Aker Solutions offers technology and solutions for the entire carbon capture, utilization and storage value chain.
Carbon Capture Technology, Process Design and Equipment

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. EPC partnering.

Technology Characteristics
- Excellent performance data from coal, gas, cement and waste-to-energy plants
- 50,000 operating hours in six pilot plants globally
- Cost, energy and environmental focus
- Modularization

Key Equipment
- Absorber Tower
- Desorber incl. reboiler
- Direct contact cooler
- Reclaimer
- Energy Saver

Technology advantages
- Most mature
- Flexibility
- For retrofit and new built
- For various flue gases
- Lifecycle cost
- Verified improvements
- Excellent solvent performance
Development and Qualification of ACC™ Technology

- Participation in many Norwegian and international research projects
- Large 8-year R&D program SOLVit to improve solvents and process technology
- Operation of Aker Solutions’ Mobile Test Unit (MTU) since 2008 at various industrial emission sources
- Test & demonstration for 2 years at Technology Centre Mongstad (TCM)
- Comprehensive technology qualification programme executed
- Design matured through numerous engineering studies (CCM, Norcem CCS, Longgannet, Kårstø Demo, Port Tolle, etc.)

<table>
<thead>
<tr>
<th>Develop</th>
<th>Test</th>
<th>Improve</th>
<th>Deploy</th>
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<tbody>
<tr>
<td>1996 NTNU/SINTEF Lab Rig</td>
<td>1996 Sleipner Field</td>
<td>1998 Kårstø CO₂ Pilot</td>
<td>2007 Kårstø Demo Study</td>
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<tr>
<td>2008 Mobile Test Unit (MTU)</td>
<td>2012 Large Scale Pilot TCM</td>
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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 and W-t-E
  - Over 20,000 operation hours

2008 and 2012

2009

2011

Risavika & TCM Norway

National CCC
Alabama, US

ACCTM 1st at TCM

ACCTM 1st at NCCC

ACCTM 1st in UK

Longannet Power Plant
Scotland
Improved Energy Efficiency (SOLVit)

- A reduction of the energy consumption with **10-25%** has been demonstrated in pilot plants with SOLVit solvents, compared to project references “Bellingham plant” (NG) and Esbjerg pilot plant (Coal) using MEA.

- Applying an advanced process flow sheet increases energy saving of SOLVit solvents with up to **35%** compared to reference.
Improved Solvent HSE and Degradation Performance

- Green solvents with improved HSE characteristics (non-toxic, nonhazardous for aquatic organisms, ready biodegradable, etc.) developed in SOLVit
- Consumption of MEA is almost 5 and 10 times higher than that of CC2 and CCx2, respectively, demonstrating the superior degradation resistance of the solvents developed in SOLVit
- Degradation rate (heat stable salts) in SOLVit solvents (especially for CCx2) remain very low after 3,300 operation hours

<table>
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<tr>
<th>Solvent</th>
<th>Total solvent loss (kg amine/ton CO₂)</th>
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<tbody>
<tr>
<td>MEA</td>
<td>2.6</td>
</tr>
<tr>
<td>CC2</td>
<td>0.6</td>
</tr>
<tr>
<td>CCx2</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Reduced Formation of Harmful Degradation Products

- CC2 and CCx2 are developed to be green solvents that is solvents with similar or better HSE performance than MEA
- Miniscule formation of harmful degradation products such as nitrosamines and nitramines

![Nitrosamine formation in solvent during long-term test campaigns at TCM](image)
Improved Emission Control

- Very low emission of solvent amines (<1 mg/Nm³) with optimized water wash sections
- Low emission of ammonia and other volatile degradation products (e.g. alkyl amines) from selection of amines with low oxidative degradation rate
- Emissions of amine mist can be virtually eliminated with the ACC™ anti-mist design
- Control of nitrosamine emission through selection of amines that does not readily form nitrosamines
- If desirable, emissions of alkaline components can be almost completely eliminated (<0.01 mg/Nm³) with acid wash

MTU test of anti-mist design at NCCC, Alabama

MTU emission sampling at Norcem, Brevik
Investigation of New Concepts for Further Improvement of Absorption Technology
Heat integration between CO₂ desorber and CO₂ compression plant may significantly reduce regeneration steam and cooling demands.

This solution is particularly relevant for industrial plants without or with limited steam supply system (e.g. cement).

Aker Solutions have developed a heat integrated compression concept for the Norcem CCS demonstration project which reduces reboiler steam demand to ∼2.0 MJ/kg CO₂.
Advanced heat integrated desorber developed and implemented in MTU (CLIMIT project “New desorber design”).

Main test findings:

- Able to reduce SRD by 10% at typical desorber pressure, and up to 14% reduction in SRD at slightly increased pressure (2-3 bara)
- Learned that there is a limited room for low grade heat recovery, the desorption process can not utilise all low grade heat available
- Other desorber configurations will not perform better, the limitations in low grade heat recovery are fundamental
- However other solvents and higher desorber pressure may increase the potential for utilisation of low grade heat
Many promising biphasic solvent systems identified based on CO$_2$ absorption/desorption screening tests and equilibrium data,

However many solvent systems were not feasible in practice

Liquid two-phase systems (e.g. DEEA + MAPA) tested at realistic conditions in the Tiller pilot plant at SINTEF

Best energy numbers were obtained in test runs without circulation of “light phase”

Best energy number 2.7-3.0 GJ/ton, which is not significantly better than with the best single phase solvents
Case Study:
Using Absorption Technology for CO$_2$ capture in the Cement Industry
Cement industry – A good candidate for CCS

- Cement industry is responsible for approx. 5% of global anthropogenic CO₂ emissions
- CO₂ emission from cement production is inevitable – approx. 60% originate from calcination of limestone (i.e. stuck with CO₂ emissions)
- Plants are in continuous operation at high load factor
- Absorption processes are also attractive for the cement industry:
  - High CO₂ content gives more compact and competitive capture plants
  - Potential for waste heat recovery for solvent regeneration
  - Tail end process => does not interfere with the clinker burning process unlike oxy-fuel combustion, carbonate looping, etc.

Norcem’s cement plant in Brevik, Norway
Qualification of ACC™ Technology and Concept Development for a Cement Kiln
- Norwegian CCS Demonstration at Norcem, Brevik

- Performance of ACC™ capture technology has been verified during 18 months of pilot plant testing (MTU) at Norcem’s cement plant in Brevik:
  - Stable operation on flue gas from cement kiln demonstrated
  - Easy to obtain 90% CO₂ capture due to high CO₂ content in flue gas (17-20%)
  - No negative influence of capture plant performance observed due to presence of trace level pollutants from the cement kiln
  - Low solvent degradation and emissions

- Concept developed for a 400,000 tpa CO₂ capture plant from the Brevik plant (nearly 50% of annual emissions) incl. compression, liquefaction, integration, intermittent CO₂ storage and ship loading

- Capture plant driven solely by waste heat recovery from cement process and compression plant

Norcem:
- Part of HeidelbergCement Group
- One of three candidates for Norwegian CCS demo project
- Aker Solutions is selected by Norcem as provider of CO₂ capture technology for a 400,000 tpa demo plant
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