



# ENERGY for the FUTURE

## *Opportunities for Offshore International Whole Value Chain CCUS*

Prof. Arne Graue

Department of Physics and Technology, University of Bergen, Norway

Interdisciplinary CCUS Workshop, U. of Houston, TX, USA, Sept.23-24<sup>th</sup>, 2019

# Norway's Sovereign Wealth Fund Hits \$1 Trillion

Largest sovereign wealth funds by assets under management in 2017\*



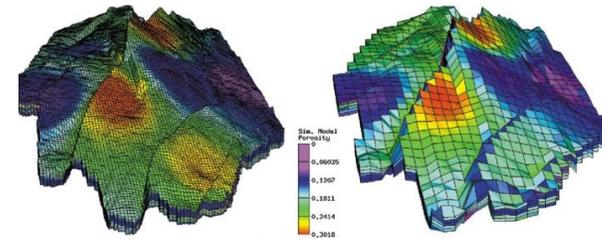
@StatistaCharts

\* As of September 19, 2017

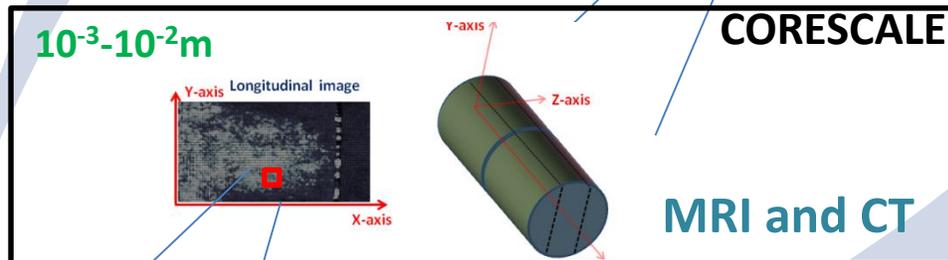
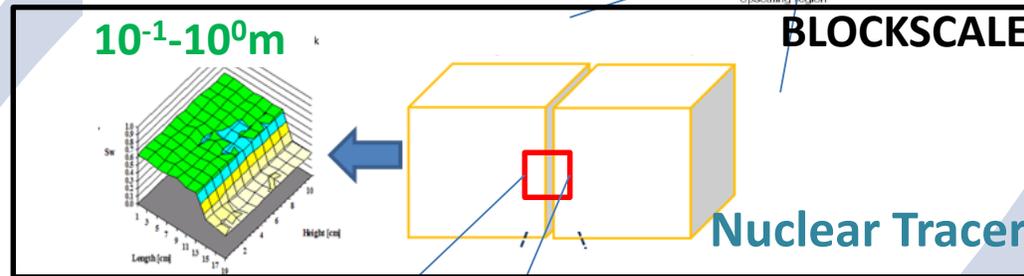
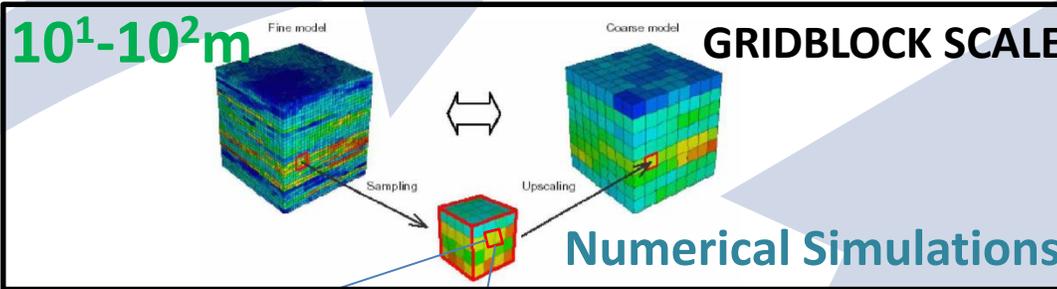
Source: The Sovereign Wealth Fund Institute

# Length Scales

$10^3-10^4\text{m}$



Petroleum Geo-Services Homepage  
www.pgs.com



# Imaging techniques

# CO<sub>2</sub> Storage from Lab to On-Shore Field Pilots Using CO<sub>2</sub>-Foam for Mobility Control in CCUS

RCN CLIMT 2015-2019

PI: Prof. Arne Graue, University of Bergen

## Primary objective

Advance the technology of CO<sub>2</sub> 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 CO<sub>2</sub>-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 CO<sub>2</sub>-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 CO<sub>2</sub>-foam
3. Foam Stability in Challenging and Harsh Environment

## 1 Post doc in the project



# Subsurface Carbonate CO<sub>2</sub> 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 CO<sub>2</sub>-foam in challenging reservoirs that lead to environmentally sustainable energy production by CCUS.

