



ENERGY for the FUTURE

Opportunities for Offshore International Whole Value Chain CCUS

Prof. Arne Graue

Department of Physics and Technology, University of Bergen, Norway

4th Biennial CO₂ for EOR as CCUS Conference, Rice University, TX, USA, Sept. 25-27th, 2019

Norway's Sovereign Wealth Fund Hits \$1 Trillion

Largest sovereign wealth funds by assets under management in 2017*



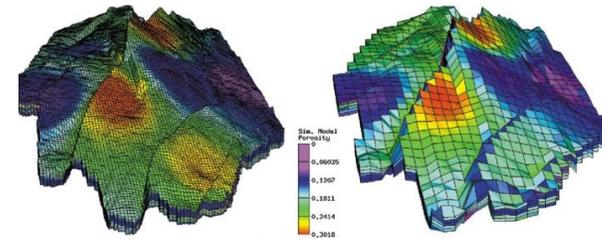
@StatistaCharts

* As of September 19, 2017

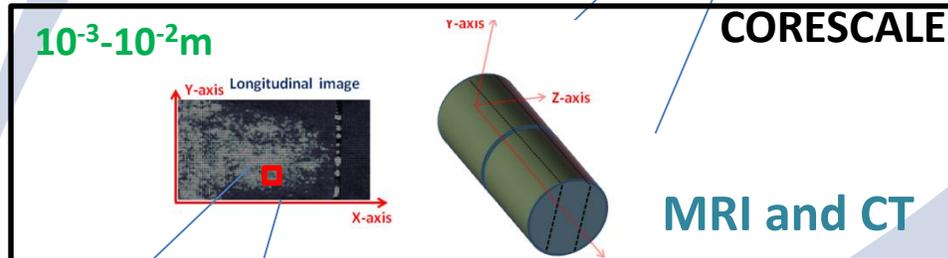
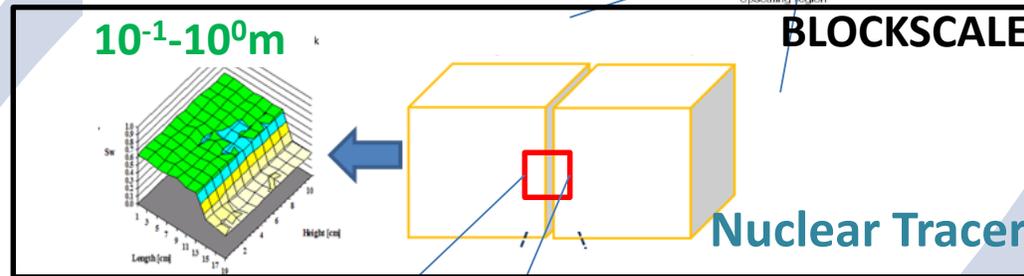
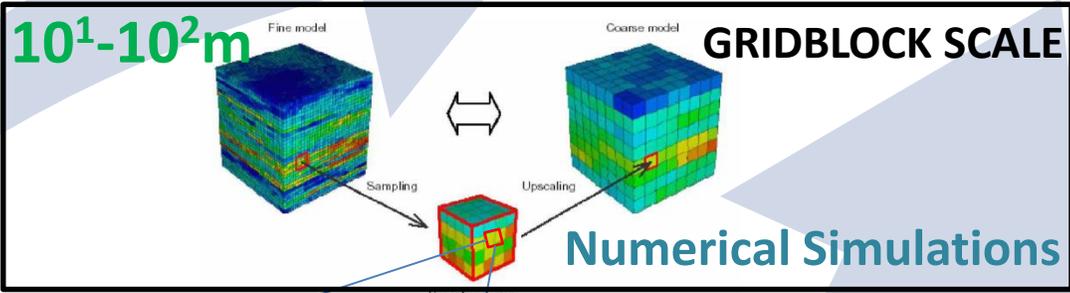
Source: The Sovereign Wealth Fund Institute

Length Scales

10^3-10^4m



Petroleum Geo-Services Homepage
www.pgs.com



Imaging techniques

CO₂ Storage from Lab to On-Shore Field Pilots Using CO₂-Foam for Mobility Control in CCUS

RCN CLIMIT 2015-2019

PI: Prof. Arne Graue, University of Bergen

Primary objective

Advance the technology of CO₂ foam mobility control to be a feasible option for EOR and aquifer storage in the USA and on the Norwegian Continental Shelf.

Tasks

1. Transport of aqueous surfactants, wettability changes and oil-tolerance (Rice Univ., UT Austin, USA)
2. Laboratory upscaling and visualization of EOR by foam (Univ. of Bergen, Norway)
3. Foam coalescence and transient flow with population balance model (Stanford Univ., USA)
4. Numerical upscaling of foam: from laboratory to field scale (UT Austin, USA, TU Delft, The Netherlands)
5. Field pilot implementation (3 Operators, 3 Advisor Companies and Schlumberger as Service Company)

5 PhD students in the project



The Research Council
of Norway



Nanoparticles to Stabilize CO₂-foam for Efficient CCUS in Challenging Reservoirs

RCN PETROMAKS2 2017-2021
PI: Prof. Martin Fernø, University of Bergen

Primary objective

Utilize nanotechnology to stabilize foam for successful implementation of CO₂-foam in challenging reservoirs that lead to environmentally sustainable energy production by CCUS.

Tasks

1. Corefloods with Stabilization of Foam using Silica Nanoparticles
2. Pore-scale Mechanisms for Nanoparticles in CO₂-foam
3. Foam Stability in Challenging and Harsh Environment

1 Post doc in the project



Subsurface Carbonate CO₂ Storage and Security

RCN CLIMIT 2018-2021

PI: Prof. Martin Fernø, University of Bergen

Primary objective

Utilize nanotechnology to stabilize foam for successful implementation of CO₂-foam in challenging reservoirs that lead to environmentally sustainable energy production by CCUS.

