US Norway Joint projects

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Espen Steinseth Hamborg
Hilsen til Norge!

Vær hilset du vitt fødeland, deroppe hølt i Nord!
Jeg længes mod din kjendte strand,
den kjæreste paa jord.

Har tak for alt, som du mig gav,
som du gav fri til him og lav,
som jeg tog med om bord.
US - NORWAY COLLABORATION ON CCUS

MoU\textsubscript{2004}

- Bilateral meetings
- Internships
- NETL supported test campaigns
  - RTI: Norcem Cement plant and Sintef Research
  - 2 of 6 awardees for Phase 1 of Large Pilots aimed at TCM

- CSLF: US and Norway endorse International Test Center Network

- catching our future
«Walk the talk !»
major CCS in Norway for 20 yrs

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
<th>Operator</th>
<th>CO$_2$:</th>
<th>Operational:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleipner</td>
<td>Gas sweetening, saline aquifer</td>
<td>Statoil</td>
<td>1 MT/year</td>
<td>1996</td>
</tr>
<tr>
<td>Snøhvit</td>
<td>LNG: onshore to offshore storage</td>
<td>Statoil</td>
<td>700 kT/year</td>
<td>2008</td>
</tr>
<tr>
<td>TCM</td>
<td>Worlds largest CO$_2$ Test Center</td>
<td>TCM DA</td>
<td>100 kT/yr</td>
<td>2012</td>
</tr>
</tbody>
</table>
Catching our future

Norwegian Govt. subsidiary

CLIMIT
RD&D funding

FULL SCALE CCS

GASSNOVA
Norwegian Govt. subsidiary

TCM
Testing, verification, and improving CO₂ capture
19 YEARS TECHNOLOGY DEVELOPMENT

Klimatek 1997 --

CO₂ tax 1991

R&D (CLIMIT) 2005--

Piloting (CLIMIT, TCM)

Demonstration (TCM)

Full-scale 2017-2021

- catching our future
CLIMIT: RD&D funding

- Annual budget 230 MNOK / 27 MUSD p.y.
- Approx. NOK 1.7 bn / 200 MUSD since 2005
- More than 300 projects
Govt. ambition: One full scale CCS chain by 2020

- Diversity: 3 different industrial CO₂ sources, <500kt/yr
- Intermediate storage/transportation
- Industrial incentives, Business model and funding

Cement industry: Norcem
Fertilizer industry: Yara
Waste to Energy: Oslo
Two feed streams
- NGCC flue gas (3.5% CO$_2$)
- Refinery cracker gas (13% CO$_2$)
Key features

- Two (13MW) post combustion capture test plants
- Two live flue gas streams: NGCC (3.5% CO2), and RFCC (13% CO2)
- 24/7 operations, industrial ops mode.
- R&D staff
- Laboratories
- 4000 live sensors
- Infrastructure and utilities for further capture technologies
- Dedicated control rooms
International customer base

- Aker Solutions, Norway
- Alstom, France (now GE)
- Cansolv Technologies, Canada
- CCSL, UK/India
- IoN Engineering, USA
MEA baseline campaign at TCM DA

Dr. Espen Steinseth Hamborg
Technology Manager
TCM DA
Baseline results are of utmost importance!

- Open dissemination of results
- 3rd party baseline verification
- Fair comparison to proprietary technologies
- Monoethanolamine (MEA, 30 wt%) is a conventional amine suited for baseline purposes
- Conducted with U.S. based EPRI
2015 MEA CAMPAIGN

Baseline

- Application of Independent verification protocol developed by EPRI
  Equipment and instrument accuracies and verifications
- Test execution
- Independent data treatment and reporting

Additional activities

- Plant capacities
- Testing for modern gas turbine characteristics
- Aerosol and mist born emission testing
- Etc.
### Performance

- Establishing baseline results
- CO₂ capture rates, energy duties, mass balances, etc.
- Emission products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine flue gas</td>
<td>60,000 Sm³/hr</td>
</tr>
<tr>
<td>CO₂ capture rate</td>
<td>~85%</td>
</tr>
<tr>
<td>CO₂ content in/out (dry)</td>
<td>~3.8 / ~0.5%</td>
</tr>
<tr>
<td>Energy penalty</td>
<td>3.5 GJ/t CO₂</td>
</tr>
<tr>
<td>CO₂ produced</td>
<td>3350 kg/hr</td>
</tr>
<tr>
<td>MEA degradation rate</td>
<td>~1.4 kg MEA / t CO₂</td>
</tr>
<tr>
<td>CO₂ mass balance</td>
<td>100 ± 0.5 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA</td>
<td>0.02 ppmv</td>
</tr>
<tr>
<td>Ammonia</td>
<td>15 ppmv</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.2 ppmv</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.5 ppmv</td>
</tr>
<tr>
<td>Total nitrosamines</td>
<td>&lt; 0.00008 mg/m³</td>
</tr>
<tr>
<td>Total nitramines</td>
<td>&lt; 0.0002 mg/m³</td>
</tr>
</tbody>
</table>
Degradation

- Degradation and reclaiming
- Removal of degradation products
- Long-term operations
Baseline results are of utmost importance!

- Accurate and well established baselines are essential
- Fair comparison to proprietary technologies
- TCM provides baselines, developed with U.S. based EPRI
Thank you!