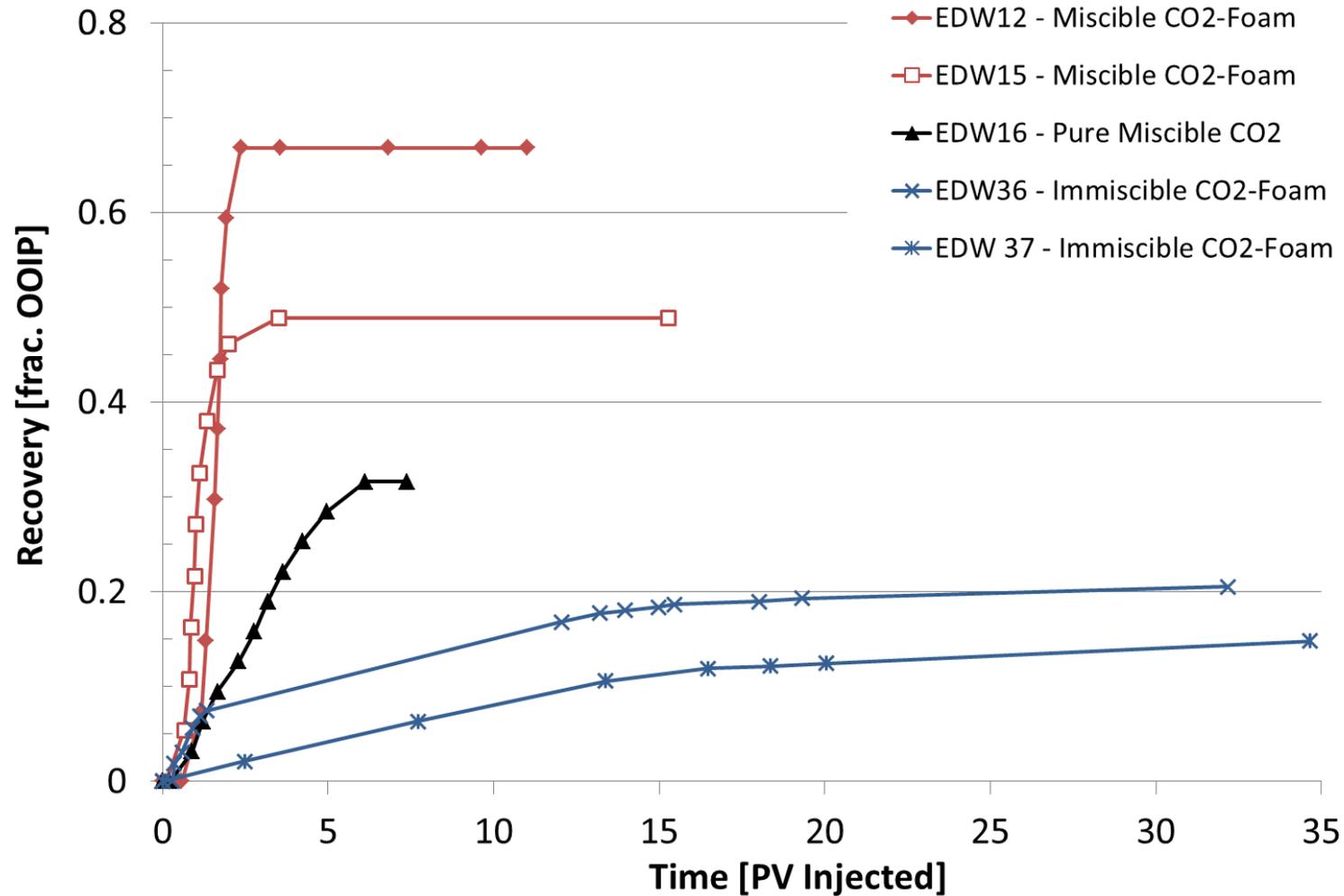
## Work Packages

1. Microvisualization of new dissolution mechanisms during geological CO<sub>2</sub> storage
2. Darcy-scale measurement of carbonate reactive flow patterns and seal layer storage security

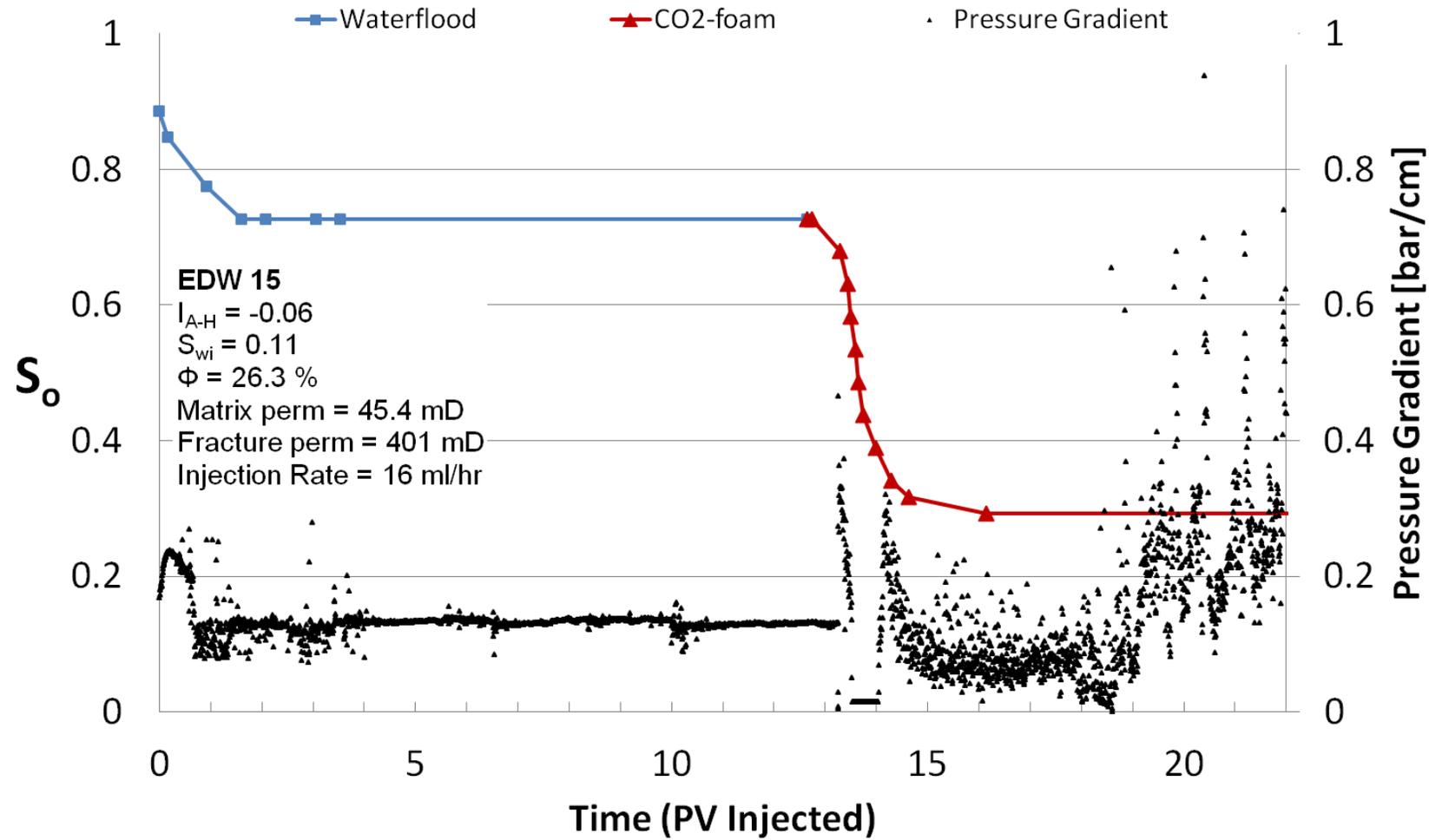
**1 researcher and 1 PhD student in the project**