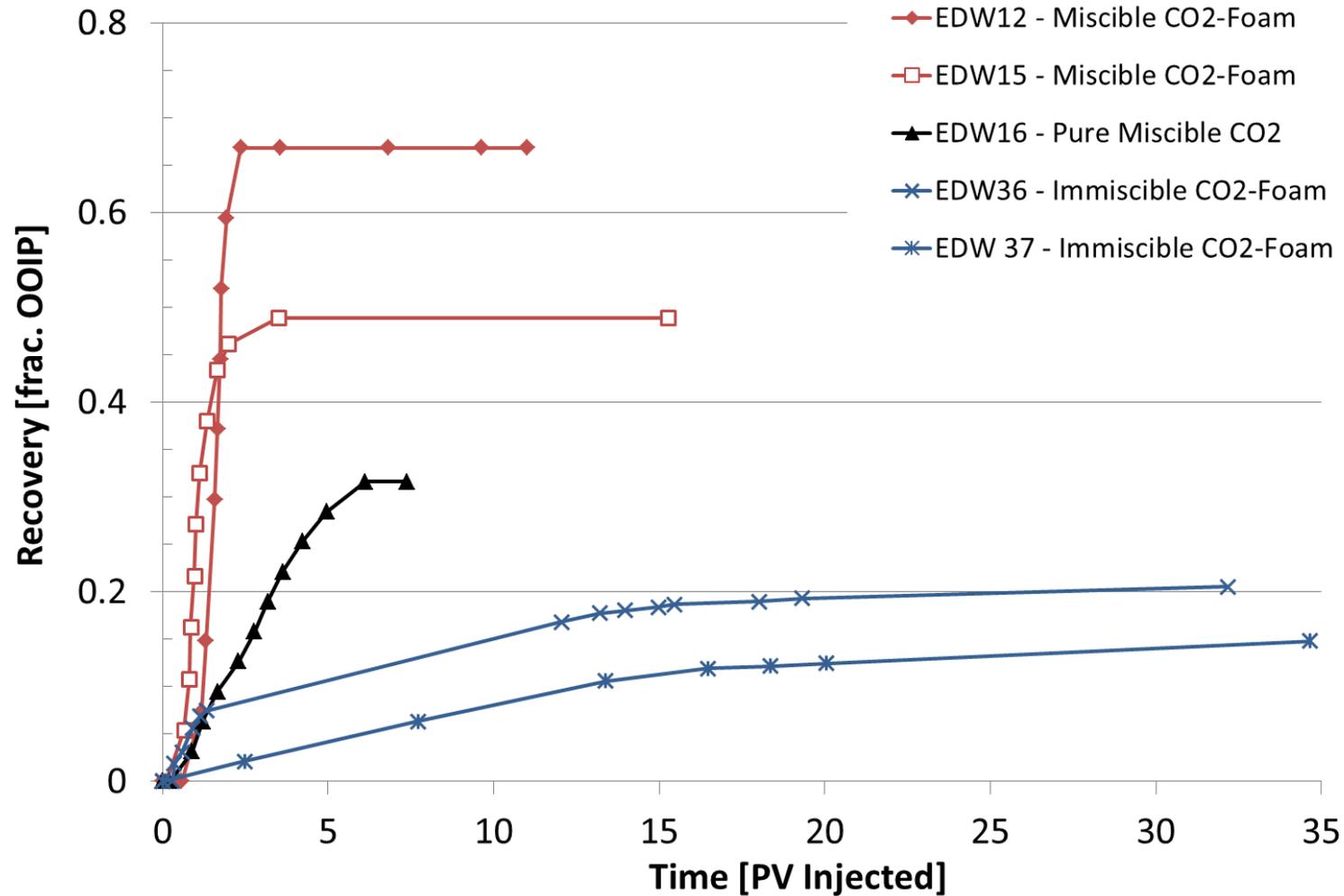
Work Packages

1. Microvisualization of new dissolution mechanisms during geological CO₂ storage
2. Darcy-scale measurement of carbonate reactive flow patterns and seal layer storage security

