PENTAIR

FINDINGS FROM THE ARC CARBON CAPTURE PILOT PLANT & FUTURE CO_2 TECHNOLOGIES

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Agenda

About Pentair

Carbon Capture Technology

- Introduction to Pentair

Pilot Projects

- The heart of CCSU at ARC – insights from the carbon capture pilot plant and its impact on future plants
- Developments in process technology and solvents for carbon capture

CO_2 Capture & Biogas

- Upgraded biogas – a readily-available CO_2 source

11,250 employees serving customers at

120 locations in

25 countries with

>$3.8B in revenue

A long history, in short

1933

Founded
In Fredericia,
Denmark

1972

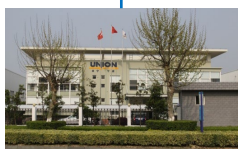
First CO_2 plant installed; Coca Cola, Iran (CBU)

Acquired by British Oxygen Company BOC)

1984

Acquired by Norsk Hydro Danmark

1994



Sales and production in China established

1994

Sales and production in Brazil established

1997

First flue gas extraction plant installed

2004

First Pat. NOxFlash installed

2004

Patented FlashCO_2 introduced

2009

CO_2Scrub introduced and patented

2010

RPM
Introduced

2013

ECO2Brew launched and patented

2013

Acquisition of Wittemann, USA

2017

Acquired by Pentair

CO_2mpactBrew launched & pat.

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PENTAIR CARBON CAPTURE SOLUTIONS

With 90 years of expert know-how in CO_2 capture and recovery technology engineering and the delivery of over 75 membrane plants, 350 amine plants, and more than 2000 CO_2 plants worldwide, let's work together to tackle your emissions target.

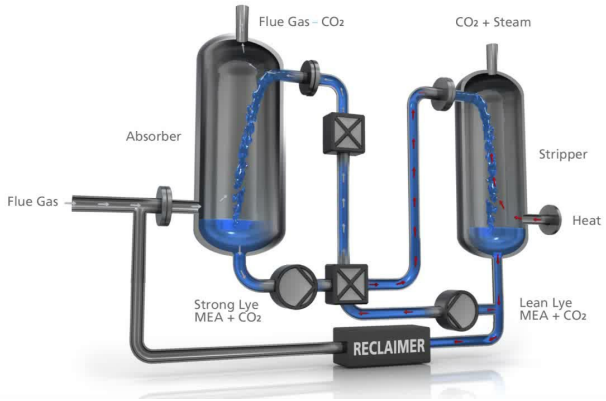
Developing our Core Technology, using Open-Source Solvents

- Amine solvents will be the **only available, properly tested Carbon Capture Technology for flue gasses**, at least until 2030.

  Further for Pentair AAT using **MEA** applies
  - Known behavior caused by flue gas impurities.
  - Predictable gaseous and liquid phase quality.
  - Avoid the risk of an un-proven technology in a full-scale carbon capture plant.
- The Pentair propriety AAT is used in industrial scale CCU plants for more than 25 years.
- Continuous research ensures ability to handle high concentrations of NO_X and O_2.
- Developing new patents that can reduce the overall steam consumptions by up to 20%.
- And yes: we will be offering solutions with 2nd generation solvents.