# Comparison between miscible CO<sub>2</sub> injection and immiscible and miscible CO<sub>2</sub>-foam



# Oil-Wet Carbonate Core Plugs: IEOR (WF+CO<sub>2</sub>-foam)



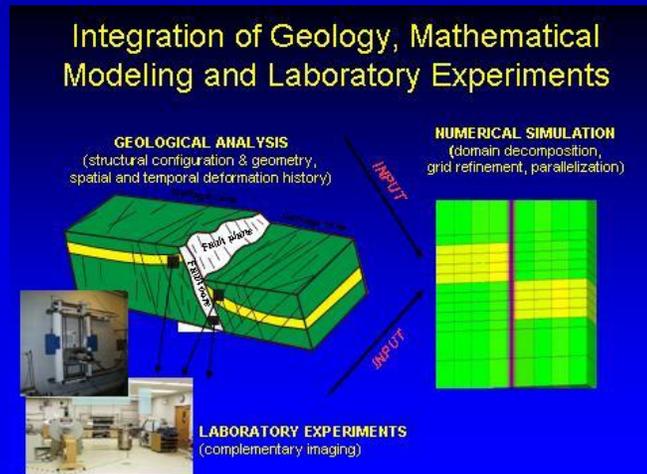
# *CO<sub>2</sub> EOR Enables CCUS: Integrated EOR (IEOR) for CO<sub>2</sub> Sequestration*

## CO<sub>2</sub> Foam EOR Mobility Control in Field Pilots in Texas

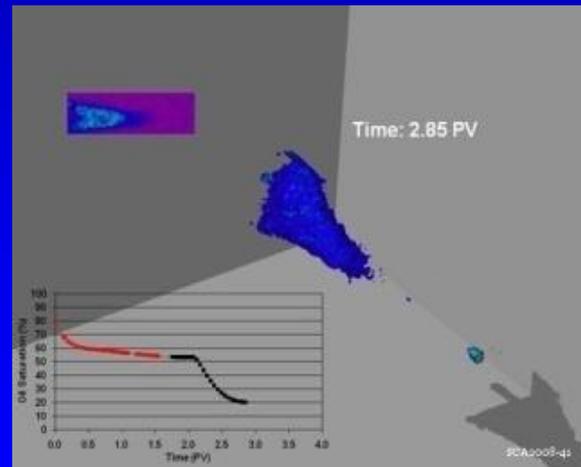
Collaboration: 11 Universities in France, The Netherlands, UK, USA and Norway

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 CO<sub>2</sub> injection



Complementary NTI & MRI facilities

# CO<sub>2</sub> Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

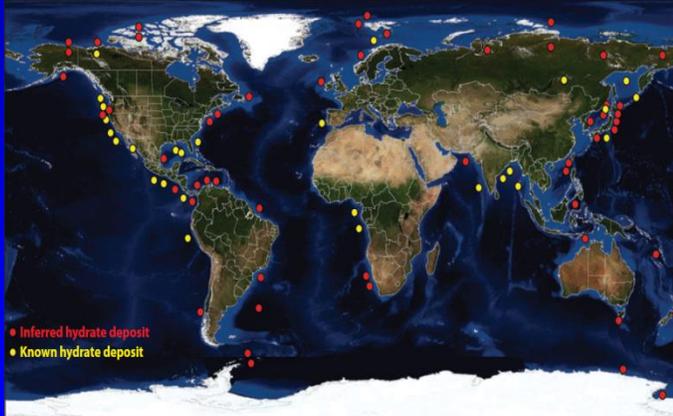
Arne Graue and Bjørn Kvamme, Dept. of Physics, University of Bergen, NORWAY  
Funding: ConocoPhillips, Statoil and The Research Council of Norway