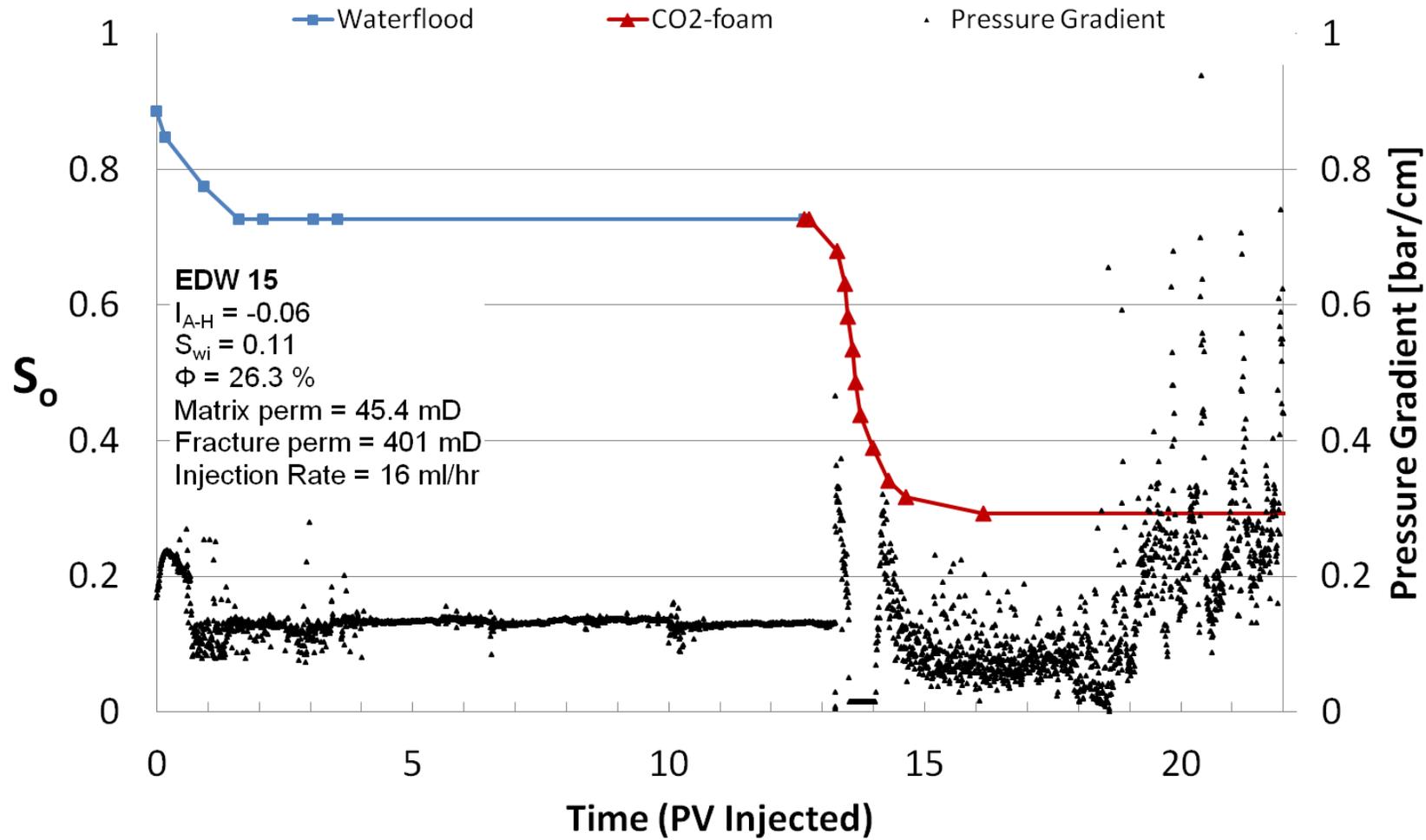
1 researcher and 1 PhD student in the project



Comparison between miscible CO₂ injection and immiscible and miscible CO₂-foam



Oil-Wet Carbonate Core Plugs: IEOR (WF+CO₂-foam)



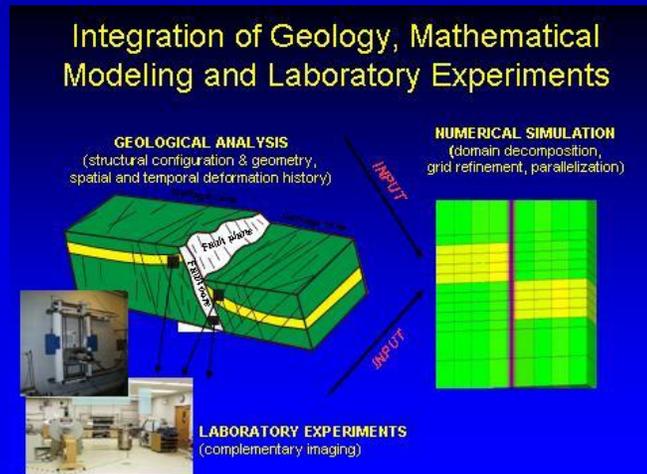
CO₂ EOR Enables CCUS: Integrated EOR (IEOR) for CO₂ Sequestration

CO₂ Foam EOR Mobility Control in Field Pilots in Texas

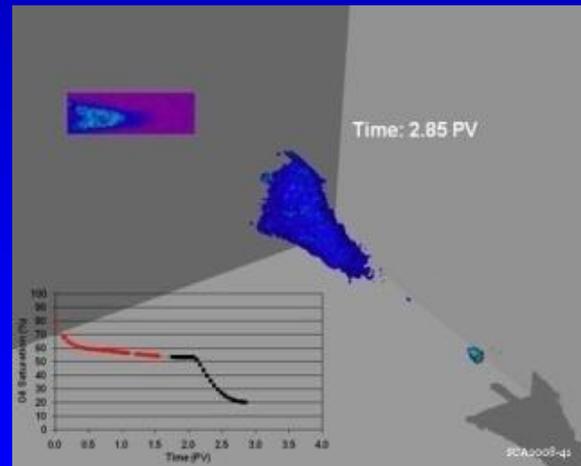
Collaboration: 11 Universities in France, The Netherlands, UK, USA and Norway

Coordinator: Arne Graue, Dept. of Physics, University of Bergen, NORWAY

Funding: CLIMIT Program at the Research Council of Norway and 7 oil companies



Lab to pilot field test



MRI of CO₂ injection



Complementary NTI & MRI facilities

CO₂ Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

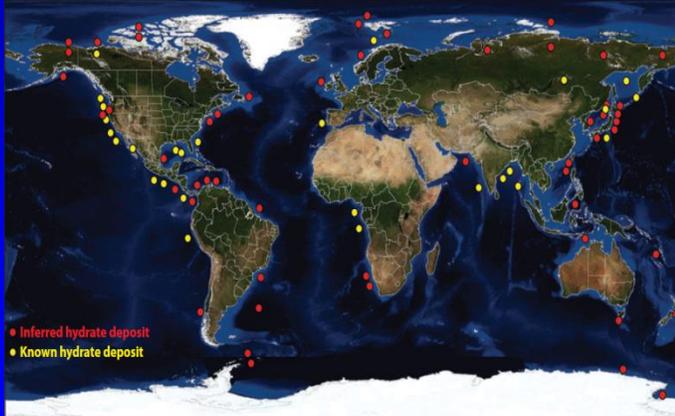
Arne Graue and Bjørn Kvamme, Dept. of Physics, University of Bergen, NORWAY
Funding: ConocoPhillips, Statoil and The Research Council of Norway



