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…towards net zero carbon emissions

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Strategic DTI – Carbon Capture & Energy Transition

August 19th, 2020

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Introduction

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Committed to net zero carbon emissions

CLIMATE LEADERSHIP AWARDS

First oil & gas winner in March 2020

CDP

Over 10 years of reporting to the Carbon Disclosure Project

BARRON'S

100 Most Sustainable Companies

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

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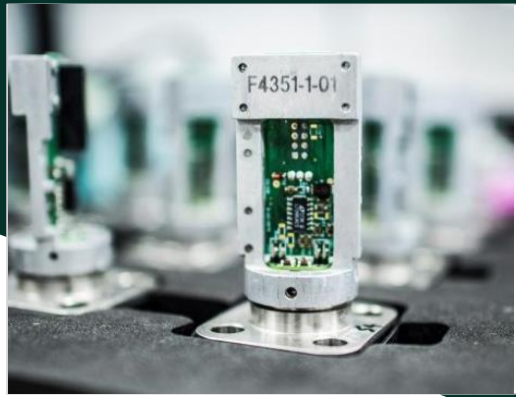
Our product companies

Oilfield Services

Lower cost per barrel over the life of field



Digital Solutions

Peace of mind for the world's infrastructure

Oilfield Equipment

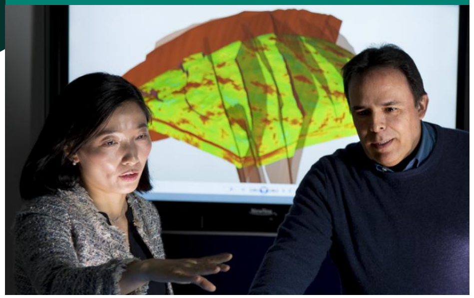
Ultra-reliable technologies for the harshest environments

Turbomachinery & Process Solutions

Industry-leading availability and reliability

A broad CCUS technology portfolio

Feasibility & design



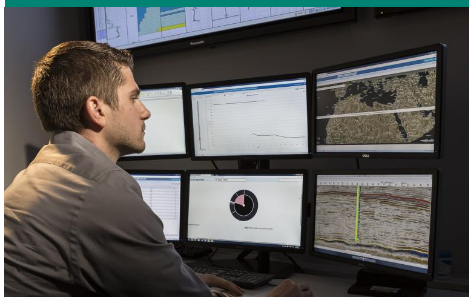
Carbon capture

Pipeline and transport

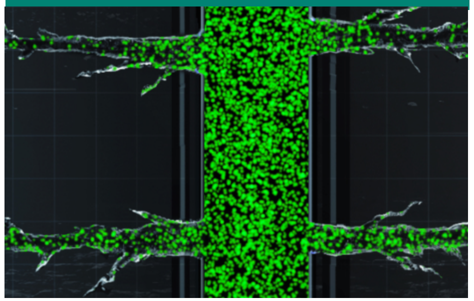
Compression

Well construction

Closure and monitoring



Enhanced oil recovery



Project development

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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 CO_2 emissions

- Underground storage (CCS)
- Production enhancement (EOR)
- Recycling (Power to Fuel)
- Using CO_2 as feedstock (e.g., urea)

Requires additional energy for capture, transport and injection

Reducing CO_2 emissions

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

Does not completely eliminate CO_2 emissions from the industry

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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)
  - CO_2 / H_2 / SNG compression
- Heat pumps for cooling & heating
- Organic rankine cycle
- Supercritical CO_2 cycle