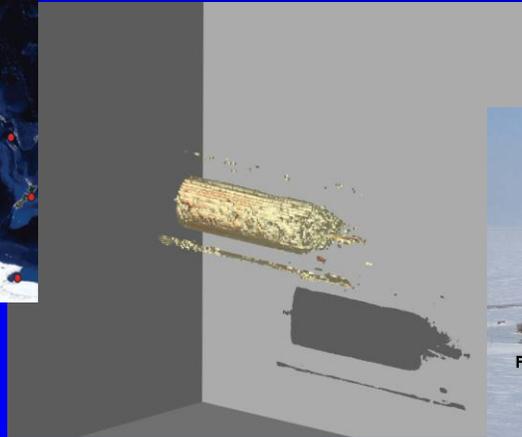
## Objectives:

*Experimentally and theoretically determine spontaneous methane production when hydrate is exposed to CO<sub>2</sub>; with the purpose of CO<sub>2</sub> sequestration.*

## Methane hydrate reservoirs



## *In-Situ* imaging (MRI) of hydrate formation



## Methane production by CO<sub>2</sub> injection in field test in Alaska 2012



# Reduced Carbon Footprint in Oil and Gas Production Utilizing CO<sub>2</sub> Storage

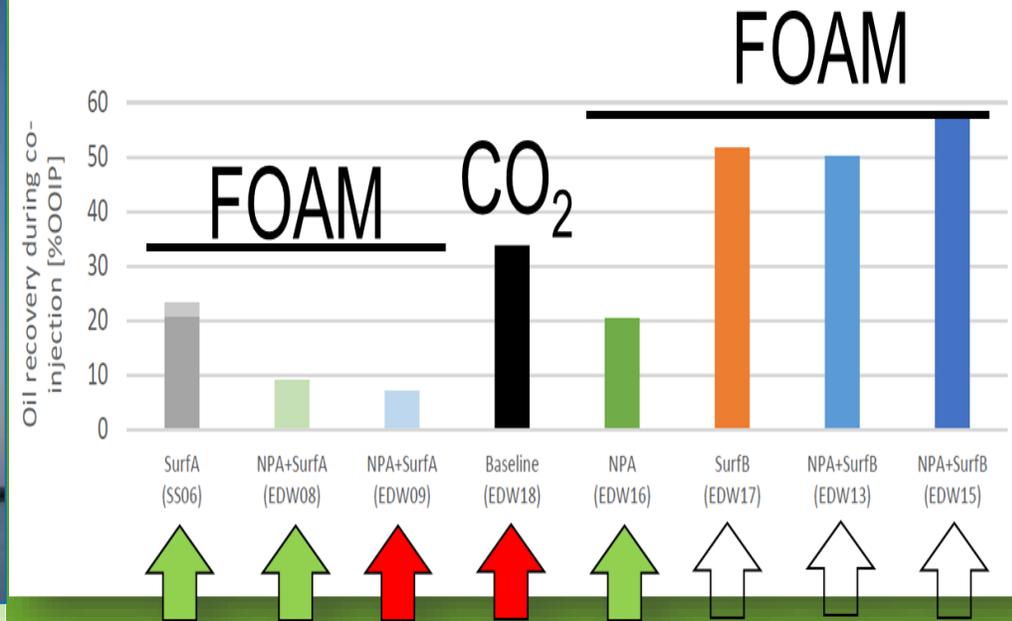
## Carbon **NEUTRAL** Gas Production



Iñnik Sikumi test site, Alaska

Equal amounts of C-atoms stored as produced

## Carbon **NEGATIVE** EOR



More C-atoms stored underground than produced

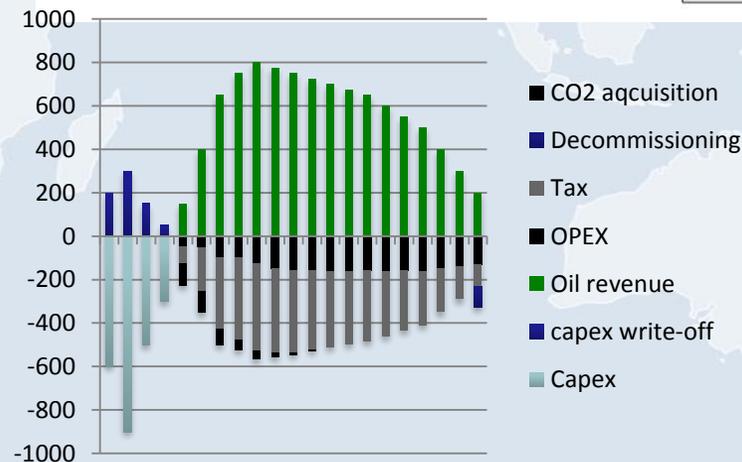
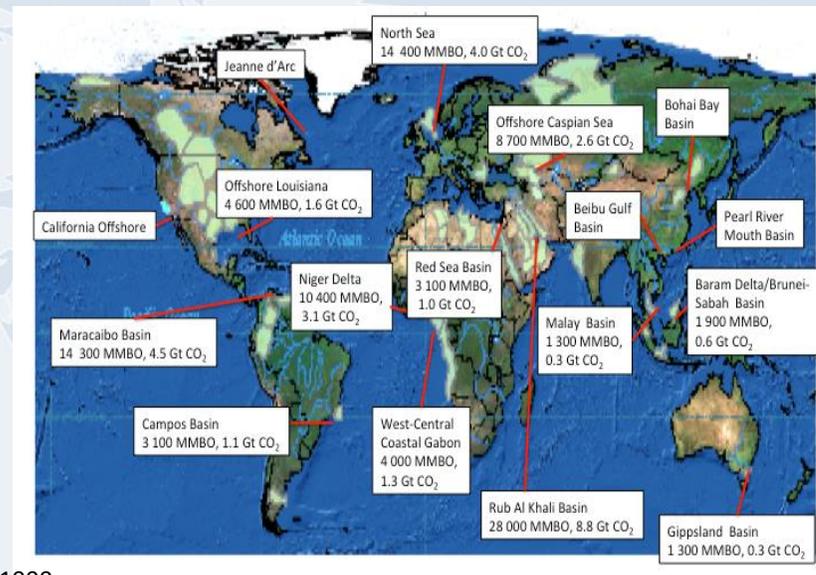
# Success Criteria for Global CO<sub>2</sub> Storage

