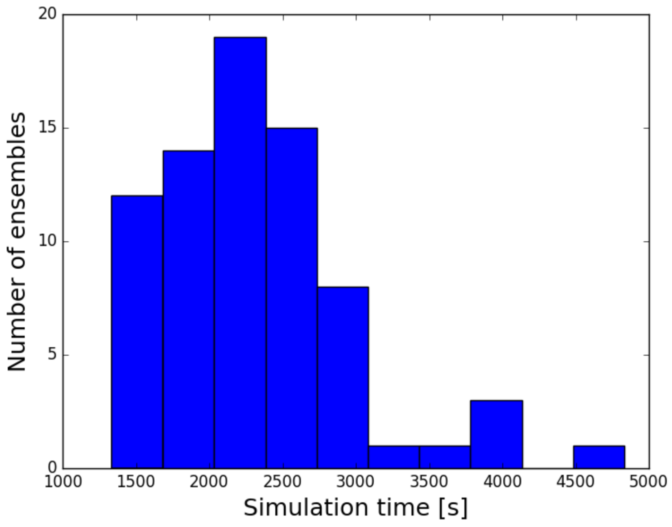




Ensemble robustness

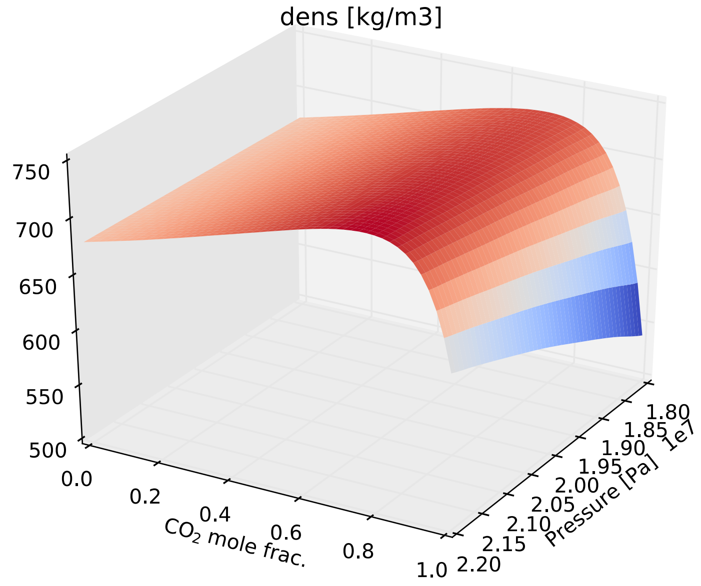
Run times in seconds for ***Flow*** *(left) and Eclipse (right).*