Solutions to remove CO_2 emissions

- Post-combustion
- Flue gas compression
- CO_2 compression
- CO_2 pumping

Solutions to reduce CO_2 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

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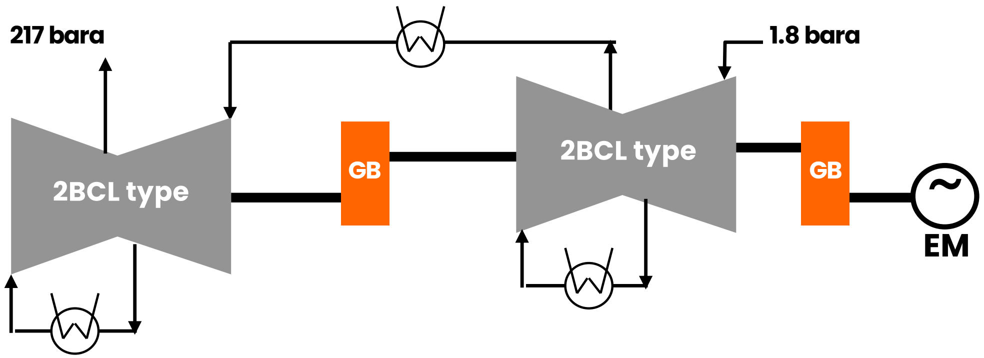
Gorgon CCS project

Three main refrigerant compression trains and six CO_2 compression trains required to drive Gorgon's pioneering CO_2 sequestration project



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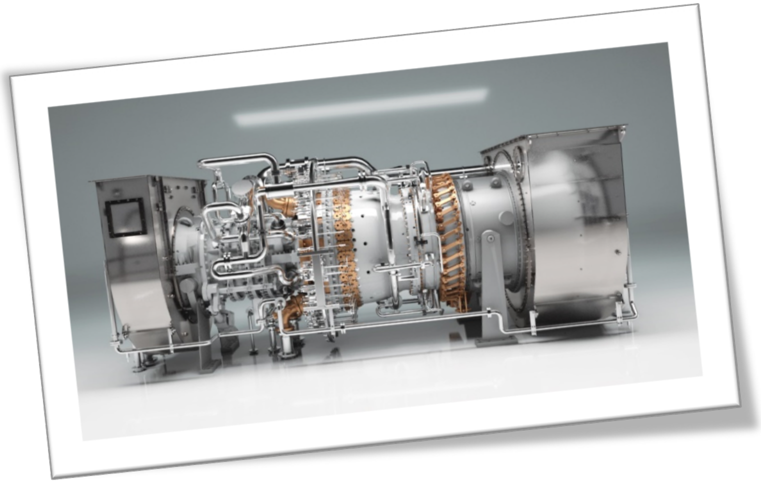
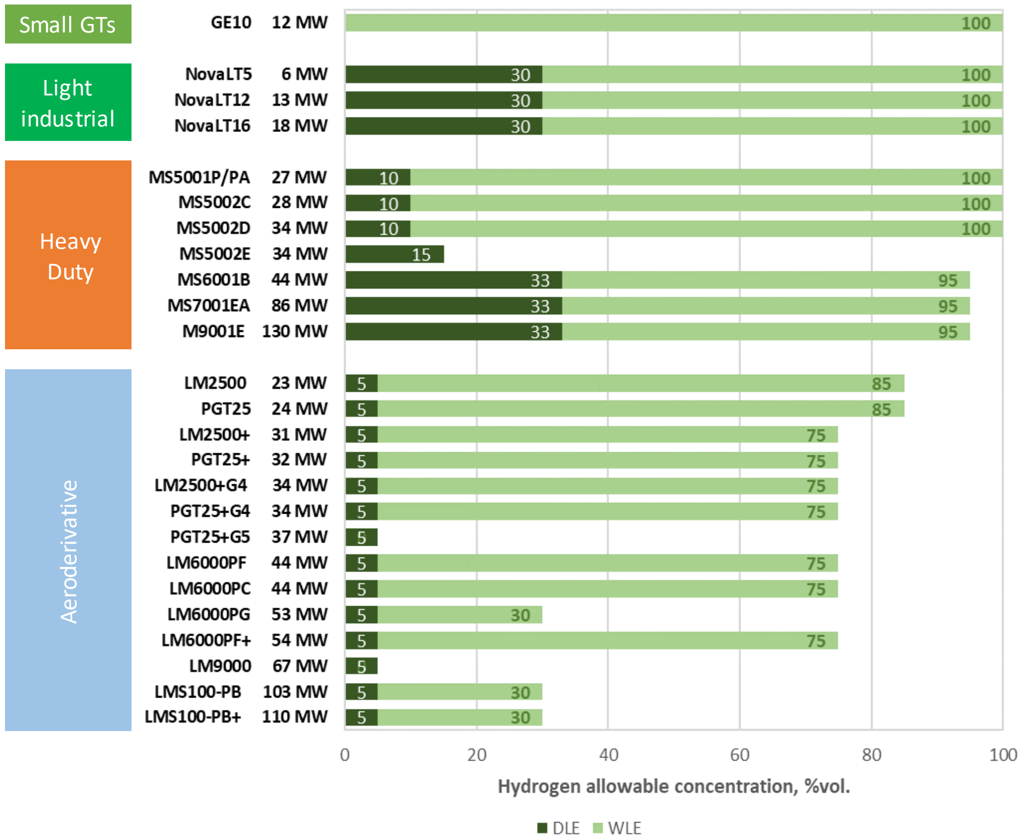
Baker Hughes gas turbine H_2 capabilites