- Industry participation
  - Sustainable Economy; Disruptive Technologies at Low Cost
    - CO<sub>2</sub> 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

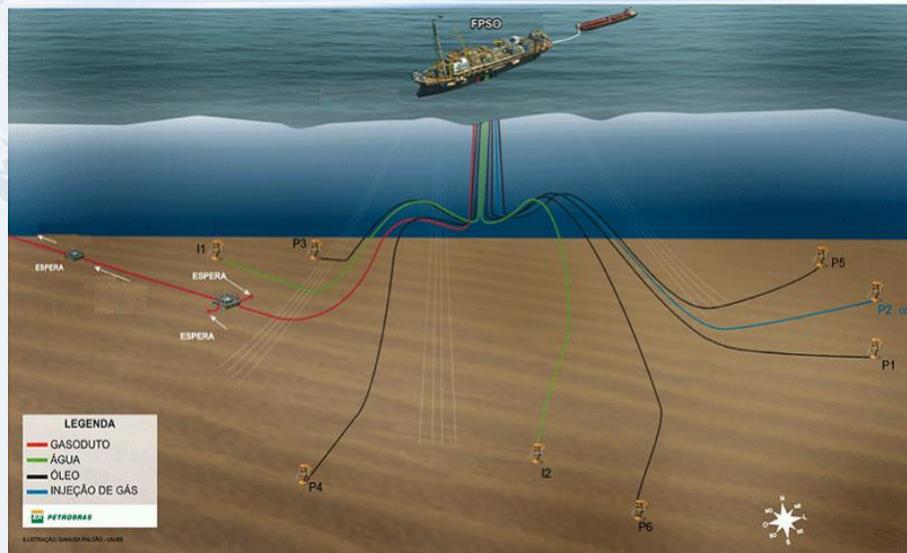
- Potential updated with available sources
  - Incremental oil production: 114000 million bbl
  - Stored CO<sub>2</sub>: ≈41 GT
  
- Economics
  - Discuss some key parameters
  - Cash flow fictitious example





## Lula Project

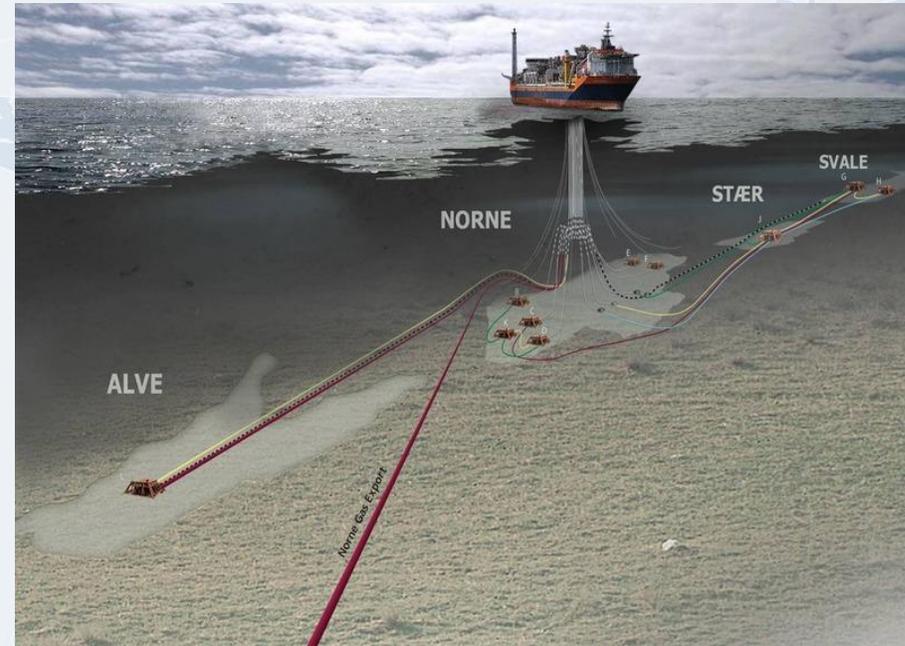
- Reservoir well suited for miscible gas EOR
- CO<sub>2</sub> content in gas ≈ 11 %
- Extensive reservoir characterization
- Robust and flexible development strategy
- Careful choice of topside solution and materials
- Membranes used for CO<sub>2</sub> separation
- WAG solution with six producers, two WAG injectors, one CO<sub>2</sub> injector
- No major operational or reservoir problems
- Monitoring with downhole pressure gauges and tracers