NO_X Flash

Reboiler technology



Amine absorption system

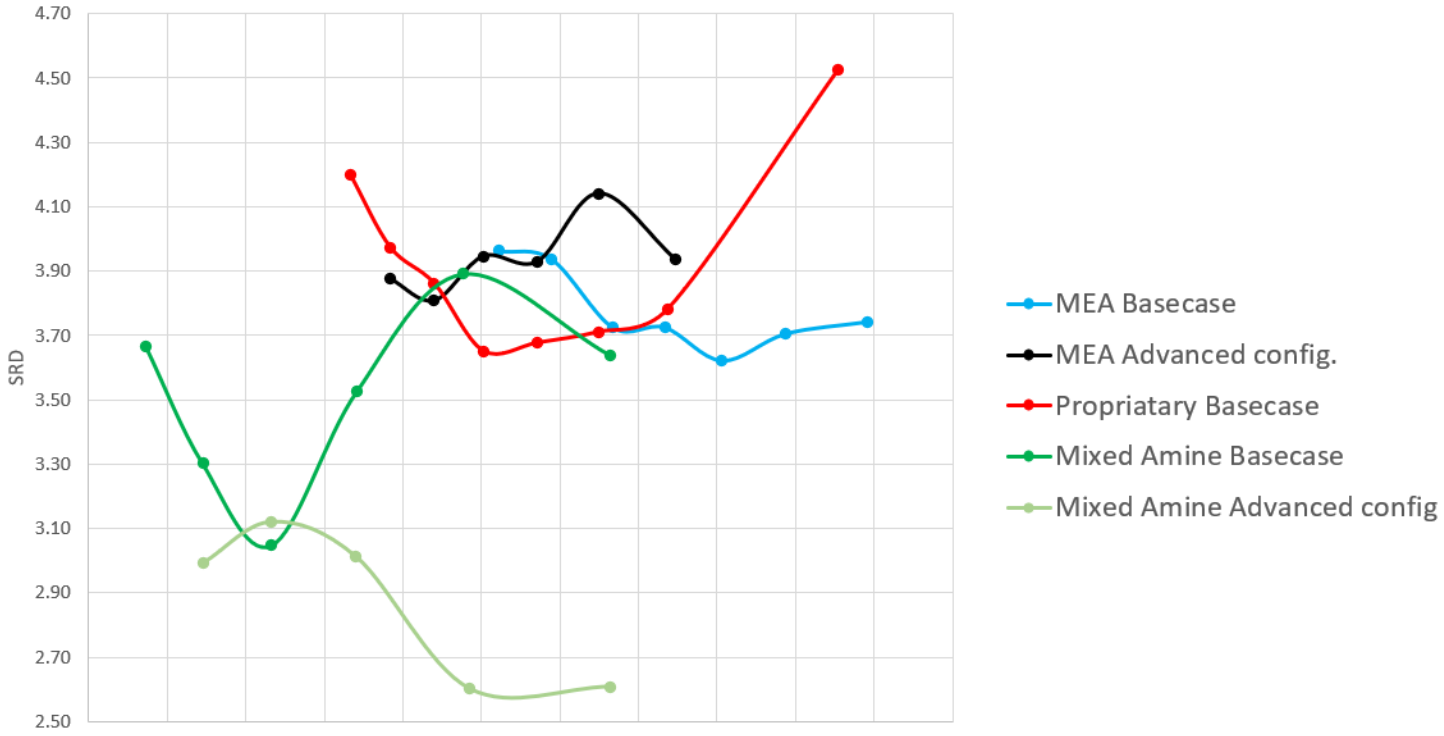
Our Core Propriety Technologies: NOXFlash for NOX handling; Reclaimer for solvent and corrosion control

Pilot Unit Campaigns

Specific Reboiler Duty (SRD) Findings

- Pilot unit results 2nd gen solvent
  - Reduces SRD by approx. 15% between cases with basic setup.
  - Reduces SRD by approx. 28% with advanced configurations.

- Most promising process configurations tested on the pilot is implemented in the design for the ARC demonstration plant with at **bigger scale** and **commercial operation** in mind.