- 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% H_2
- The NovaLT™ 12 recently tested for Snam gas network with 10% H_2

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CO_2 capture using the Chilled Ammonia Process

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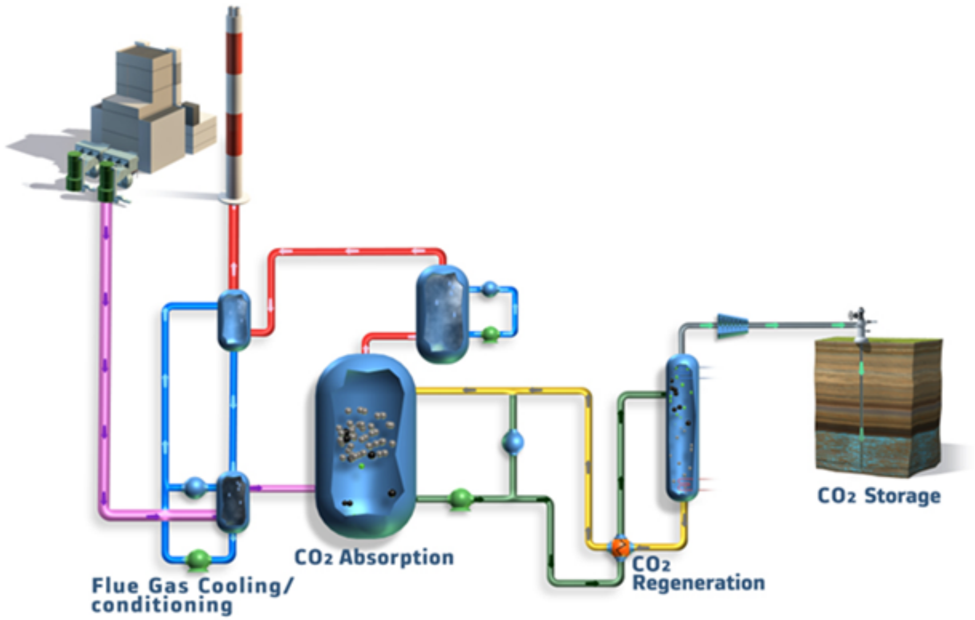
Chilled Ammonia Process (CAP)

- Ammonium carbonate solution reacts with the CO_2 in the flue gas to form ammonium bicarbonate
- Raising the temperature reverses this reaction; CO_2 is released and the solution is recycled

ADVANTAGES

- High CO_2 purity and delivery pressure
- Tolerant to oxygen and flue gas impurities
- No degradation
- No emission of trace contaminants
- Efficient capture of CO_2 (90%)
- Low-cost, globally available reagent