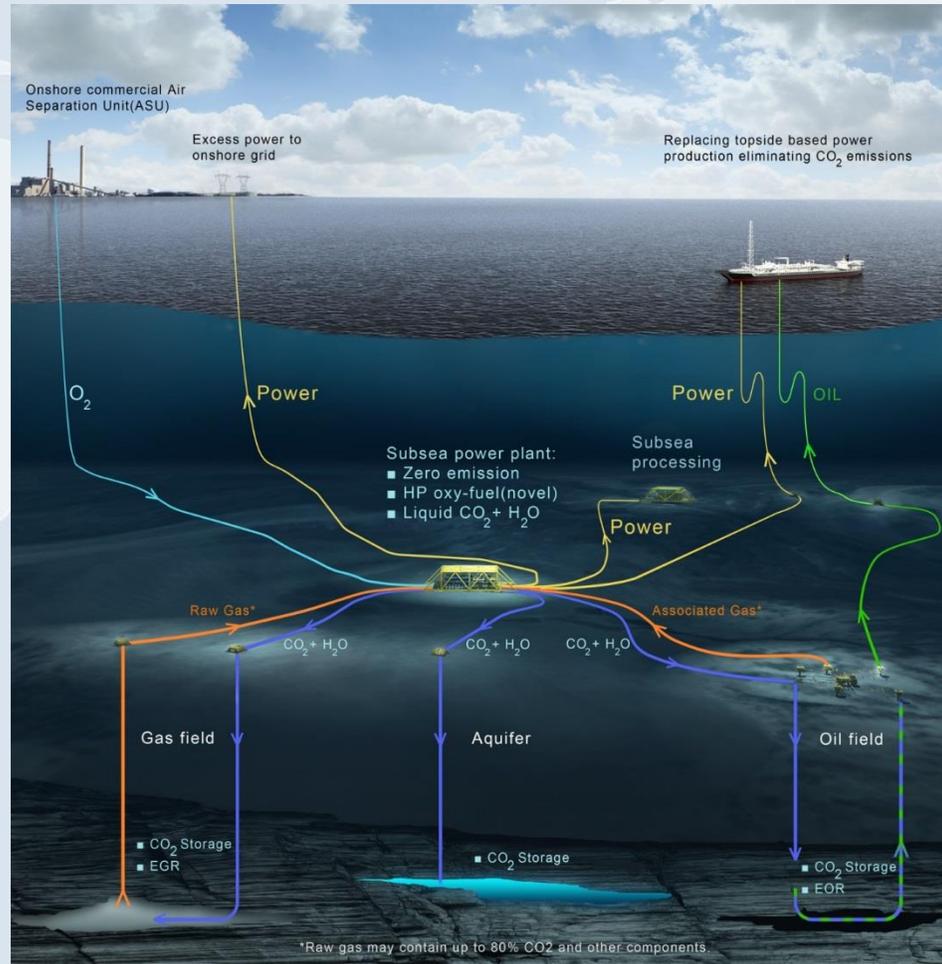
## Approaches for enabling offshore CO<sub>2</sub>-EOR

- Using late-life oilfield infrastructure
- Using oilfield satellite projects
- Focusing CO-EOR on the residual oil zone (ROZ)
- Reservoir modelling: Issues particular to CO<sub>2</sub>-EOR
  - Phase behaviour
  - Reactions with rocks
  - Multiphase flow in porous media
  - Oil instability





## Illustration of subsea zero emission offshore power generation and CO<sub>2</sub> separation concept

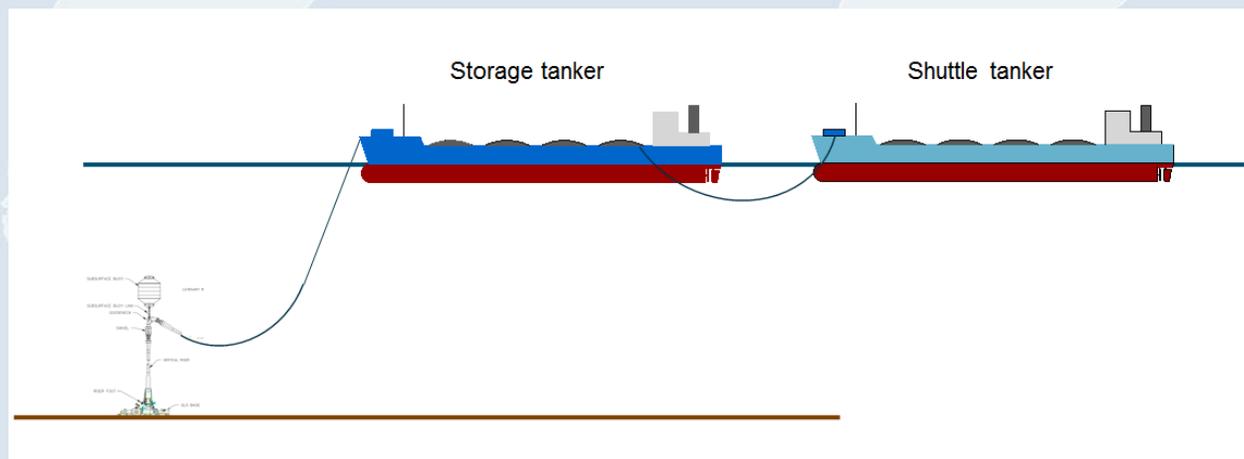


(Courtesy Aker Solutions)