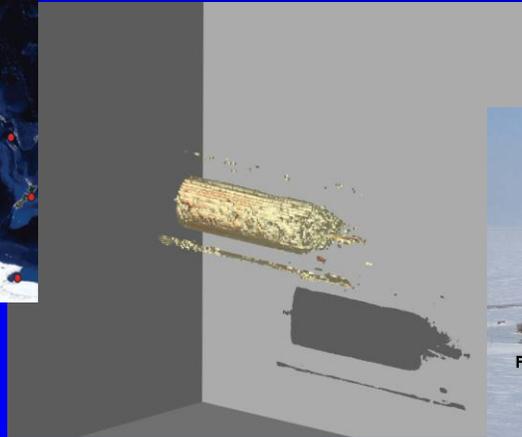
Objectives:

Experimentally and theoretically determine spontaneous methane production when hydrate is exposed to CO₂; with the purpose of CO₂ sequestration.

Methane hydrate reservoirs



In-Situ imaging (MRI) of hydrate formation



Methane production by CO₂ injection in field test in Alaska 2012



Reduced Carbon Footprint in Oil and Gas Production Utilizing CO₂ Storage

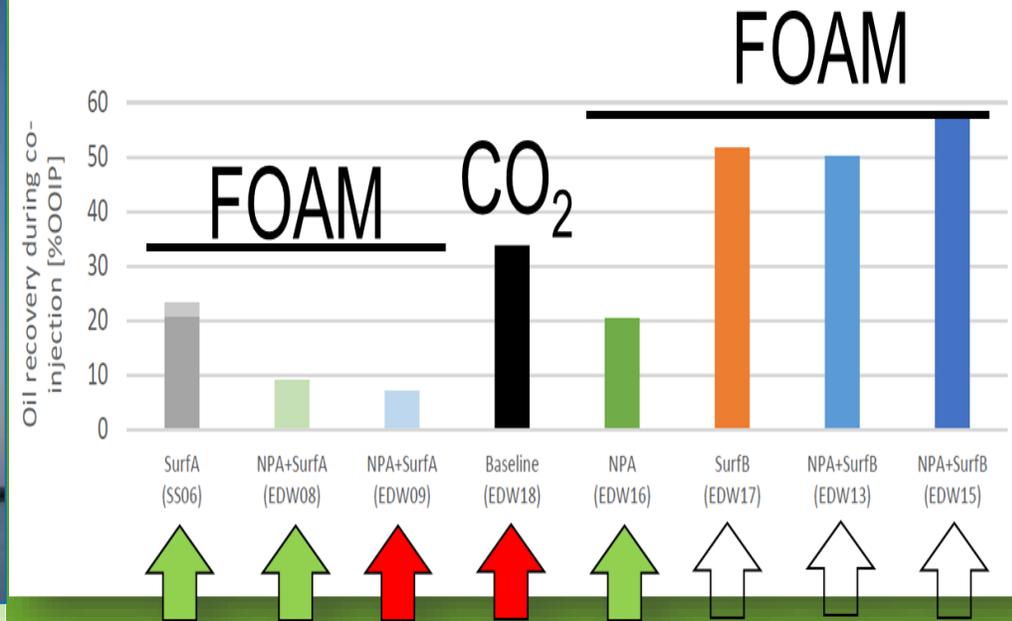
Carbon **NEUTRAL** Gas Production



Iñnik Sikumi test site, Alaska

Equal amounts of C-atoms stored as produced

Carbon **NEGATIVE** EOR



More C-atoms stored underground than produced

Success Criteria for Global CO₂ Storage

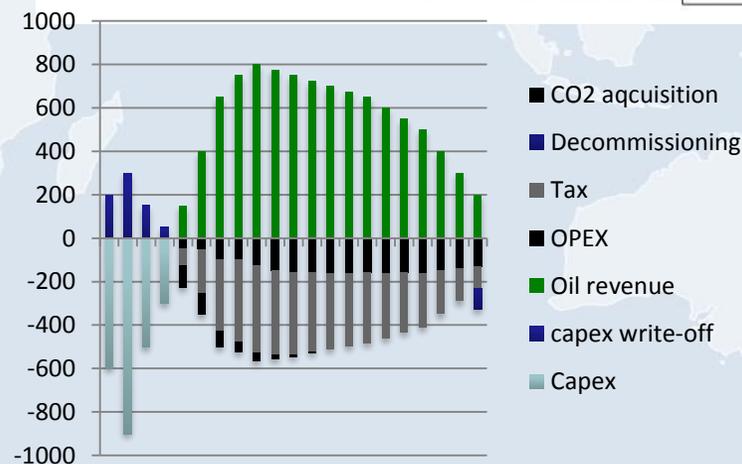
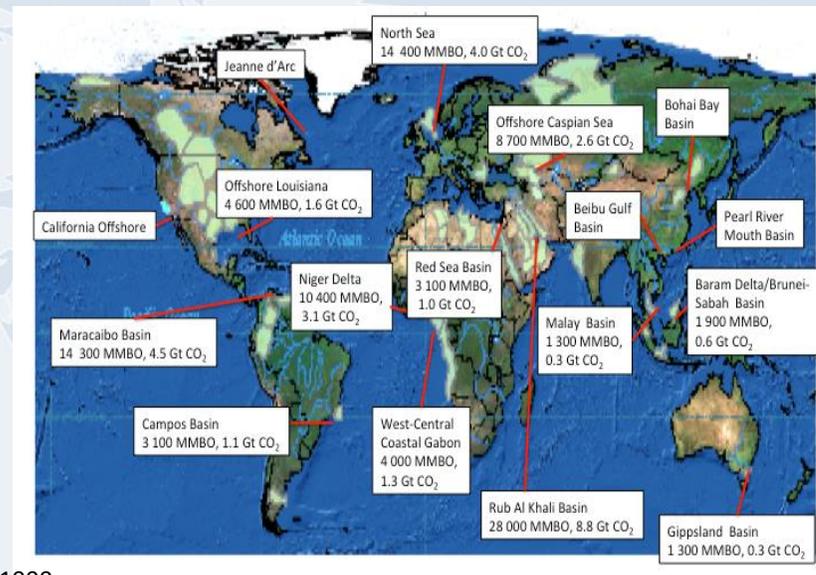
- Industry participation
 - Sustainable Economy; Disruptive Technologies at Low Cost
 - CO₂ EOR
 - Verification at Field Scale & at Relevant Location
 - Cost Effective On-Shore Analogues
 - Offshore pilots
 - Whole Value Chain Pilots
 - Whole Value Chain Field Wide CCUS