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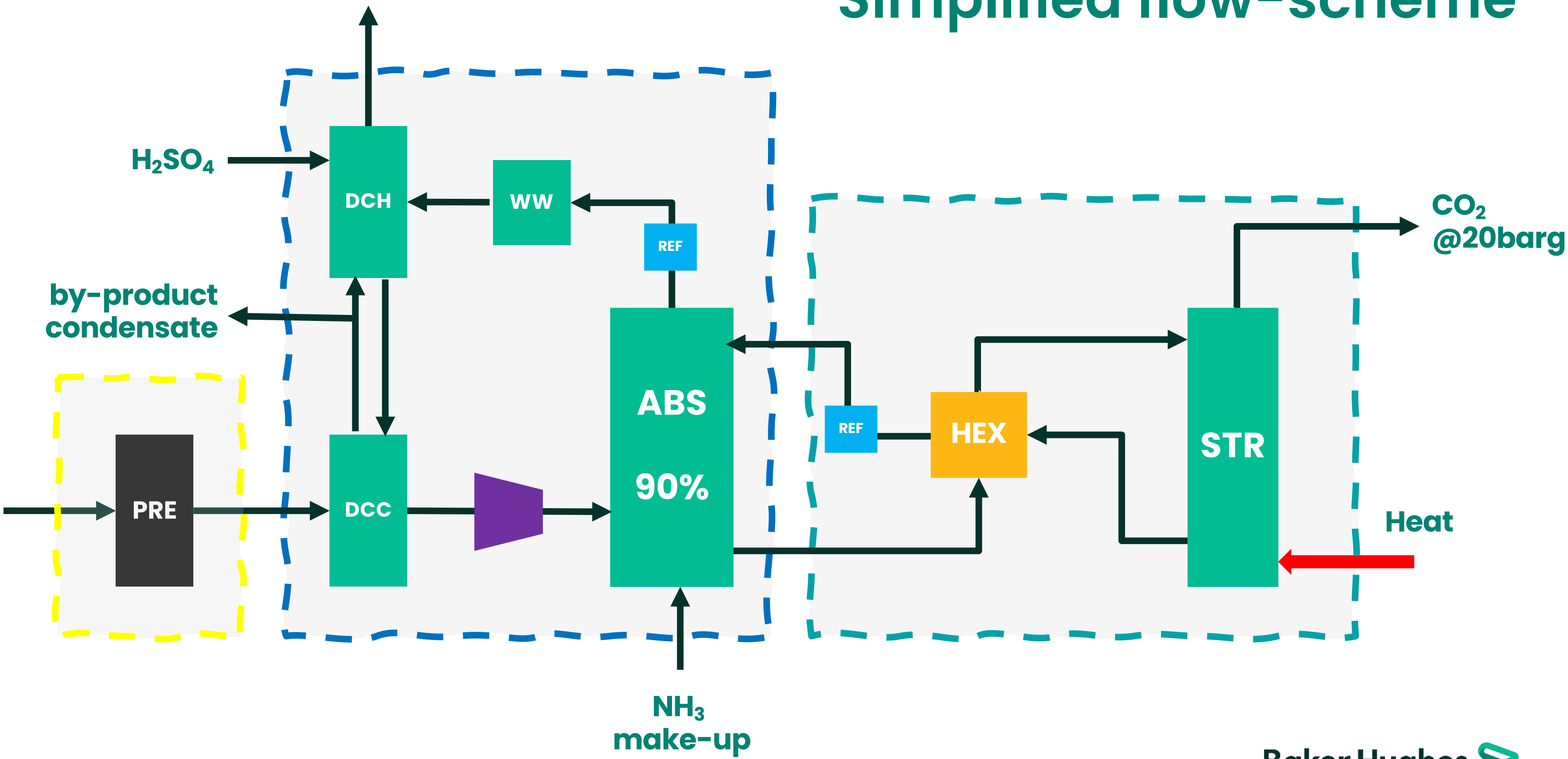
Simplified flow-scheme



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CAP chemistry

$$CO_2\ (g) \leftarrow\!\!==\!\!\rightarrow CO_2\ (aq)$$

$$CO_2\ (aq) + H_2O \leftarrow\!\!==\!\!\rightarrow H_2CO3\ (aq)$$

$$CO_2\ (g) + H_2O + NH_3\ (aq) \leftarrow\!\!==\!\!\rightarrow NH_4HCO_3\ (aq) + \text{Heat}\ \ \text{(Ammonium bicarbonate)}$$

$$CO_2\ (g) + 2\ NH_3\ (aq) \leftarrow\!\!==\!\!\rightarrow NH_4NH_2CO_2\ (aq) + \text{Heat}\ \ \text{(Ammonium carbamate)}$$