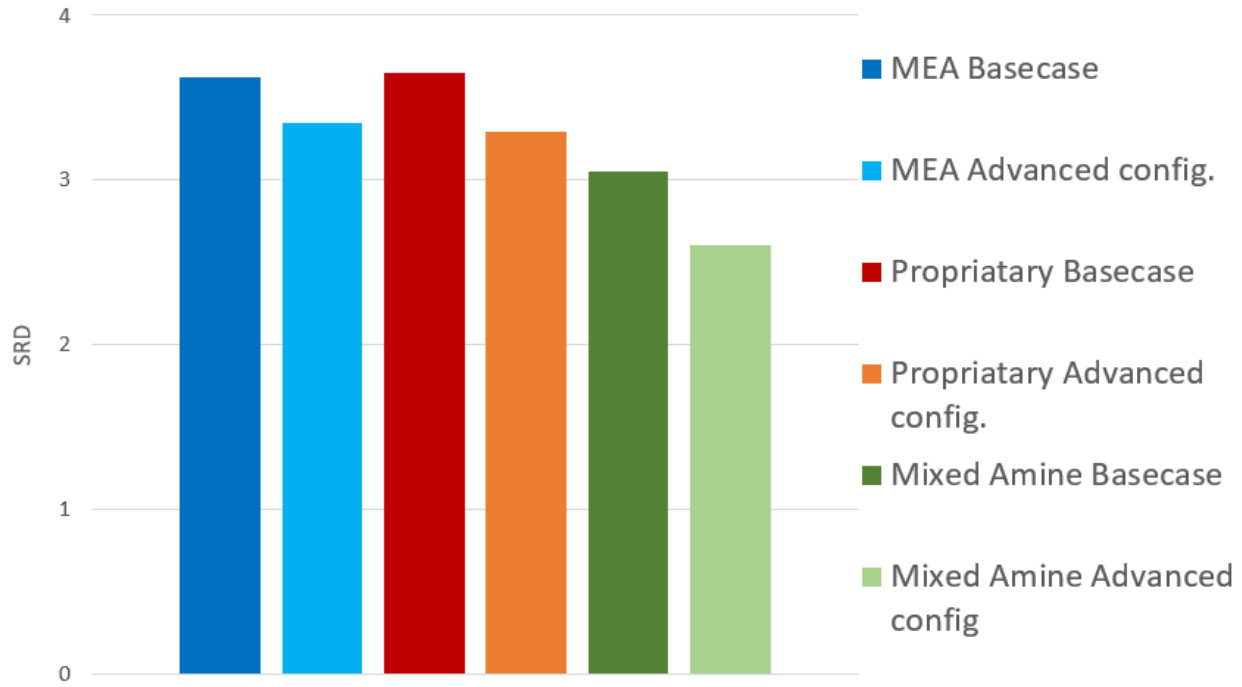


Maturing new solvents, verification of results and upscaling

Pilot Unit Campaigns

Specific Reboiler Duty (SRD) Findings

- Performance of several solvents has been evaluated under same parameters for direct comparison.
- Best configurations tested on pilot are build into the ARC demonstration plant for commercial testing



Maturing new solvents, verification of results and upscaling

ARC Demonstration Plant, Copenhagen

Waste-to-Energy Industry

- The demonstration plant will be in operation **during the summer 23', capable of capturing approximately 4 ton of CO_2 per day.**
- Aiming at proving a **'net zero carbon capture'** solution, where the CO_2 plant is fully integrated with the heat recovery in the WtE plant.
- The captured CO_2 is **purified to beverage quality** for further use in industry and merchant market.