Potential and economics

- Potential updated with available sources
 - Incremental oil production: 114000 million bbl
 - Stored CO₂: ≈41 GT

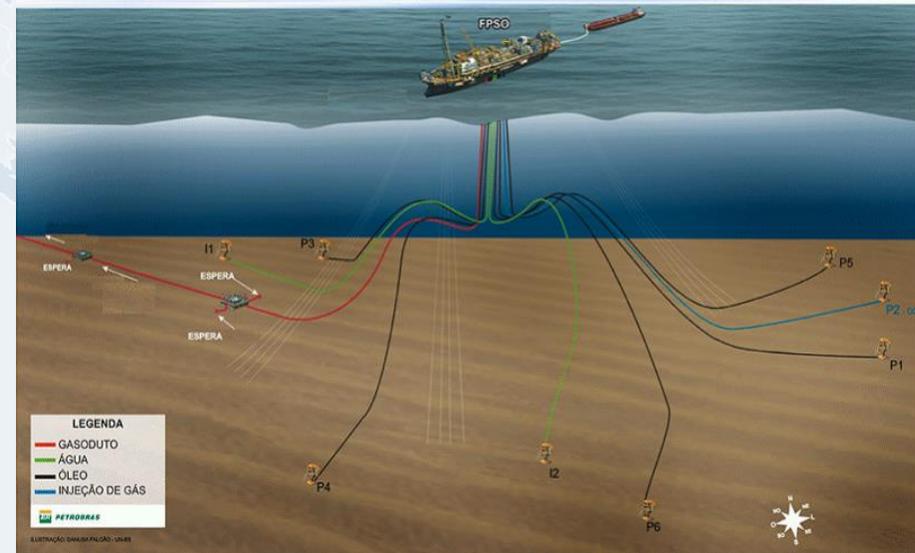
- Economics
 - Discuss some key parameters
 - Cash flow fictitious example





Lula Project

- Reservoir well suited for miscible gas EOR
- CO₂ content in gas ≈ 11 %
- Extensive reservoir characterization
- Robust and flexible development strategy
- Careful choice of topside solution and materials
- Membranes used for CO₂ separation
- WAG solution with six producers, two WAG injectors, one CO₂ injector
- No major operational or reservoir problems
- Monitoring with downhole pressure gauges and tracers





Approaches for enabling offshore CO₂-EOR

- Using late-life oilfield infrastructure
- Using oilfield satellite projects
- Focusing CO-EOR on the residual oil zone (ROZ)
- Reservoir modelling: Issues particular to CO₂-EOR
 - Phase behaviour
 - Reactions with rocks
 - Multiphase flow in porous media
 - Oil instability