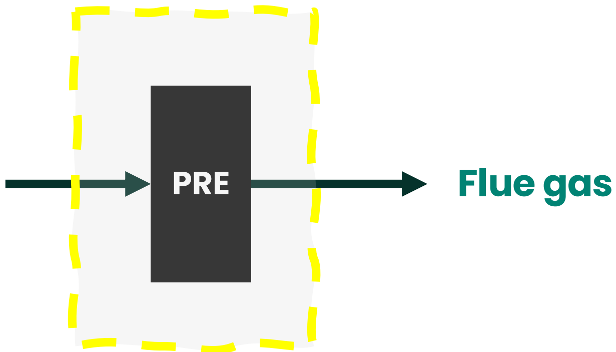
$$CO_2\ (g) + H_2O + 2\ NH_3\ (aq) \leftarrow\!\!==\!\!\rightarrow (NH_4)_2CO_3\ (aq) + \text{Heat}\ \ \text{(Ammonium carbonate)}$$

$$CO_2\ (g) + H_2O + (NH_4)_2CO_3\ (aq) \leftarrow\!\!==\!\!\rightarrow 2\ NH_4HCO_3\ (aq) + \text{Heat}\ \text{(Ammonium bicarbonate)}$$

Pre-treatment section

- 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



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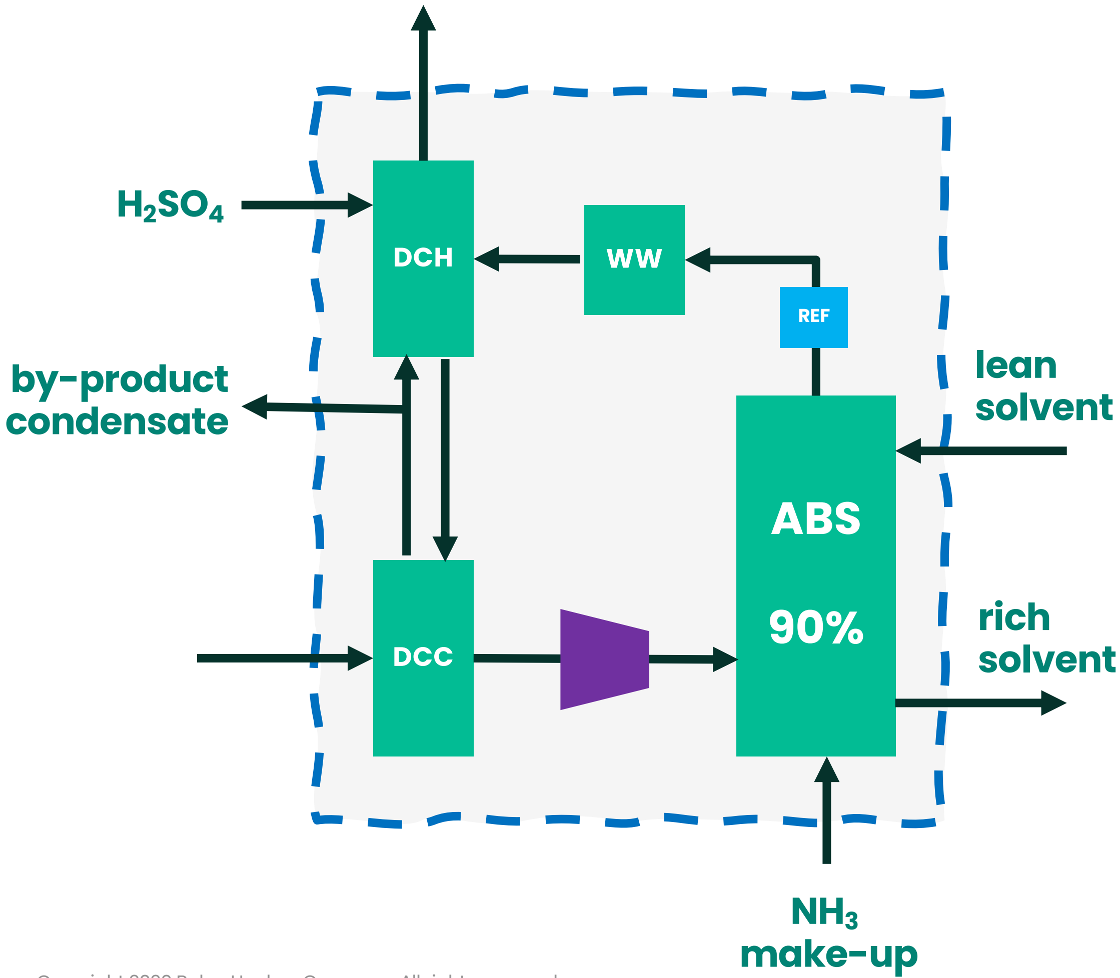