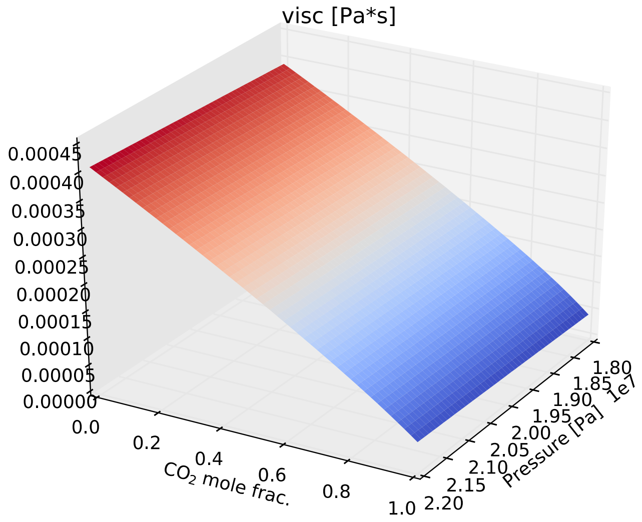




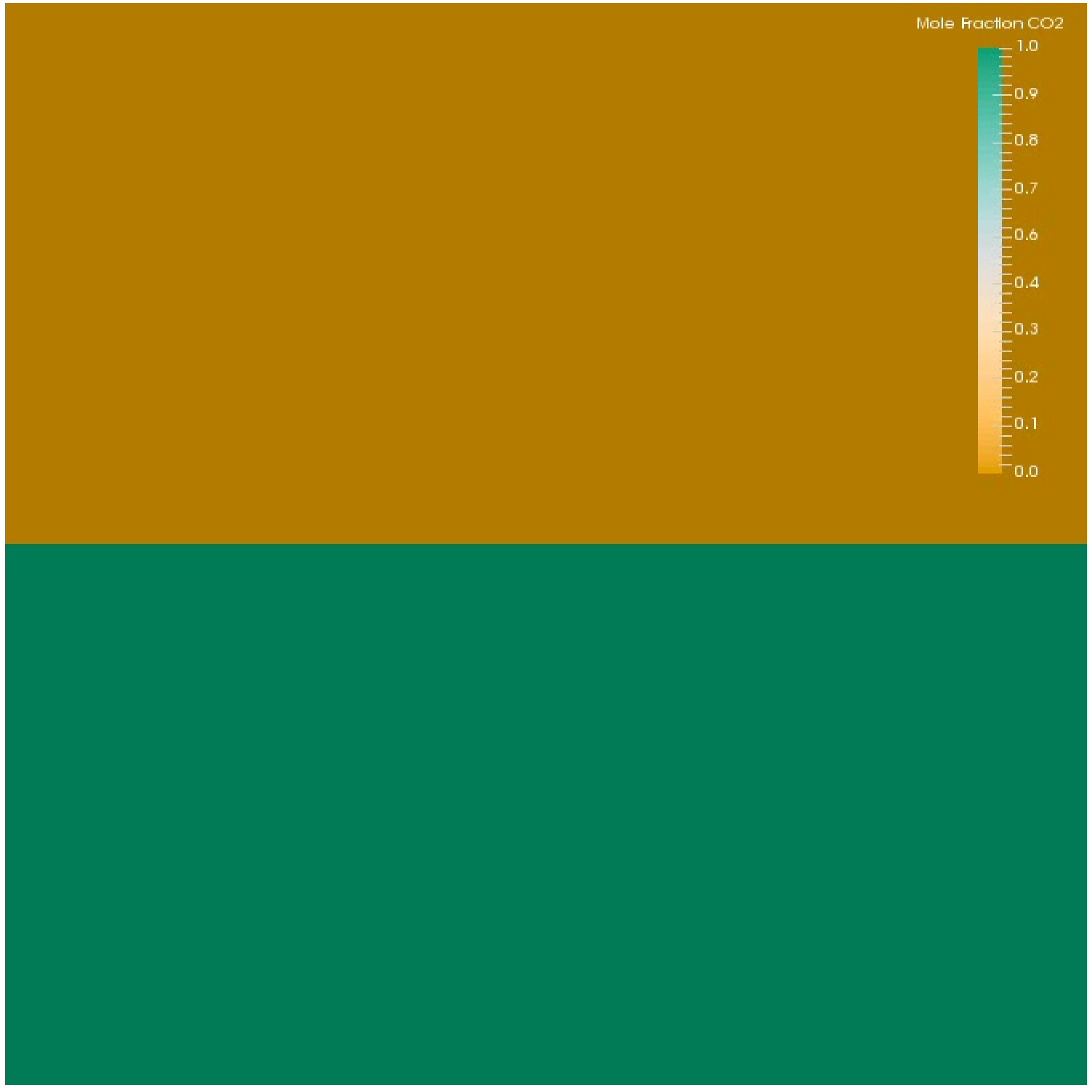
Fine-scale simulations in Opm:

- Density and viscosities from GERG-2008 (TREND 3.0)
  - Kunz, O.; Wagner, W. (2012): The GERG-2008 Wide-Range Equation of State for Natural Gases and Other Mixtures: An Expansion of GERG-2004. J. Chem. Eng. Data 57 (2012), 3032–3091.
- Approximate using Chebyshev polynomials in Padua points.
  - Caliari, Marco, Stefano De Marchi, and Marco Vianello. "Bivariate Lagrange interpolation at the Padua points: Computational aspects." *Journal of Computational and Applied Mathematics* 221.2 (2008): 284-292.