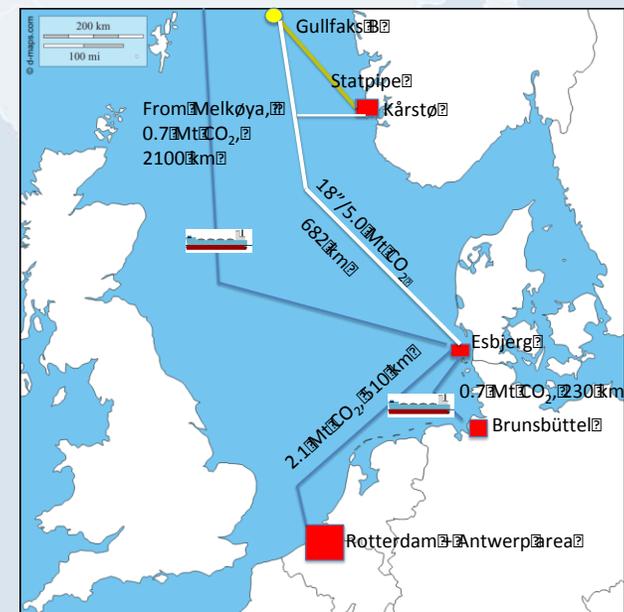


## CO<sub>2</sub> supply chain issues

- No technical barriers to CO<sub>2</sub> 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 CO<sub>2</sub>/year. Based on Agustsson and Grinestad (2005), Berger et al. (2004) and Elsam et al., 2003

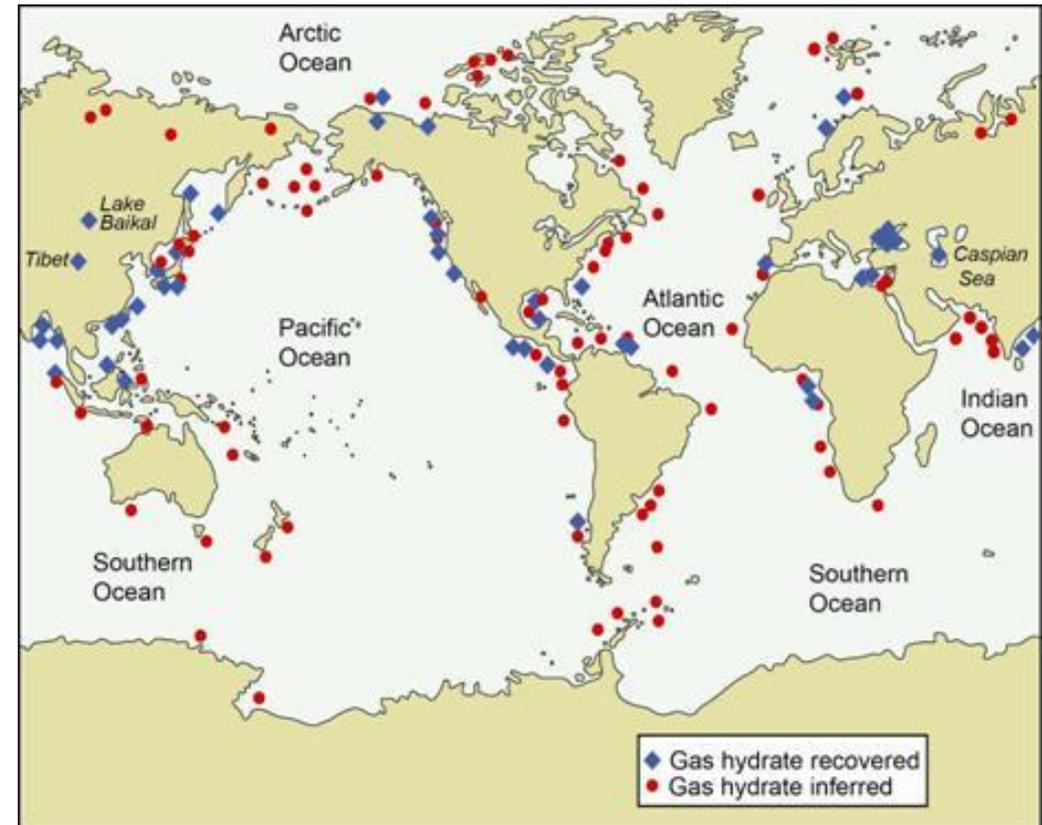
# Global Business Opportunities



**CH<sub>4</sub> 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

GUIDING  
GOOD IDEAS

— Visit us at  
[bergento.no](http://bergento.no)



# 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 CO<sub>2</sub> availability

- Numerous Asian oil fields are currently producing as much as 70% CO<sub>2</sub>
- Large production of CO<sub>2</sub> in industrial clusters

Integrated  
CO<sub>2</sub>-EOR

CO<sub>2</sub>-CH<sub>4</sub>  
Exchange

Applying CO<sub>2</sub> as a commodity in CO<sub>2</sub> injection, either for:

- CO<sub>2</sub> foam EOR
- Methane production from hydrates

**Will significantly contribute to the supply of energy in Southeast Asia and enable CO<sub>2</sub> sequestration**

# Easy Accessible CO<sub>2</sub> Sources in Asia



## Non-exhaustive list of reservoirs and industrial clusters with high CO<sub>2</sub> concentration

### Malaysia

- K5 Gas Field (70% CO<sub>2</sub>)
- Tangga Barat Gas Field (48% CO<sub>2</sub>)
- Muda Gas Field (47% CO<sub>2</sub>)
- Cakerawala Gas Field (37% CO<sub>2</sub>)