Absorption section

- 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

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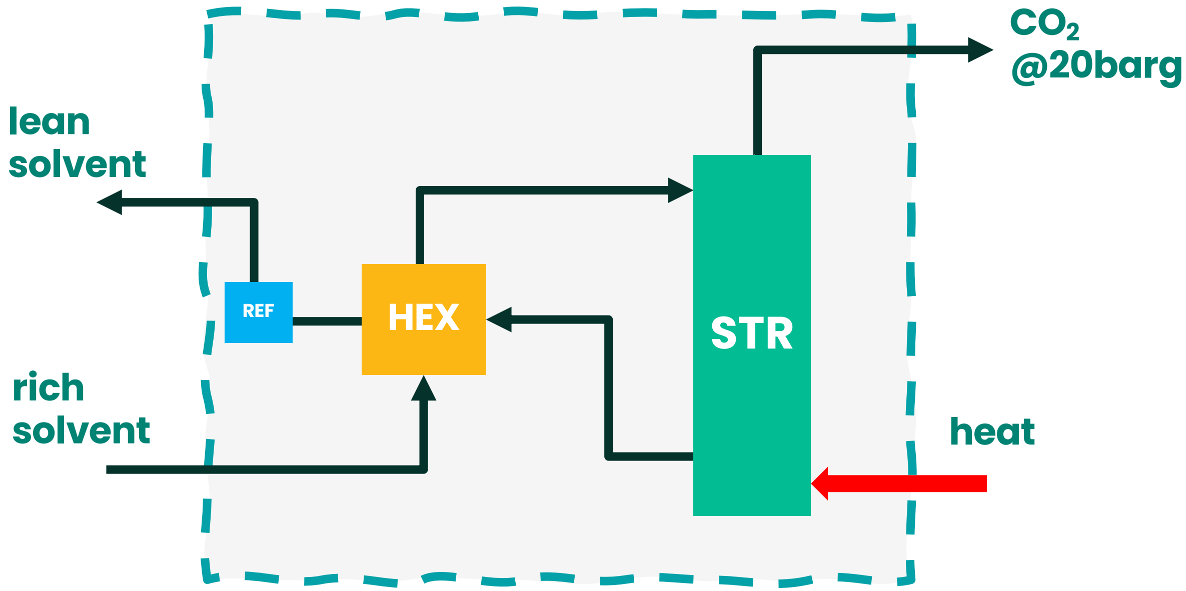
Regeneration section

- 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, O_2) 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

CAP at TCM Mongstad facility
Images provided courtesy of Technology Centre Mongstad

