Carbon Capture from industrial flue gases

O. Graff, Head of CCUS

Liquid Wind Workshop
Göteborg, 23rd of February 2017
Aker Solutions creates solutions to unlock energy safely and sustainably for future generations

13,000
EMPLOYEES

20
COUNTRIES

50
LOCATIONS

175
YEARS OF EXPERIENCE
Expertise

From subsea to surface and concept to decommissioning, our technical expertise and strong partnerships provide energy companies what they need to succeed.
Why is Carbon Capture, Utilization & Storage (CCUS) important?

- COP 21 Paris; 196 nations:
  - CCS is required to meet global warming target (+ 2 deg.C)
- CCS must be applied on CO\(_2\) emitters:
  - Fossil fuel power plants
  - Cement, steel, aluminum, W-t-E, etc.
- CCS will secure the future market for fossil fuels
- CCS will make CO\(_2\) available for EOR and as feed stock for production of other products such as methanol and fish feed (fuels, plastics, chemicals, urea, etc.)
CO₂ roadmap for Norwegian process industry ~ 60% CCS
The positive effect of CO₂ in an oil reservoir is well known

- CO₂ injection may increase the recovery in an oil reservoir by 5 - 12 % points (OD report 2005)
- CO₂ has a value for the oil companies
- Part of the CO₂ remains in the reservoir (less CO₂ footprint of oil)
- Increased oil production on NCS:
  - ~370 M Sm³ from 19 fields (BIGCO2) (potential based on CO₂ for EOR)
  - or
  - ~10% of total acc. oil produced in Norway
Aker Solutions offers technology and solutions for the entire carbon capture, utilization and storage value chain:

- Carbon capture technology
- CO₂ transport solutions
- CO₂ injection templates (subsea)
- CO₂ storage evaluations
- CO₂ EOR evaluations
- CO₂ separation from natural gas
- Closed flare systems
- Equipment and plant delivery
- CO₂ as feed stock for products

Engaged in CCS projects since 1996
Sleipner CO₂ Platform - in operation since 1996

- First offshore CO₂ injection and storage project
- Design & delivered by Aker Solutions
- ~1 million tons of CO₂ injection per year into aquifer
CCUS in Aker Solutions

- A focused technology company within carbon capture
  - 20 years of CCUS know-how and experience
  - Design & delivery of the Sleipner CO₂ platform
  - Core competence within CCUS value chain
  - Invested ~400 MNOK (~$52M) in capture technology
  - Completed one of the largest CC R&D programs in Europe (SOLVit)
  - Operating a unique, advanced mobile test unit (MTU), engaged in several CCUS projects.
  - Design, construction, start-up and operation of amine plant at Technology Centre Mongstad (TCM)
  - A leading technology provider within CCUS world-wide

<table>
<thead>
<tr>
<th>Develop</th>
<th>Test</th>
<th>Improve</th>
<th>Deploy</th>
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<tbody>
<tr>
<td>1996</td>
<td>NTNU/SINTEF Lab Rig</td>
<td>1996</td>
<td>Mobile Test Unit (MTU)</td>
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<td>1996</td>
<td>The Sleipner field in the North Sea CO₂ storage 1000m below</td>
<td>1998</td>
<td>Kårstø CO₂ Pilot</td>
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<td>1998</td>
<td>Sleipner Field</td>
<td>2007</td>
<td>Kårstø Demo Study</td>
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<td>2007</td>
<td>Kårstø CO₂ Pilot</td>
<td>2008</td>
<td>Aker Clean Carbon</td>
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<tr>
<td>2008</td>
<td>NTNU/SINTEF Lab Rig</td>
<td>2012</td>
<td>Large Scale Pilot TCM</td>
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Technology, Process Design and Equipment

**ACC™ = Advanced Carbon Capture™ Process**

Full scale plant and process design, specification and delivery of proprietary equipment packages, solvent formulation, performance guarantees and licencing of technology.

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**Technology Characteristics**

- Excellent performance data from coal, gas, cement and waste-to-energy plants
- Ongoing long term testing of flue gas from waste-to-energy
- Cost, energy and environmental focus
- Modularization

**Technology advantages**

1. Most mature
2. Flexibility
3. For retrofit and new built
4. For various flue gases
5. Life Cycle Cost
6. Verified improvements
7. Excellent “green” solvent performance

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**Key Equipment**

- Absorber Tower
- Desorber incl. Reboiler
- Direct Contact Cooler
- Reclaimer
- Energy Saver

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**Generic Flow Diagram**

- **CO₂ to transport**
- **CO₂ Compressor**
- **ACC Direct Contact Cooler**
- **Flue Gas Fan**
- **ACC Absorber Tower**
- **ACC Emission Control & Anti-Mist Water Wash & Water Balance**
- **Absorption Section Rich/Lean Hx**
- **Filter package**
- **ACC Reclaimer**
- **ACC Energy Saver**
- **ACC Reboiler**
Unique carbon capture R&D program in Europe
SOLVit – main objectives

Develop and demonstrate solvents with minimum energy consumption and lowest possible environmental impact. This is done step-wise and systematic:

- Lab-bench scale
- Lab-pilot scale
- Full-height pilot, Tiller
- Real exhaust - MTU - Heilbronn

- Theoretical evaluations
- Solvent developments & testing
- Emission monitoring
- Material testing (steel & PP)
- Reclaiming testing (IFE)

Develop demonstration program to transfer experimental data to cost effective process and plant design

Slide 12
### SOLVit R&D Programme

88 months & 332 MNOK (~35 M€)

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<tr>
<th>Research partners</th>
<th>SINTEF, NTNU, IFE, Norner</th>
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<tr>
<td>Sponsors</td>
<td>CLIMIT/Gassnova, SINTEF, Aker Solutions &amp; industry partners</td>
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<tr>
<td>Industry Partners</td>
<td>Statkraft, ScottishPower, E.ON &amp; EnBW</td>
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<tr>
<td>Involvement</td>
<td>50 researchers, 5 PhD's &amp; 4 Post doc's</td>
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<tr>
<td>Operated six test pilots</td>
<td>SDR, Gløshaugen, Tiller, MTU, Heilbronn, TCM</td>
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<tr>
<td>Extensive test data from</td>
<td>Gas and coal power plants, oil refinery and cement factory</td>
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<tr>
<th>Number of solvents tested</th>
<th>~90</th>
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<tr>
<td>Accumulated pilot operating hours</td>
<td>~45 000</td>
</tr>
<tr>
<td>Number of advanced sample analysis</td>
<td>~10 000</td>
</tr>
<tr>
<td>Number of characterised degradation products</td>
<td>73</td>
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Achievements – Improved Energy Efficiency

- Compared to project references “Bellingham plant“ (NG) and Esbjerg pilot plant (Coal) a reduction of the energy consumption with 10-25% has been demonstrated in pilot plants with 1st generation solvents.

- Applying an advanced process flow sheet increases energy saving of 1st gen. solvents with up to 35% compared to reference
Achievements – reduced degradation

- Discoloration of solvents (indicator of solvent instability) during operation on coal flue gas at EnBW’s Heilbronn pilot plant

  MEA Reference Campaign, 920 h

  SOLVit CC2 Campaign, 1 210 h

  SOLVit CCx2 Campaign, 2 090 h

  No further discoloration until end of campaign (2090 h)
Amine Mist Emission

- Mist is aerosols (small droplets) and formed in some amine plants
- Evidence for amine mist is white plume and high amine emission, low capture rate in water wash & acid wash sections
- Can be avoided by gas cleanup upstream of absorber, but this is very expensive
- If formed, amine mist is difficult to capture

Aker Solutions has developed a novel Anti-Mist System (patented)

Our anti-mist design has several advantages vs. alternative mist abatement technologies:

- No additional pressure drop over capture plant
- No additional power consumption
- No increased maintenance cost, i.e. filter replacement, cleaning, etc.
- No increase in capital cost in contrast to alternatives like BD filter or wet ESP
Early test of Anti-mist Design  (NCCC, Alabama, 2011)

- MTU operation alternating between conventional and anti-mist operation (during daytime)
- Absorber amine emissions monitored by online FTIR system
- Anti-mist performance was nicely demonstrated:

MTU at NCCC, Alabama, USA
MTU – our key to validate new type of flue gases

“Long term, realistic testing in an industrial environment”
MTU (Mobile Test Unit) – operating a complete capture plant from 2008
Long term testing with clients actual flue gas at their site

MTU test purpose:
- Different, actual flue gases
- Process performance
- Dynamic response
- Process improvements
- New robust solvents
- Reclaiming
- Degradation
- Corrosion, materials
- Emissions, waste
- Equipment & packing mat.
- LCC evaluations
- Max. capacity: ~2000 TPA CO$_2$
MTU, Mobile Test Unit - Advanced CO₂ capture pilot
Owned & Operated by Aker Solutions
Test campaigns in industrial environment since 2008:
coal & gas power, refinery, cement industry & W-t-E

Risavika & TCM
Norway
2008
2012
ACC™ 1st at TCM

National CCC
Alabama, US
2011
ACC™ 1st at NCCC

Longannet Power Plant
Scotland
2009

Over 20,000 operating hours
Technology Centre Mongstad (TCM)

- World’s most advanced amine plant (CC from CHP & cracker)
- Designed and delivered by Aker Solutions/Kvaerner
- Excellent industrial scale test results from 2 years operations
- Demonstrated scale up from MTU with SOLVit solvents
- Our Advanced Carbon Capture Technology is ready for the market
Cooperation with Norcem in Brevik, Norway

- 1st large scale testing globally on a cement factory – pioneer work!
- Excellent MTU test results from May 2014 till October 2015
- Ongoing study (capture, integration, intermittent storage & ship loading)
- Cement industry is a good candidate for carbon capture:
  - High CO₂ content (18-22 volume-%), (Gas power= 3.5%, coal= 13%)
  - Available waste heat for the amine plant (almost for free)
  - Gives more compact and competitive capture plants
- Capture plant 400 000 tons CO₂/year
  - equivalent to 205 000 fossil fuelled cars

