ENERGY for the FUTURE

Opportunities for Offshore International Whole Value Chain CCUS

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Norway's Sovereign Wealth Fund Hits $1 Trillion

Largest sovereign wealth funds by assets under management in 2017*

<table>
<thead>
<tr>
<th>Fund</th>
<th>Country</th>
<th>Origin</th>
<th>Assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government Pension Fund - Global</td>
<td>Norway</td>
<td>Oil</td>
<td>$1t</td>
</tr>
<tr>
<td>Abu Dhabi Investment Authority</td>
<td>UAE</td>
<td>Oil</td>
<td>$828b</td>
</tr>
<tr>
<td>China Investment Corporation</td>
<td>China</td>
<td>Non-Commodity</td>
<td>$814b</td>
</tr>
<tr>
<td>Kuwait Investment Authority</td>
<td>Kuwait</td>
<td>Oil</td>
<td>$524b</td>
</tr>
<tr>
<td>SAMA Foreign Holdings</td>
<td>Saudi Arabia</td>
<td>Oil</td>
<td>$514b</td>
</tr>
<tr>
<td>Hong Kong Monetary Authority Investment Portfolio</td>
<td>Hong Kong</td>
<td>Non-Commodity</td>
<td>$457b</td>
</tr>
<tr>
<td>SAFE Investment Company</td>
<td>China</td>
<td>Non-Commodity</td>
<td>$441b</td>
</tr>
<tr>
<td>Government of Singapore Investment Corporation</td>
<td>Singapore</td>
<td>Non-Commodity</td>
<td>$359b</td>
</tr>
<tr>
<td>Qatar Investment Authority</td>
<td>Qatar</td>
<td>Oil &amp; Gas</td>
<td>$320b</td>
</tr>
<tr>
<td>National Social Security Fund</td>
<td>China</td>
<td>Non-Commodity</td>
<td>$295b</td>
</tr>
</tbody>
</table>

* As of September 19, 2017

Source: The Sovereign Wealth Fund Institute

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

RCN CLIMT 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
Nanoparticles to Stabilize CO$_2$-foam for Efficient CCUS in Challenging Reservoirs

Primary objective
Utilize nanotechnology to stabilize foam for successful implementation of CO$_2$-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$_2$-foam
3. Foam Stability in Challenging and Harsh Environment

1 Post doc in the project
Subsurface Carbonate CO$_2$ Storage and Security

Primary objective

Utilize nanotechnology to stabilize foam for successful implementation of CO$_2$-foam in challenging reservoirs that lead to environmentally sustainable energy production by CCUS.

Work Packages

1. Microvisualization of new dissolution mechanisms during geological CO$_2$ 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$_2$ injection and immiscible and miscible CO$_2$-foam
Oil-Wet Carbonate Core Plugs: IEOR (WF+CO₂-foam)

EDW 15
- $I_{A\text{-H}} = -0.06$
- $S_w = 0.11$
- $\phi = 26.3\%$
- Matrix perm = 45.4 mD
- Fracture perm = 401 mD
- Injection Rate = 16 ml/hr

![Graph showing waterflood and CO₂-foam with pressure gradient over time.](chart.png)
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
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**: Equal amounts of C-atoms stored as produced.
- **Carbon NEGATIVE EOR**: More C-atoms stored underground than produced.

Iġnik Sikumi test site, Alaska
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 Analogue
  - 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$_2$: $\approx$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 CO\textsubscript{2}-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 CO$_2$ 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
Global Business Opportunities

CH$_4$ 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
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 \( \text{CO}_2 \)-EOR \( \text{CO}_2 \)-\( \text{CH}_4 \) 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

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% CO₂ EOR, EOR target 137Bbbl)
- Offshore Opportunities: NCS, Middle East, Asia, Africa and Brazil
- International Whole Value Chain CCUS Collaboration Offshore