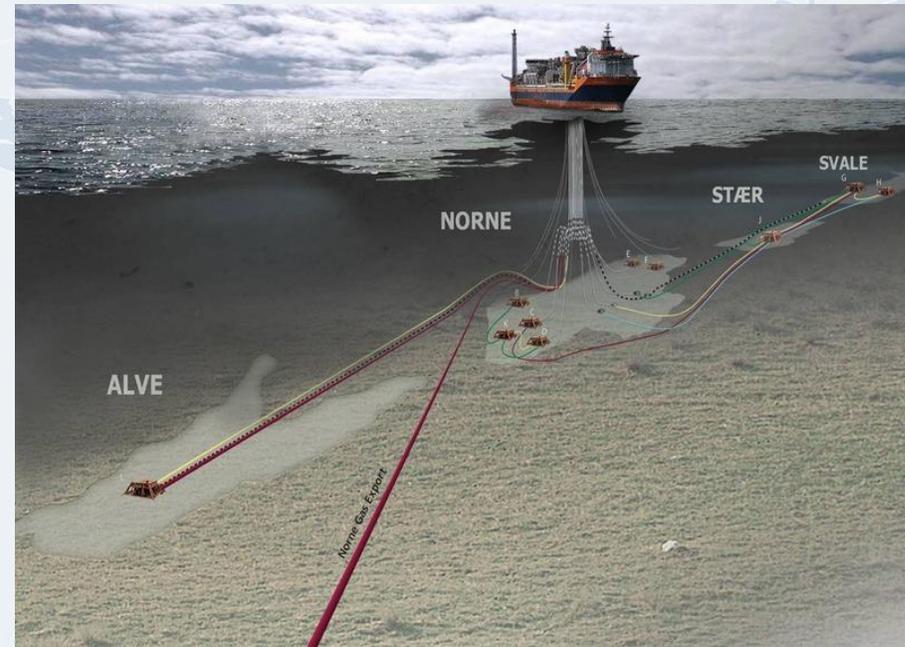
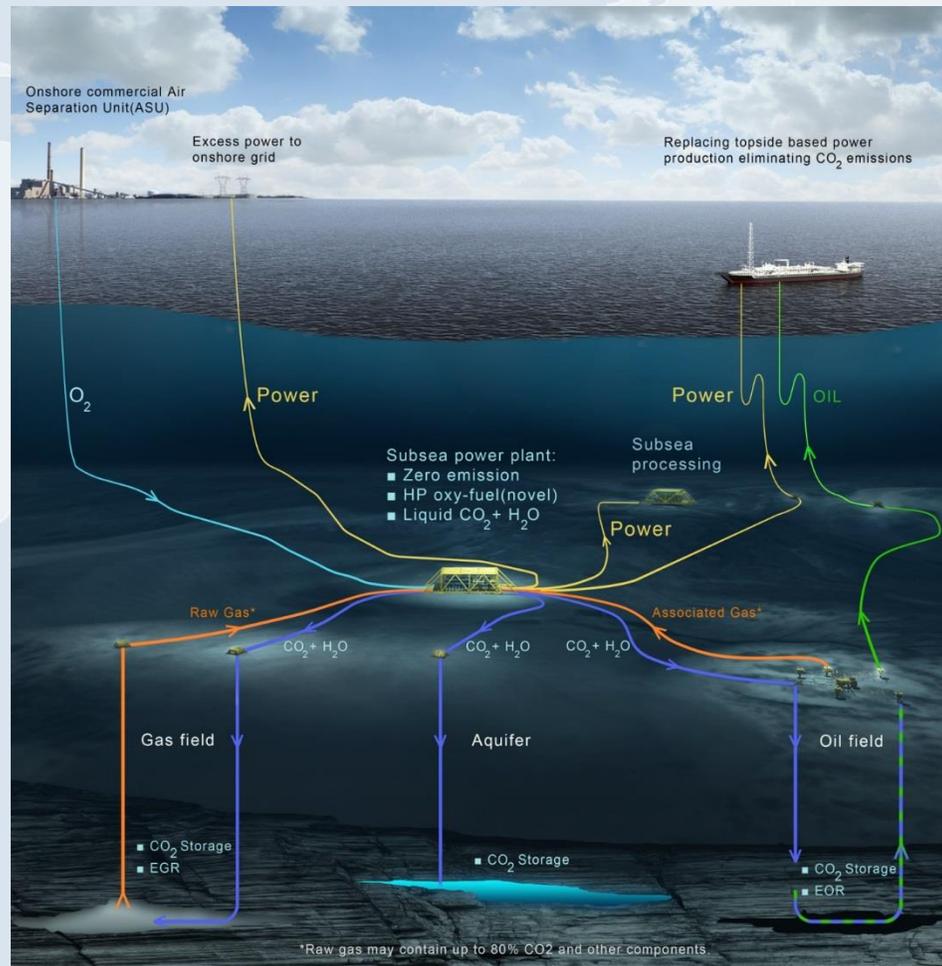




Illustration of subsea zero emission offshore power generation and CO₂ separation concept

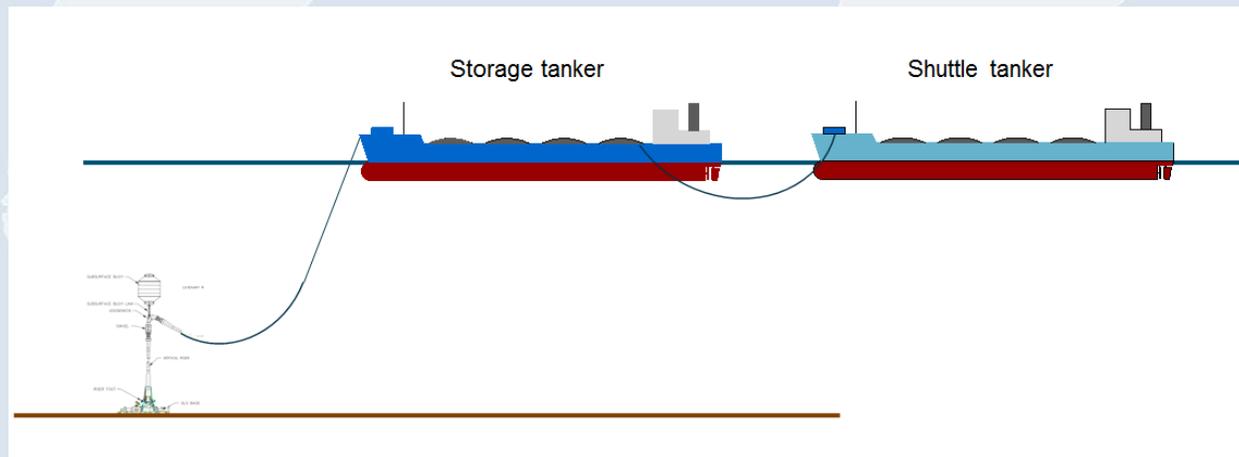


(Courtesy Aker Solutions)

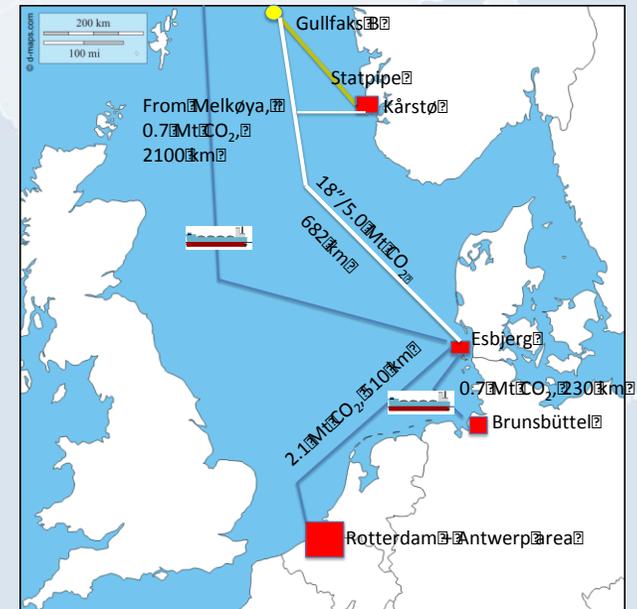


CO₂ supply chain issues

- No technical barriers to CO₂ infrastructure for offshore EOR
- Optimisation will bring costs down
- Some system parts need qualification
- Barriers are commercial and political in nature