Maturing new solvents, verification of results and upscaling

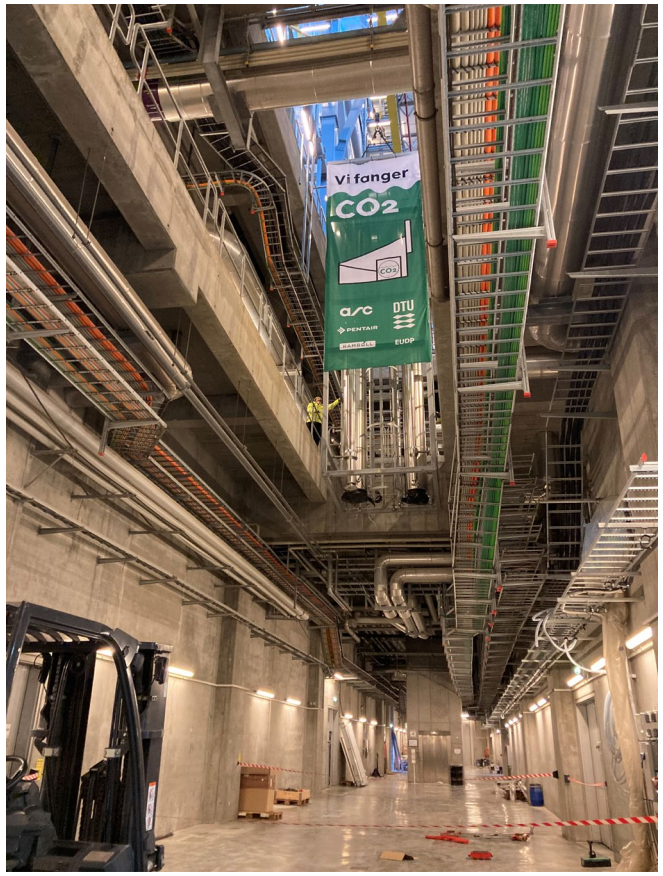
ARC – Skid manufacturing

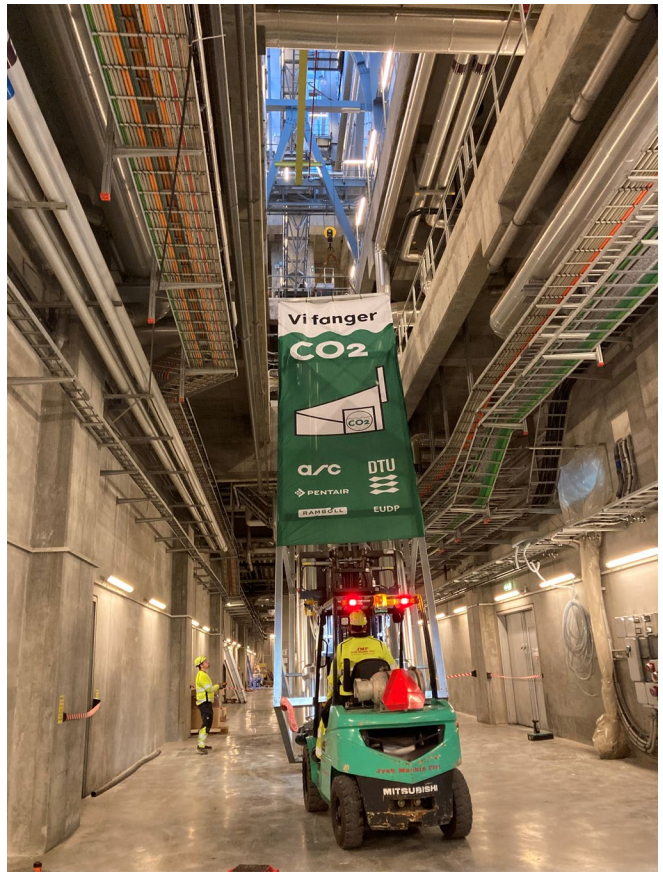
Assembly in our own workshop

All process plant skids are assembled in own workshops

ARC Site

Installation in progress



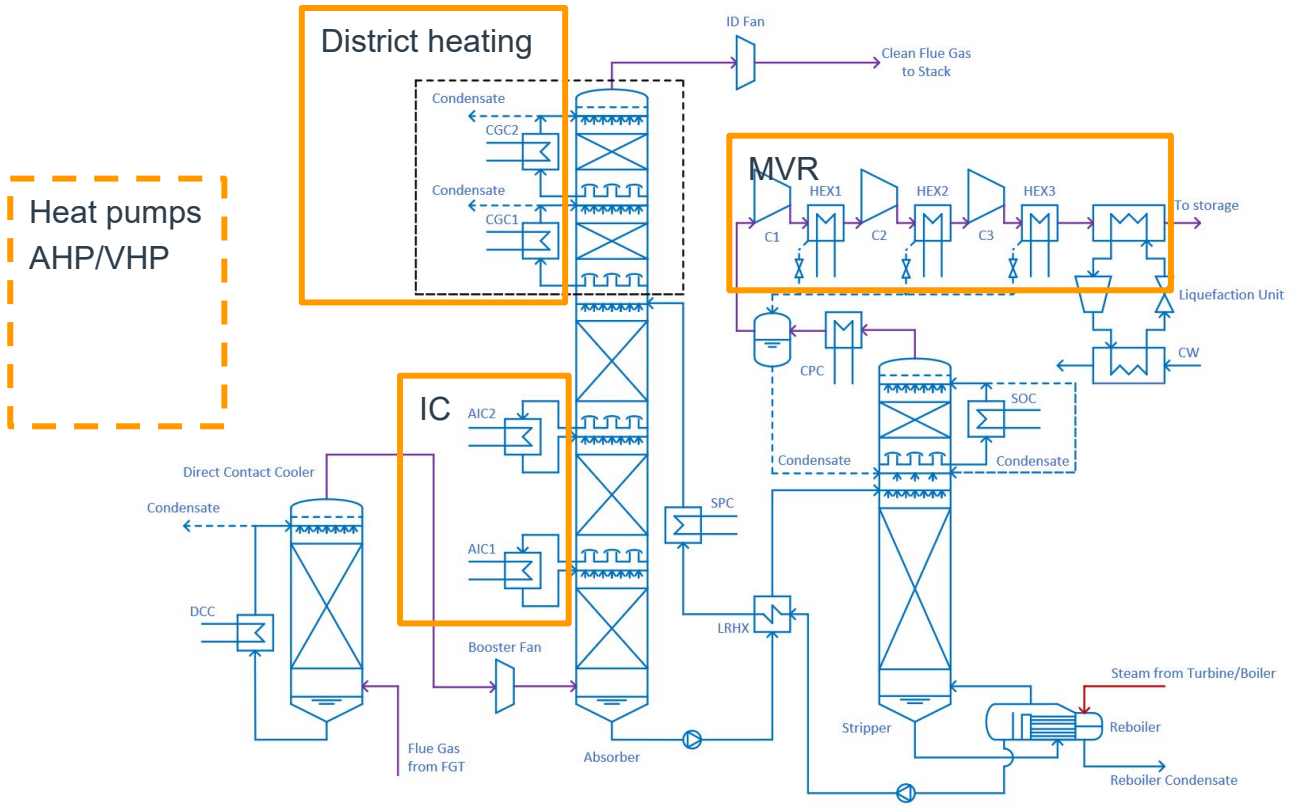


Liquefaction and Amine front end

Heat integration at ARC

How to achieve Net Zero CC

- Several plant setup and heat integration scenarios have been evaluated in order to find the lowest levelized cost of carbon capture (LCCC)



Source: Jensen, E. H. (2021). *Heat Pump Integration and Techno-economic Analysis for Full-scale Carbon Capture System Amager Resource Center at* [Master thesis, DTU Mechanical Engineering].

Energy integration of district heating

Energy integration of ARC

How to achieve Net Zero CC

- Obvious “savings” will not necessarily give lower TOC when thoroughly analyzed.

- A standard module-based carbon capture plant is no viable solution to bring down cost - **No two power plants will have same design OR operational conditions.**

