Baker Hughes
...towards net zero carbon emissions

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Strategic DTI – Carbon Capture & Energy Transition

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Introduction
Committed to net zero carbon emissions

Committed to net zero carbon emissions by 2050; achieved 34% reduction to date, with a goal of 50% by 2030

- Reduce Baker Hughes’ environmental footprint by minimizing carbon emissions and waste each year
- Partner with customers to help reduce their environmental footprint
- Invent new technologies and invest in a portfolio of low-carbon products and services
Our product companies

**Oilfield Services**
Lower cost per barrel over the life of field

**Digital Solutions**
Peace of mind for the world’s infrastructure

**Oilfield Equipment**
Ultra-reliable technologies for the harshest environments

**Turbomachinery & Process Solutions**
Industry-leading availability and reliability
A broad CCUS technology portfolio

- Feasibility & design
- Carbon capture
- Pipeline and transport
- Compression
- Well construction
- Closure and monitoring
- Enhanced oil recovery
- Project development
A paradigm shift in the energy transition

Increasing use of renewables
- Solar
- Wind
- Biomass
- Geothermal

Requires solutions to cope with intermittency and geographical availability, as well as a new approach for heat production

Removing CO₂ emissions
- Underground storage (CCS)
- Production enhancement (EOR)
- Recycling (Power to Fuel)
- Using CO₂ as feedstock (e.g., urea)

Requires additional energy for capture, transport and injection

Reducing CO₂ emissions
- Fuel switch (e.g., coal to natural gas and/or hydrogen)
- Waste heat recovery
- Process optimization
- New technologies

Does not completely eliminate CO₂ emissions from the industry
Where our Turbomachinery & Process Solutions portfolio is relevant

**Solutions to allow increased use of renewables**
- Mechanical storage solutions
  - LAES (liquified air)
  - CAES (compressed air)
- Chemical storage solutions (PtX)
  - CO₂ / H₂ / SNG compression
- Heat pumps for cooling & heating
- Organic rankine cycle
- Supercritical CO₂ cycle

**Solutions to remove CO₂ emissions**
- Post-combustion
- Flue gas compression
- CO₂ compression
- CO₂ pumping

**Solutions to reduce CO₂ emissions**
- Combustion solutions
  - More efficient gas turbines
  - Hydrogen-fueled turbines
  - Hybrid-fueled turbines
- Energy recovery solutions
  - Combined cycle
  - Combined heat & power
  - Organic rankine cycle
  - Waste heat recovery
  - Waste energy recovery
Gorgon CCS project

Three main refrigerant compression trains and six CO$_2$ compression trains required to drive Gorgon’s pioneering CO$_2$ sequestration project.
Baker Hughes gas turbine H₂ capabilities

- The NovaLT™ gas turbine product family (ranging from 5 MW to 20 MW) sets new standards in cost-effectiveness by providing higher efficiency and longer operational uptime.
- The NovaLT™ 16 can start and run on 100% H₂.
- The NovaLT™ 12 recently tested for Snam gas network with 10% H₂.
CO₂ capture using the Chilled Ammonia Process
Chilled Ammonia Process (CAP)

- Ammonium carbonate solution reacts with the CO₂ in the flue gas to form ammonium bicarbonate
- Raising the temperature reverses this reaction; CO₂ is released and the solution is recycled

ADVANTAGES

- High CO₂ purity and delivery pressure
- Tolerant to oxygen and flue gas impurities
- No degradation
- No emission of trace contaminants
- Efficient capture of CO₂ (90%)
- Low-cost, globally available reagent
CAP chemistry