Bow to stern loading from shuttle tanker to storage and injection vessel.
Possible buoy solution indicated. (Courtesy Aker Solutions)



A network of sources and transportation means to supply Gullfaks with 5.5 MT CO₂/year. Based on Agustsson and Grinestad (2005), Berger et al. (2004) and Elsam et al., 2003

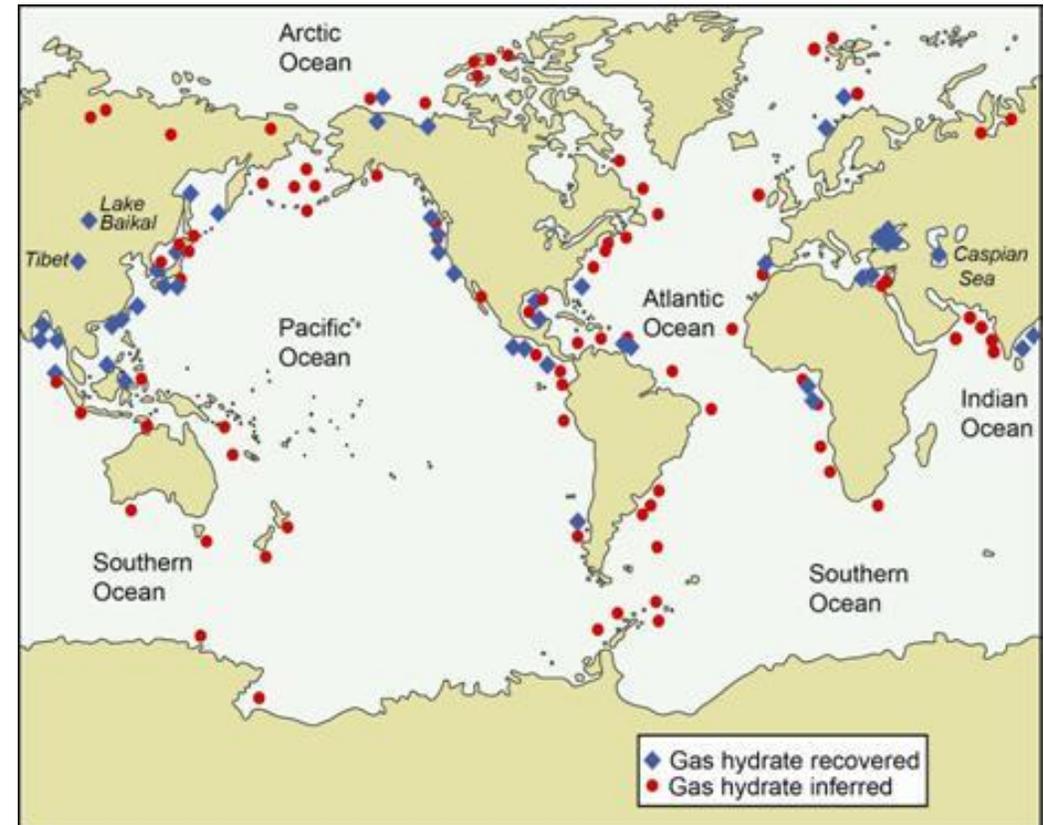
Global Business Opportunities



CH₄ deposits have been discovered off the coasts of almost all continents and are inferred to occur globally

Several countries have research programs on methane hydrate detection and extraction:

- Japan, South Korea, India, China, USA, Canada, Russia, New Zealand, Norway, Brazil, Chile, Germany, United Kingdom
- The US Government and US companies play a prominent role for research
- US Geological Survey (USGS) estimated a potentially recoverable resource of 85 trillion cubic feet of gas only in Alaska



Source: US Geological Survey

Business Opportunities in Asia

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GOOD IDEAS

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Business Opportunities in Asia



Hydrates are a unique energy source

- No similar size of energy reserves present in Asia provides strategies for countries with energy poverty and lack of energy resources

Accelerated public energy demand

- Rapid economic growth
- Urgency for developing sustainable energy solutions
- IEA predicts that 65% of the growth of the world energy demand will occur in non-OECD Asia

Favorable gas prices

- Potent market in Asia
- Gas prices seven to nine times higher than in North America

High CO₂ availability

- Numerous Asian oil fields are currently producing as much as 70% CO₂
- Large production of CO₂ in industrial clusters

Integrated
CO₂-EOR

CO₂-CH₄
Exchange

Applying CO₂ as a commodity in CO₂ injection, either for:

- CO₂ foam EOR
- Methane production from hydrates

Will significantly contribute to the supply of energy in Southeast Asia and enable CO₂ sequestration

Easy Accessible CO₂ Sources in Asia



Non-exhaustive list of reservoirs and industrial clusters with high CO₂ concentration

Malaysia

- K5 Gas Field (70% CO₂)
- Tangga Barat Gas Field (48% CO₂)
- Muda Gas Field (47% CO₂)
- Cakerawala Gas Field (37% CO₂)