Norcem:
- part of the Heidelberg Group and cooperates with ECRA
- one of three candidates for national CCS demo project in Norway
- has selected our ACC™ technology for further developments

6% of global emissions
0 GJ/ton CO₂
5 months MTU test and study at Klemetsrud WtE  
+ 5 months extended test (new feature, long term)

Pioneering test executed in Oslo – Excellent test results  
Carbon Capture from WtE - First of this kind globally

- Klemetsrud is one of three candidates for national CCS demo project in Norway

Klemetsrudanlegget AS         Norway’s largest W-t-E Plant
Capacity                   burning 310 000 tonnes waste per year
Owned by                   Oslo municipality
Operating since            1985
Power production           175 GWh
District heating            750 GWh
Feed stock                  50-60% biomass (capture=carbon negative solution)

300 000 TPA, 10-12 vol% CO₂

About 450 W-t-E plants in Europe  
~80 MTPA of CO₂ emissions
CCS Demo Project Norway

National CCS demo project within 2022

- Coordinated by Gassnova
- 3 alternative capture plants have been qualified:
  - Klemetsrud (W-t-E)
  - Norcem (cement)
  - Yara (fertilizer)
- Ship transport of CO₂ to storage site at Kollsnes
- 3 alternative offshore storage reservoir have been evaluated by Statoil. Smeaheia is recommended

Present schedule:

- Feasibility studies completed in May
- Concept/FEED period 2017-2018
- Project sanction in 2019
- Project completion 2022

Possible offshore EOR pilot as add-on

8000 tons CO₂ (-25°C & 16 bara)

*3500 tons CO₂
Cooperation with BSE & Partners for E-methanol Plants

CO$_2$-Recycling and GHG-Reduction Quota for Advanced Fuels

Small-Scale Methanol Plants
E/Bio-methanol from flue gas & electrolysis

Existing units:
- CO$_2$-source flue gas
- Power generator
- Thermal driven process
- Grid connection

Expansion units:
- CO$_2$-separation / amine gas treatment
- Alkaline electrolysis
- Methanol synthesis
- Methanol distillation

*Aker Solutions has signed an agreement with bse Engineering (Germany) for delivery of carbon capture plants for E-methanol production*
Carbon Capture Plant:
- Flue gas: ~10% CO₂ (WtE)
- Capture rate: ~90% CO₂
- Capacity: 5000 Kg/h
- Operating hours: 4000 per year
- Yearly CO₂: 20 000 TPA (>99,9% purity)
- Heat required: 4,2 MW
- Amine consumption: 3 TPA
- Area requirement: 7,5 x 24 m

Electrolysis: 20 MW
Methanol production: ~15 000 TPA
ACC™ Amine Process comparative advantages

- Well known industrial gas sweetening process (ref. Sleipner & Snøhvit)
  - Modified and optimised for flue gas applications
- Can be used on several different industrial flue gas sources
- Can be used for retrofit (add-on) and new built (integrated)
- Robust, flexible and high capture rate
- Excellent performance data from industrial scale plants
ACC™ Technology status

Based on SOLVit and other spin-off activities Aker Solutions can offer:

- Green solvent (green as an amine solvent can be) with:
  - Improved HSE characteristics (non-toxic, nonhazardous for aquatic organisms, ready biodegradable, etc.)
  - Improved energy consumption
  - Low degradation and waste (robust)
  - Minimum corrosion
  - Efficient reclamation (HSS removal ~90%)

- Improved carbon capture plants with:
  - Minimum emission (best in class)
  - Minimum liquid waste (robust solvent and efficient reclamation)
  - Less energy requirement (-35%)
  - Cheaper materials, lifetime >25 years
  - High availability (93% at TCM campaign)
  - Technology and process validated through long term operation in industrial scale
AKER SOLUTIONS position within CCUS

- Technology, competence & experience within the entire CO₂ chain

- Carbon Capture (ACC™)
- CO₂ storage & transport & EOR
- Aquifer & oil reservoir modelling
- Engineering solutions
- Operations, Maintenance & Modifications
- Oil/water/gas separation technologies
- Subsea injection, compression & separation
Why is CCUS Technologies so important?

- CCS is necessary for the continued use of fossil fuels, cement, etc. if we’re to meet global warming targets
- Captured CO$_2$ can be used to increase oil production from existing fields
- CO$_2$ can be used as feed stock for production of other commercial products
Test Center Mongstad (TCM)

- Video at youtube:

https://www.youtube.com/watch?v=adu4-ahLE_0&feature=youtu.be
Klemetsrud WtE – MTU test video


Thank you!
Contact details

Oscar Fr. Graff
Head of CCUS

Carbon Capture, Utilization & Storage (CCUS)
Snarøyveien 20
NO-1360 Fornebu
NORWAY

Mailing address: PO Box 222, NO-1326 Lysaker, Norway
Phone:  +47 67 59 50 00
Fax:    +47 67 51 35 90
E-mail: oscar.graff@akersolutions.com

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