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Development roadmap

2006 - 2012

Test Rigs

SRI
California, Bench scale

GE Växjö
Sweden 0.25 MW_{th}

2008 - 2010

Industrial Pilots

WE Energies
Pleasant Prairie
Wisconsin/USA - 5 MW_{th}, Coal

E.ON Karlshamn
Sweden - 5 MW_{th}, Oil

2009 - 2011

2012 - 2014

Validation Pilots

AEP Mountaineer PVF
West Virginia/USA - 58 MW_{th}, Coal

TCM Mongstad
Norway - 40 MW_{th}, RFCC; CHP Gas

FEED
2013

Large-Scale Demonstration

CCM Mongstad
Norway – 1 Mio t/y CO_2, CHP Gas

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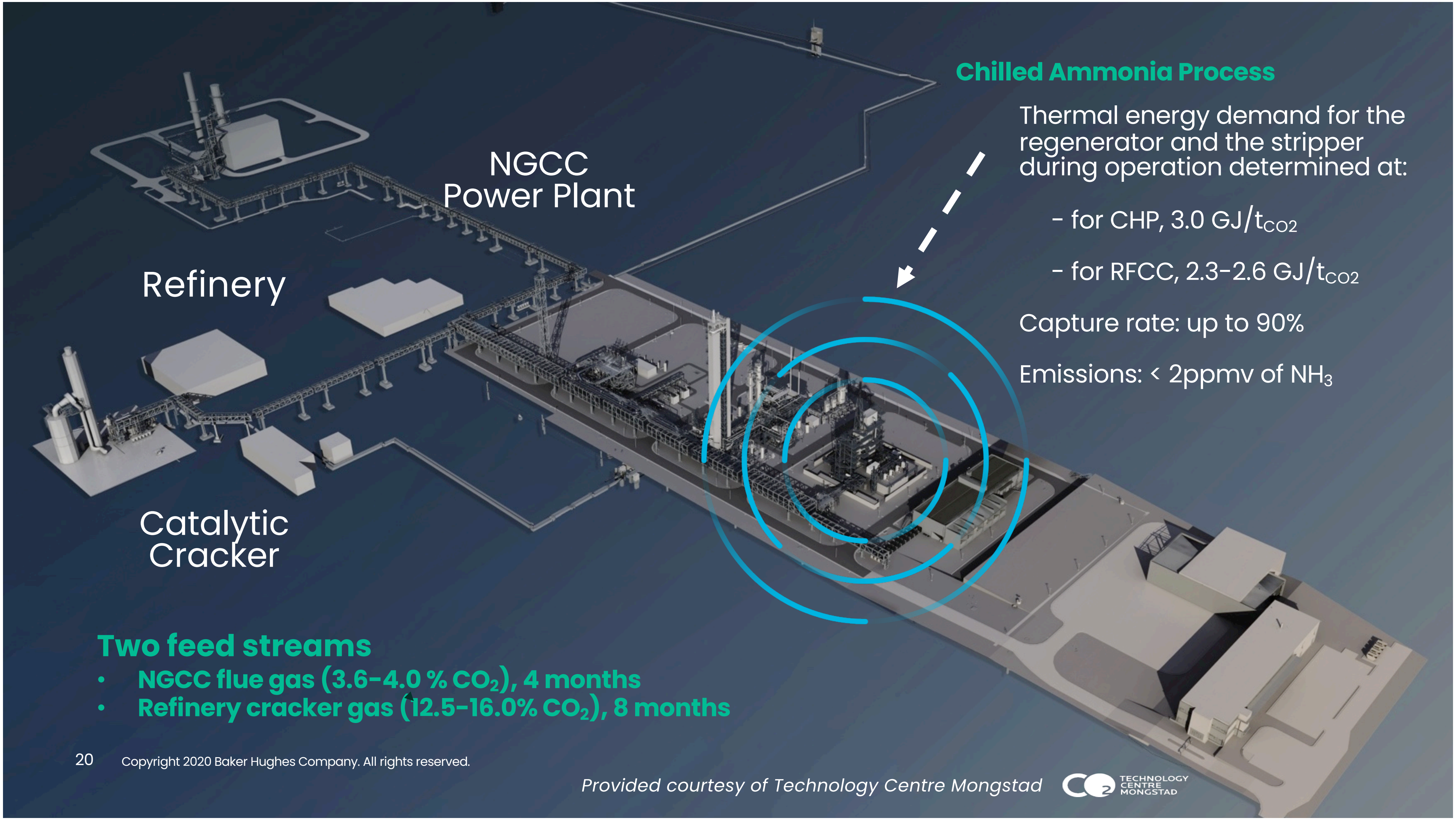


Chilled Ammonia Process

Thermal energy demand for the regenerator and the stripper during operation determined at:

- for CHP, 3.0 GJ/t_{CO2}
- for RFCC, 2.3-2.6 GJ/t_{CO2}

Capture rate: up to 90%

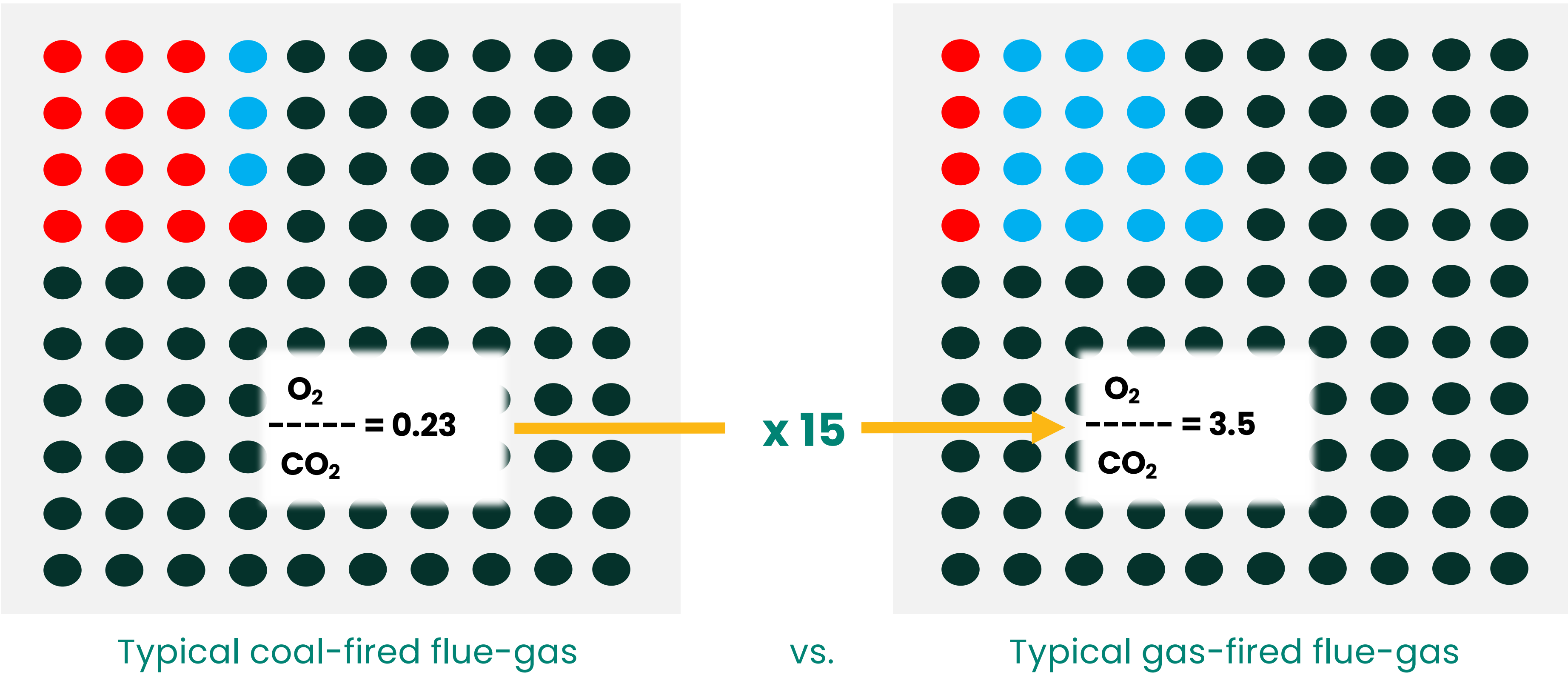
Emissions: < 2ppmv of NH_3

Two feed streams

- NGCC flue gas (3.6-4.0 % CO_2), 4 months
- Refinery cracker gas (12.5-16.0% CO_2), 8 months

Provided courtesy of Technology Centre Mongstad

Gas turbine applications: challenges



oxygen

carbon dioxide

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Conclusions

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Conclusions

- 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 CO_2 emissions, rather than being adapted to capture CO_2 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)

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