Thailand

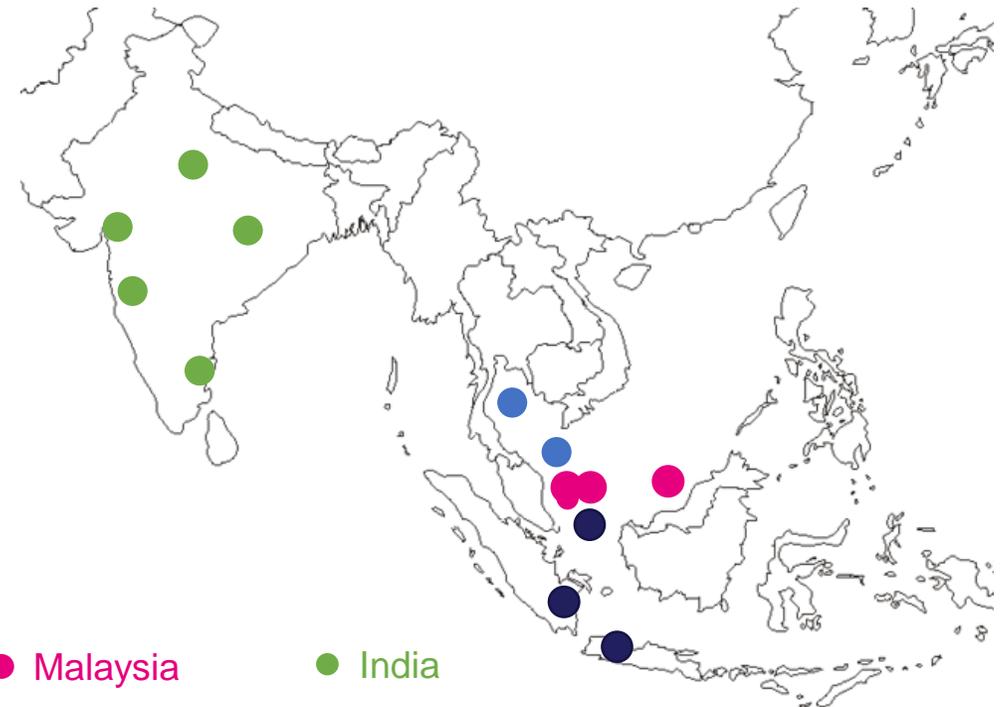
- Malay Basin, Group I (shared with Malaysia)
- Jasmine Field

Indonesia

- Natuna Gas Field (up to 75% CO₂)
- West Java Field (up to 75% CO₂)
- South Sumatra Basin

India

- Dehli Region
- Chotanagpur Plateau Region
- Mumbai-Pune Belt
- Ahmedabad-Vadodara Region
- Chennai Region



- Malaysia
- Thailand
- India
- Indonesia

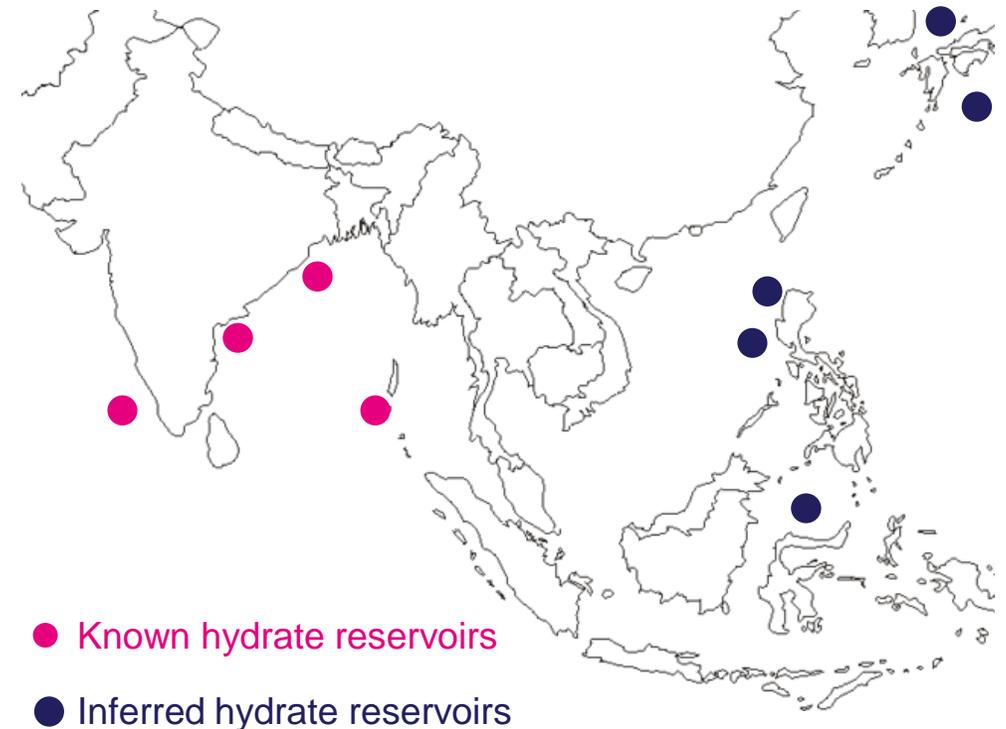
Map show non-exhaustive list of reservoirs and industrial clusters with high CO₂ concentration

Large commercial opportunities for LNG production from hydrate basins in Asia



Major hydrate basins identified in Asia show high potential to meet current and future energy needs

- Expeditions in the Krishna-Godavari and Mahanadi Basins off the coast of India show positive findings
- Preliminary work underway for gas hydrate production testing program
- Gas hydrate reserves of India estimated at nearly 1,500 times its natural gas reserves



Source: Hester and Brewer, 2009



Summary

Use of CO₂ as a commodity:

Business Case for CO₂ Storage:

- CO₂ EOR
- Integrated EOR (IEOR) with Foam: *Carbon Negative Oil Production*
- Exploitation of Hydrate Energy: *Carbon Neutral Gas Production*

Way Forward

New technologies ready for industrial scale implementation:

- Onshore in Permian Basin, USA (80% CO₂EOR, EOR target 137Bbbl)
- Offshore Opportunities: NCS, Middle East, Asia, Africa and Brazil
- International Whole Value Chain CCUS Collaboration Offshore