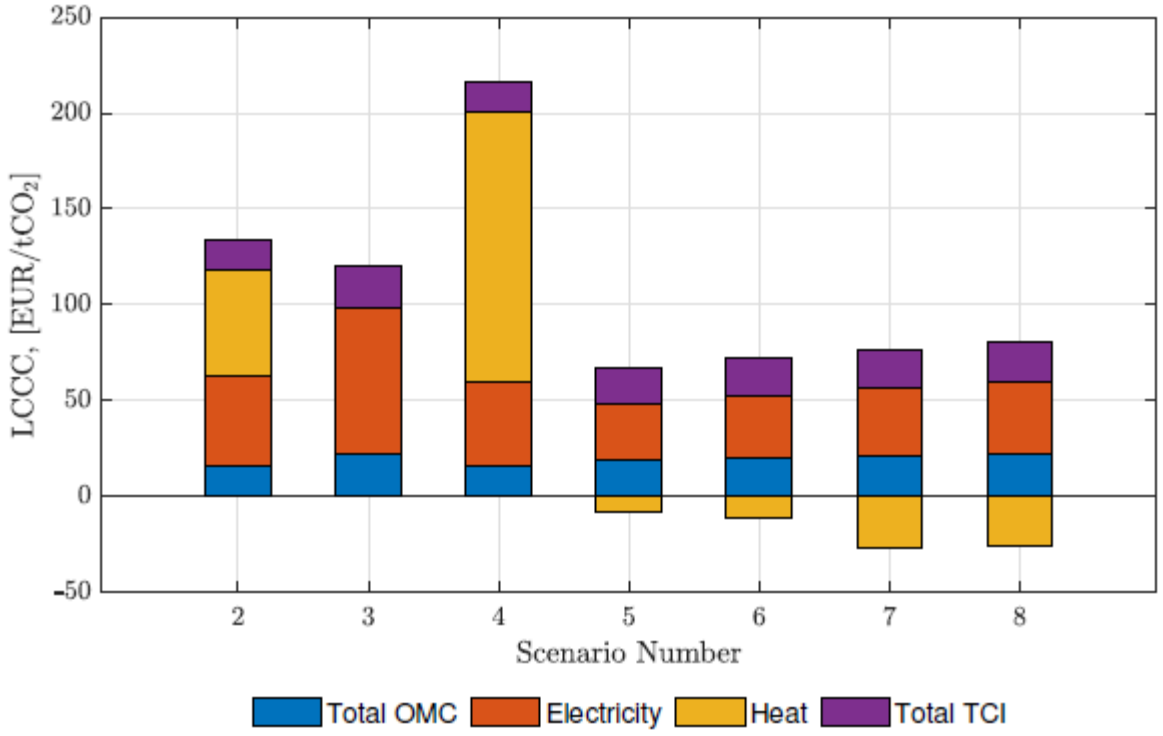


Figure 7: *Total LCCCs with the different contributions from energy sales, OMC and initial investments.*

Source: Jensen, E. H. (2021). *Heat Pump Integration and Techno-economic Analysis for Full-scale Carbon Capture System Amager Resource Center at* [Master thesis, DTU Mechanical Engineering].

Cost and heat integration of CC plant to be determined case-by-case

Technology and Solvent Performance Verification – Other Projects

- Hashøj
  - **Biogas upgrading**.
  - EUDP-funded project in cooperation with DTU, DGC.
  - Testing of MEA and other solvents, including 2nd Generation.
  - Aim at 30% energy saving (SRD).

- Aalborg Portland
  - **Cement industry**, CORT Project.
  - Lean vapor recompression, vacuum operation of the stripper column, and advanced heat integrations are some of the technologies that will be tested for the solvents on the CC pilot.

- Ørsted
  - **Biomass-fired power plant**, CORT project.
  - Testing site and details TBA.

Maturing new solvents and verification of simulation results in industrial environment

PENTAIR BIOGAS-TO-BIOMETHANE UPGRADING

Pentair Carbon Capture Solutions

Developed over time – driven by market demand

Self-manufacturing plants (CBU/EBU)

Drivers:
- Stand alone units
- Cheap fuel
- Delivery security
- Known source & technology
- Relatively small capacities

Recovery Based Units (RBU)

Drivers:
- Production for merchant market
- Larger capacities
- Advanced process design
- Large ammonia sources available
- **Biogas**

Advanced RBU & Extraction

Drivers:
- Bioethanol
- Focus on CO_2 emissions
- Quad-Gen-Solutions
- Green Footprint
- EOR
- More complex raw gases

RBU & large-scale Advanced Amine Tech.

Drivers:
- EOR
- Carbon Capture Storage (CCS)
- Steam Methane Reforming (SMR)
- **Biogas**

Extreme large-scale recovery & new sources

Drivers:
- Still more new and complex sources
- Green Fuel
- Carbon Capture Utilization (CCU)
- CO_2 Taxes
- Direct Air Capture (DAC)

A Pentair CO_2 solution for every customer and every feed gas

Pentair CCUS from Biogas

Developed over time – driven by market demand

- Already more than 15 plants supplying food-grade liquid CO_2 from a Biogas source.
- Designed for two purposes: CCUS and/or as an add-on to existing biogas upgrading unit even for other make than Pentair.
- Technology and knowhow to handle CO_2 origin from amine-, water wash, membrane- and PSA-based upgrading units.