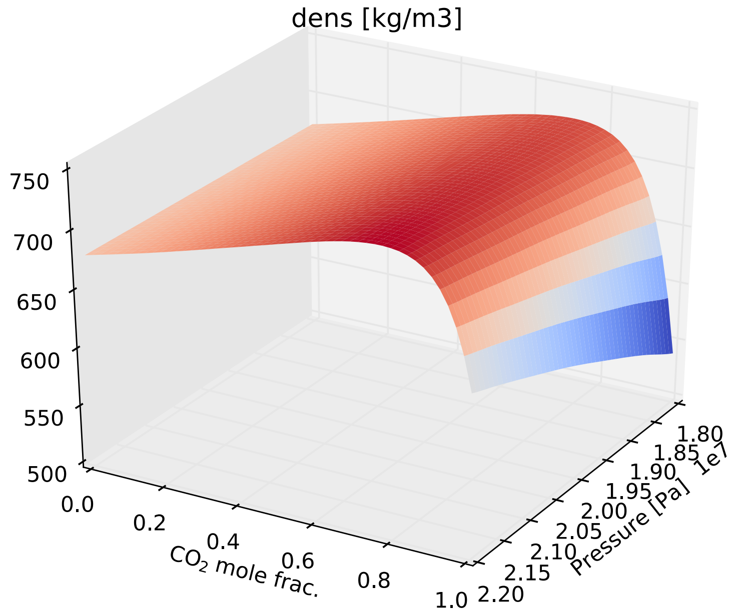




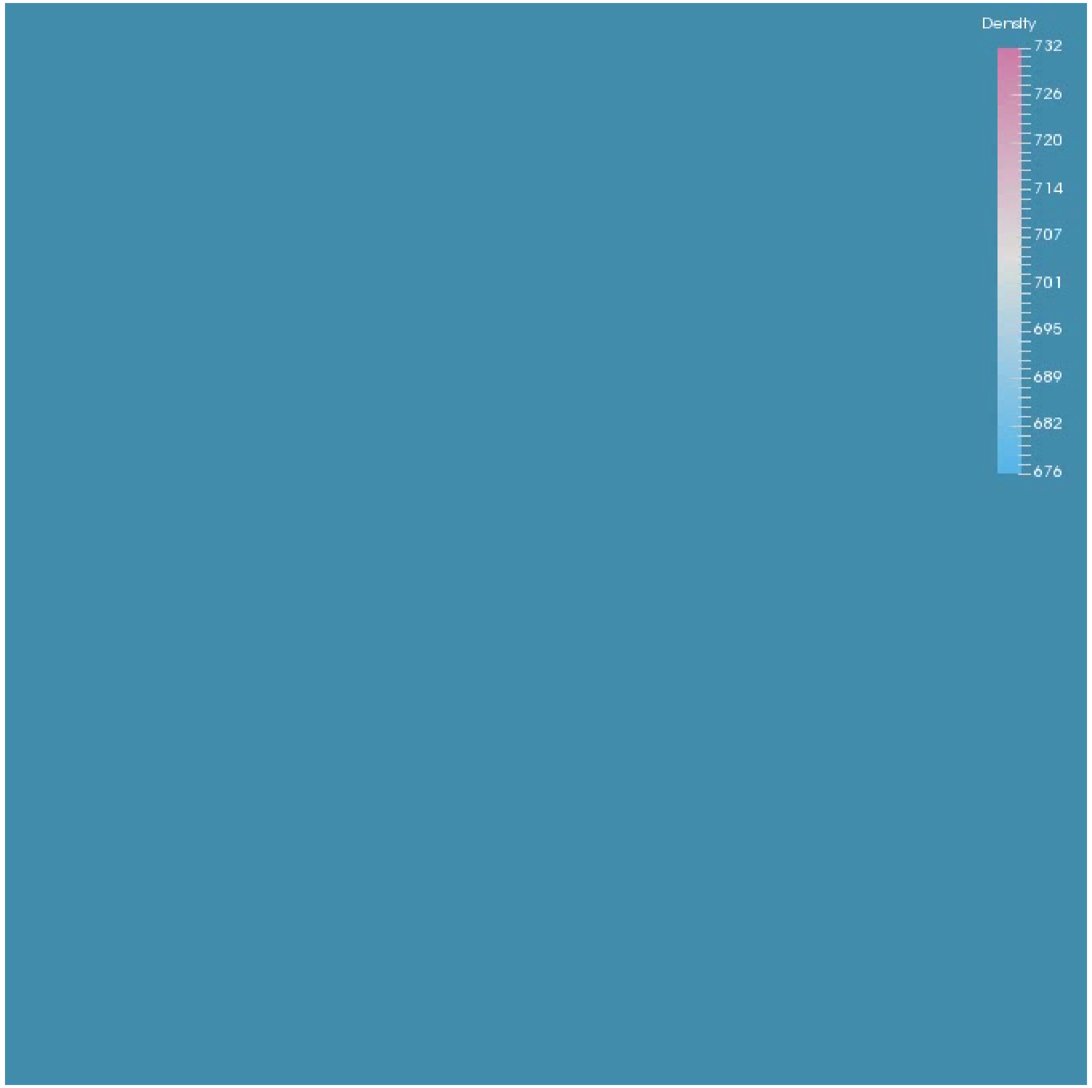
Fine-scale simulations in Opm:



- Mole fraction of CO_2
- Initially Octane on top and CO_2 on bottom.
- Run for 5 days

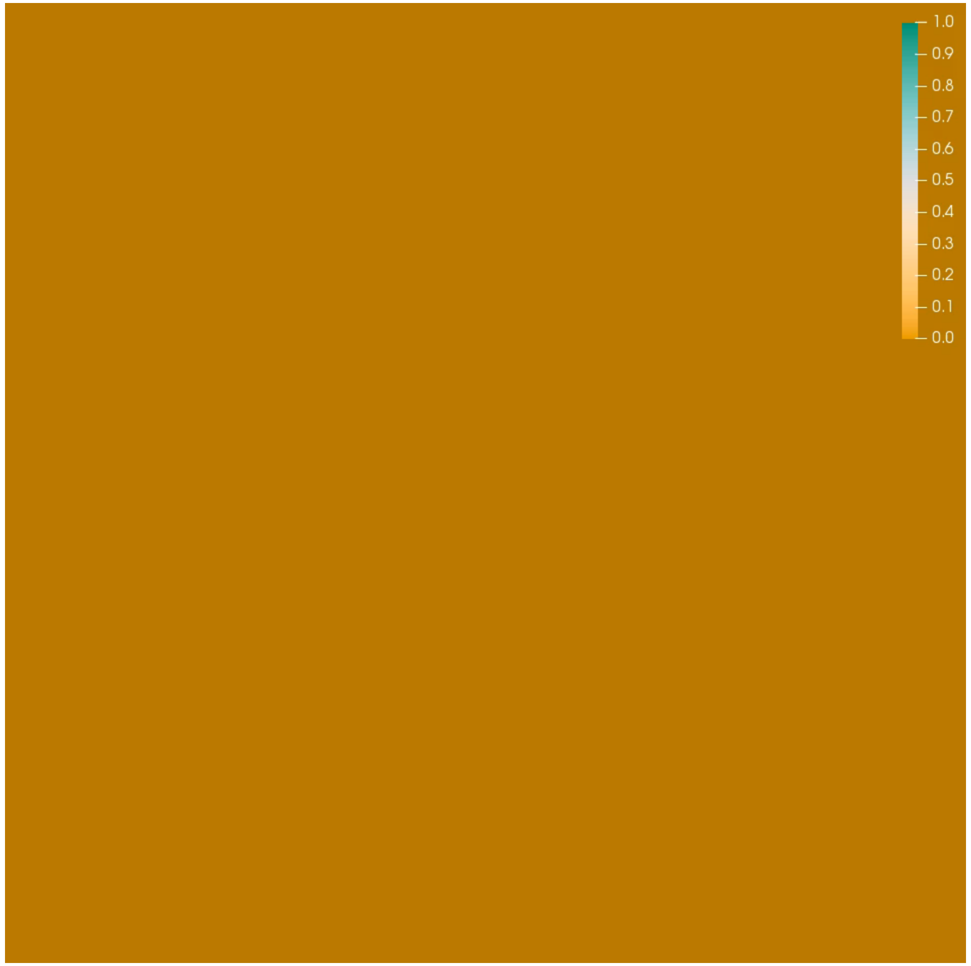


Fine-scale simulation in Opm:

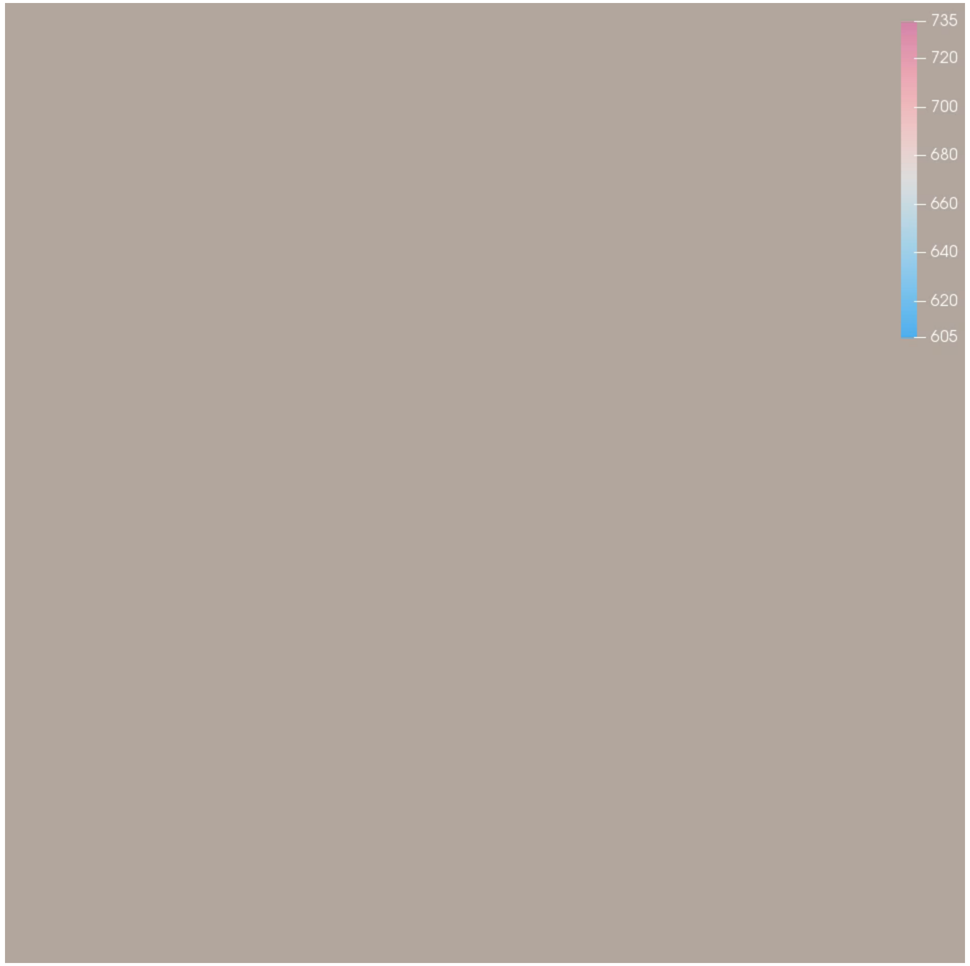


- There *is* a difference between CO_2 and Octane density
- But pure densities are much closer than to the mixture (!)

Fine-scale simulations in Opm:



Mole fraction (orange=oil, green=CO_2)



Density (blue=light, pink=heavy)

Upscaling / Multiscale modeling