\[ \text{CO}_2 (g) \leftrightarrow \text{CO}_2 (aq) \]
\[ \text{CO}_2 (aq) + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 (aq) \]
\[ \text{CO}_2 (g) + \text{H}_2\text{O} + \text{NH}_3 (aq) \leftrightarrow \text{NH}_4\text{HCO}_3 (aq) + \text{Heat (Ammonium bicarbonate)} \]
\[ \text{CO}_2 (g) + 2 \text{NH}_3 (aq) \leftrightarrow \text{NH}_4\text{NH}_2\text{CO}_2 (aq) + \text{Heat (Ammonium carbamate)} \]
\[ \text{CO}_2 (g) + \text{H}_2\text{O} + 2 \text{NH}_3 (aq) \leftrightarrow (\text{NH}_4)_2\text{CO}_3 (aq) + \text{Heat (Ammonium carbonate)} \]
\[ \text{CO}_2 (g) + \text{H}_2\text{O} + (\text{NH}_4)_2\text{CO}_3 (aq) \leftrightarrow 2 \text{NH}_4\text{HCO}_3 (aq) + \text{Heat (Ammonium bicarbonate)} \]
An additional pre-treatment step may be required to reduce NOx, SOx and other contaminants to acceptable levels, i.e., to prevent degradation and formation of heat stable salts.

This step is not usually required for CAP, as typical flue gas contaminants (from air quality control systems) are tolerated by the downstream process.
Absorption section

- Ammonia-based chiller system (REF) is employed to reduce ammonia volatility.
- Sulfuric acid is employed to reduce ammonia emissions into the atmosphere down to allowable levels.
- Only one aqueous by-product, ammonium sulfate, is discharged from DCC. It can be used as a fertilizer.
- Solvent regeneration at 20barg as the solvent can tolerate higher temperatures.
- Heat can be supplied by hot oil, direct-fired heater, steam, etc.
- Solvent make-up can be provided as anhydrous or hydrous ammonia.
Benefits

- **Simple and stable chemistry** that is not influenced by trace components (e.g., NOx, O₂) and degradation

- **Tolerant** to oxygen, high temperature and flue gas impurities – critical for gas turbine applications

- **Sustainable** as relying on a stable, low cost, and globally available reagent

- **No degradation** and controllable emission of contaminants to atm (ammonia)

- **Flexible** as it can cope with large fluctuations in flow and composition

- **Proven** as validated at TCM on various flows and compositions, including high oxygen content
Development roadmap

2006 – 2012

Test Rigs
SRI California, Bench scale
GE Växjö Sweden 0.25 MWth

2008 – 2010

Industrial Pilots
WE Energies Pleasant Prairie Wisconsin/USA – 5 MWth, Coal
E.ON Karlshamn Sweden – 5 MWth, Oil

2009 – 2011

Validation Pilots
AEP Mountaineer PVF West Virginia/USA – 58 MWth, Coal

2012 – 2014

Large-Scale Demonstration
TCM Mongstad Norway – 40 MWth, RFCC; CHP Gas

FEED 2013

CCM Mongstad Norway – 1 Mio t/y CO2, CHP Gas
Thermal energy demand for the regenerator and the stripper during operation determined at:
- for CHP, 3.0 GJ/t\textsubscript{CO2}
- for RFCC, 2.3-2.6 GJ/t\textsubscript{CO2}
Capture rate: up to 90%
Emissions: < 2ppmv of NH\textsubscript{3}

Two feed streams
- NGCC flue gas (3.6–4.0 % CO\textsubscript{2}), 4 months
- Refinery cracker gas (12.5–16.0% CO\textsubscript{2}), 8 months

Provided courtesy of Technology Centre Mongstad
Gas turbine applications: challenges

Typical coal-fired flue-gas vs. Typical gas-fired flue-gas

\[
\frac{O_2}{CO_2} = 0.23 \quad \times 15 \quad \frac{O_2}{CO_2} = 3.5
\]

- Oxygen (blue)
- Carbon dioxide (red)
Conclusions
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• We are working on achieving our net zero target while helping our customers reduce their carbon footprint
• Our product portfolio spans from highly efficient turbomachinery to sustainable carbon capture solutions
• CAP is a technology that has been developed to address CO₂ emissions, rather than being adapted to capture CO₂ from flue gases
• CAP employs a widely available commodity chemical (ammonia)
• CAP is not influenced by flue gas contaminants and does not generate additional emissions (no degradation)
• Applying carbon capture to gas-fired power plants requires a technology that can tolerate high oxygen levels and therefore an ad-hoc solution is required (CAP qualifies as one of the most suitable options)