A Pentair CO_2 solution for every customer and every feed gas

CO2 Recovery from Biogas – Ultra high Purity 6000 Nm3/h + 48 tpd CO_2

- 3rd party amine biogas upgrading (owned by utility) & bolt-on for CO_2 recovery (owned by IG comp.)
- IG company has conducted HACCP to identify any risks possible by using biogas as food grade CO_2
- CO_2 -analyzer, online monitoring of the liquid CO_2 going to the storage tanks
- When tank is filled a batch number is generated due to traceability
- Additional analysis on each storage tank as well as the CO_2 pumped to the truck is conducted
- In case of excessive impurities, the plant stops and adjustments are made
- Destillation columns and pipes are emptied for a clean start up

Approved by Danish Food Administration for food and beverages

Feedstock: 85% manure 15% organic waste from industry

A Pentair CO_2 solution for every customer and every feed gas

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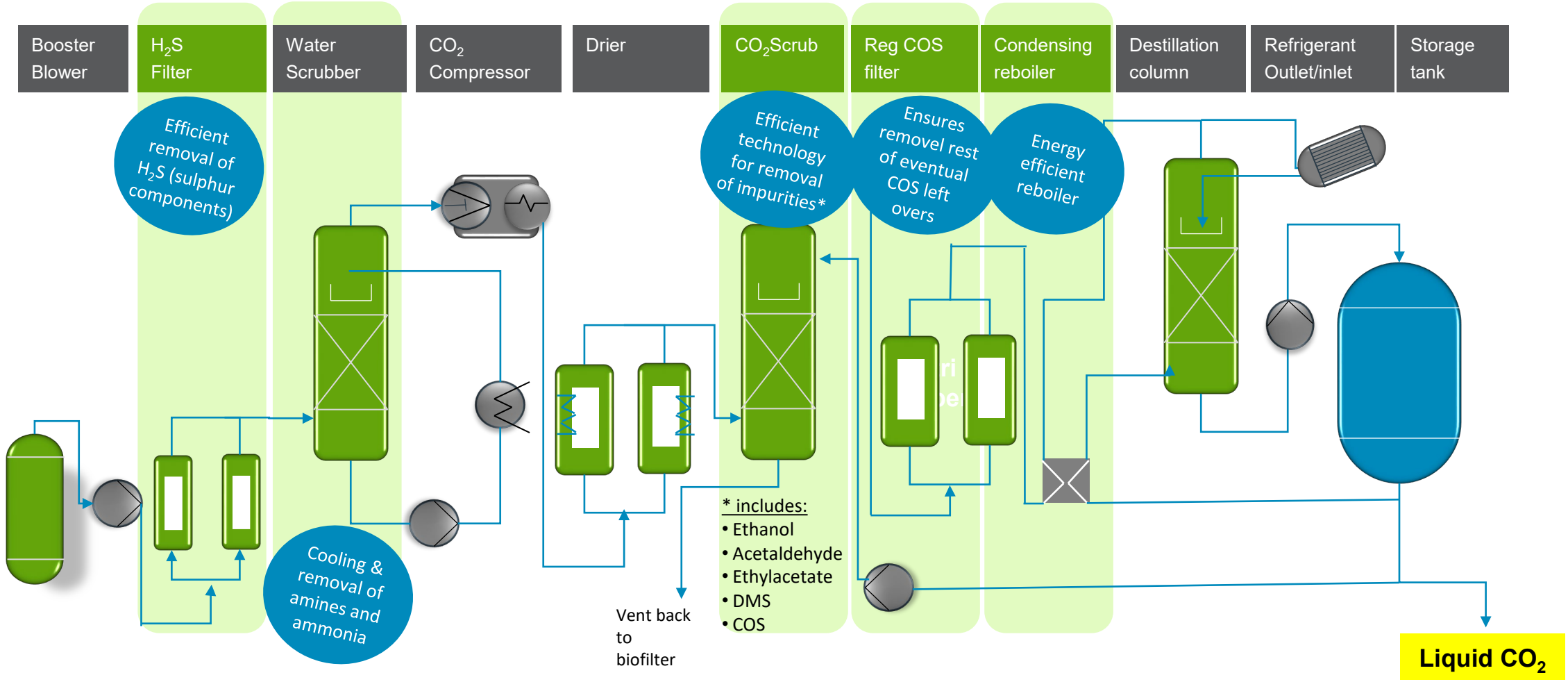
Robust, safe and flexible CO_2 Liquefaction



A Pentair CO_2 solution for every customer and every feed gas

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