### Thailand

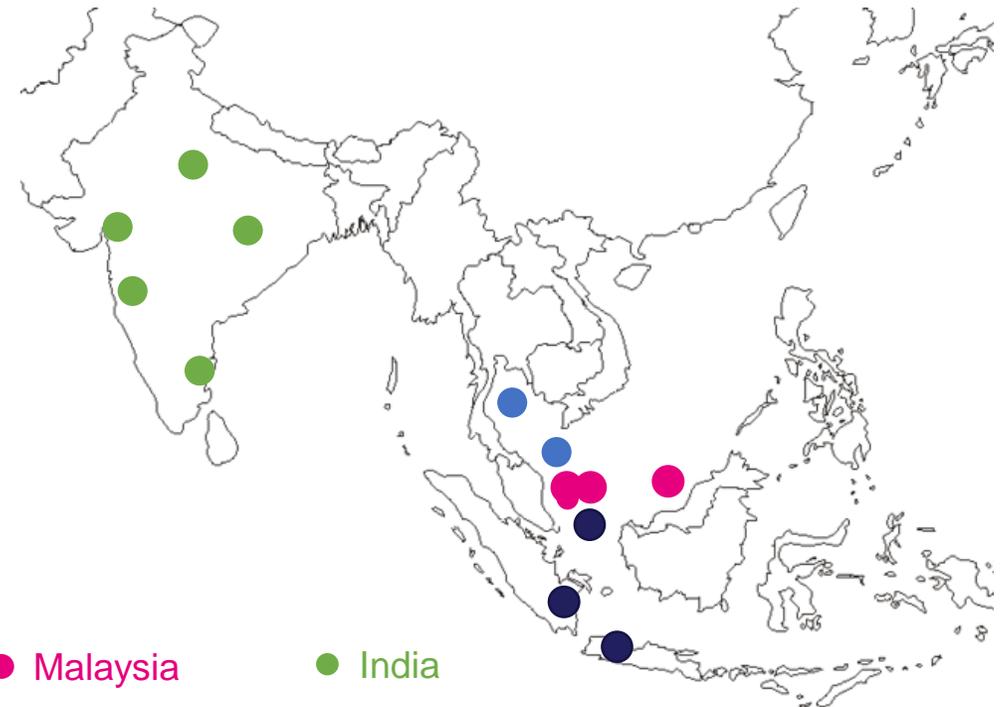
- Malay Basin, Group I (shared with Malaysia)
- Jasmine Field

### Indonesia

- Natuna Gas Field (up to 75% CO<sub>2</sub>)
- West Java Field (up to 75% CO<sub>2</sub>)
- South Sumatra Basin

### India

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



- Malaysia
- Thailand
- India
- Indonesia

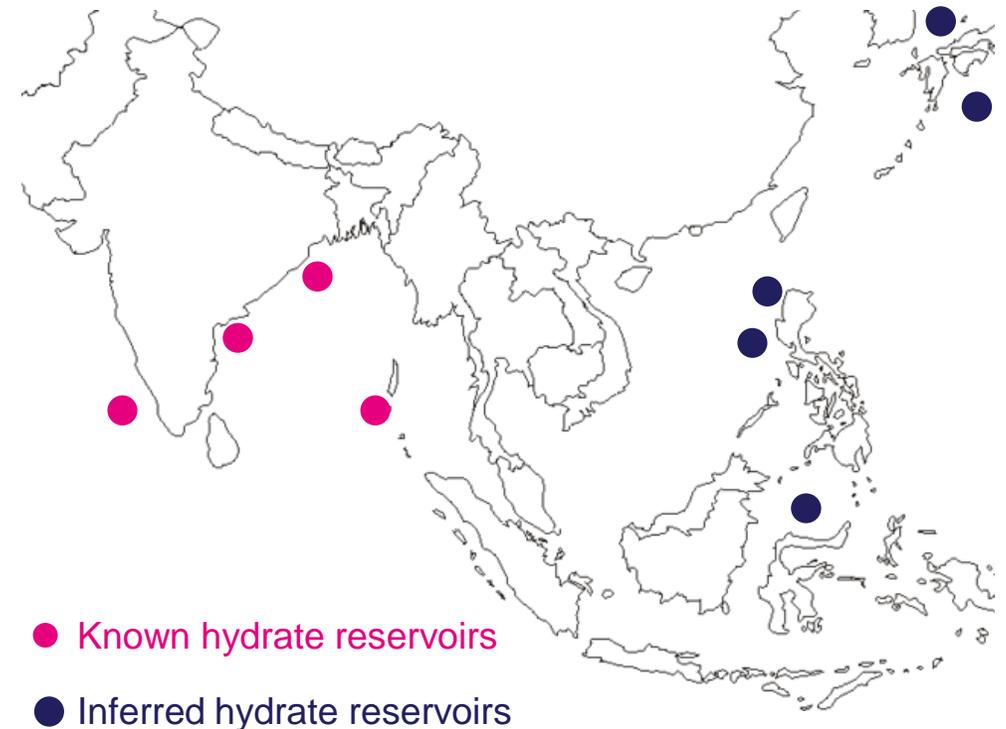
Map show non-exhaustive list of reservoirs and industrial clusters with high CO<sub>2</sub> concentration

# 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 CO<sub>2</sub> as a commodity:

### *Business Case for CO<sub>2</sub> Storage:*

- CO<sub>2</sub> 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% CO<sub>2</sub>EOR, EOR target 137Bbbl)
- Offshore Opportunities: NCS, Middle East, Asia, Africa and Brazil
- International Whole Value Chain CCUS Collaboration Offshore