

Welcome and Introduction

Uhde Ammonia Technology Users' Group Meeting

Munich, August 22nd 2023 | Tobias Birwe | thyssenkrupp Uhde



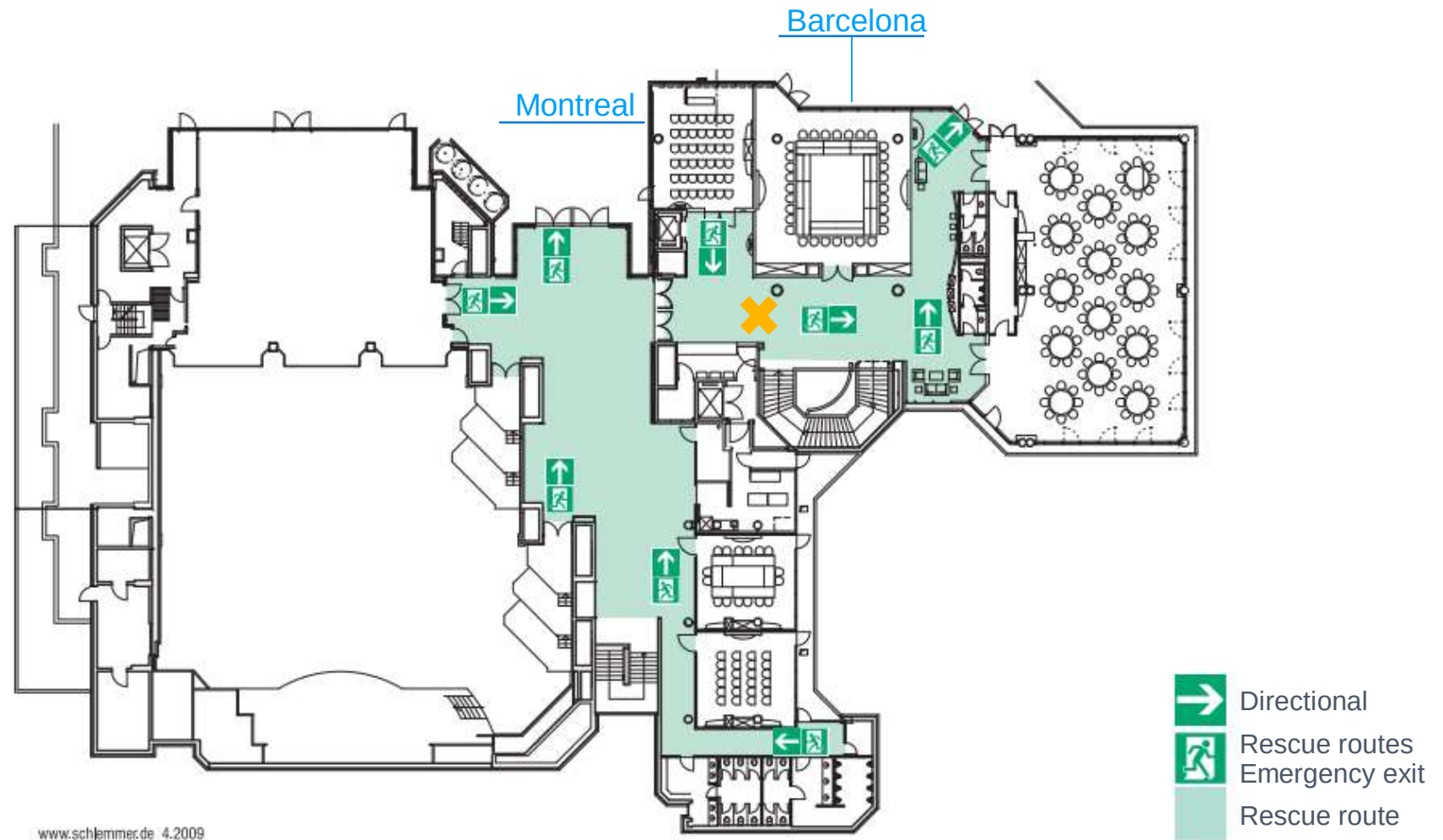
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Safety Moment

A look at the escape routes





We create a
livable planet



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UHDE

thyssenkrupp Uhde



thyssenkrupp Uhde's global footprint with world-scale chemical & process plants

Experience and more than 2,000 references in 100 years history

Fertilizers 130



Nitric acid 185



Refineries 380



Aromatics 75



Hydrogen, ammonia, methanol 120



Org. chemicals/petrochemicals 375



Plastics, synthetic fibres 115



Polyester/polyamides 400



Electrochemical technologies¹ 500



Coke plant technologies 500



Tank storage facilities 105



Industrial plants 150



¹ Now separate entity but close cooperation



What is ammonia and how do we use it today?

~180 Million tons per year, ~80% are used for fertilizer production



Nitrogen + Hydrogen

Other applications: e.g. cooling, chemical processes



Where do we find ammonia in the future?

Fossil-fuel based



Fossil-fuel based with CCS (blue)

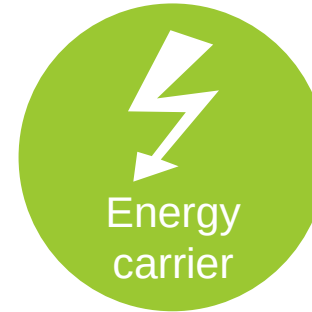


Renewable energy based

from...

Natural gas
as feed

Fertilizer
production



...to:

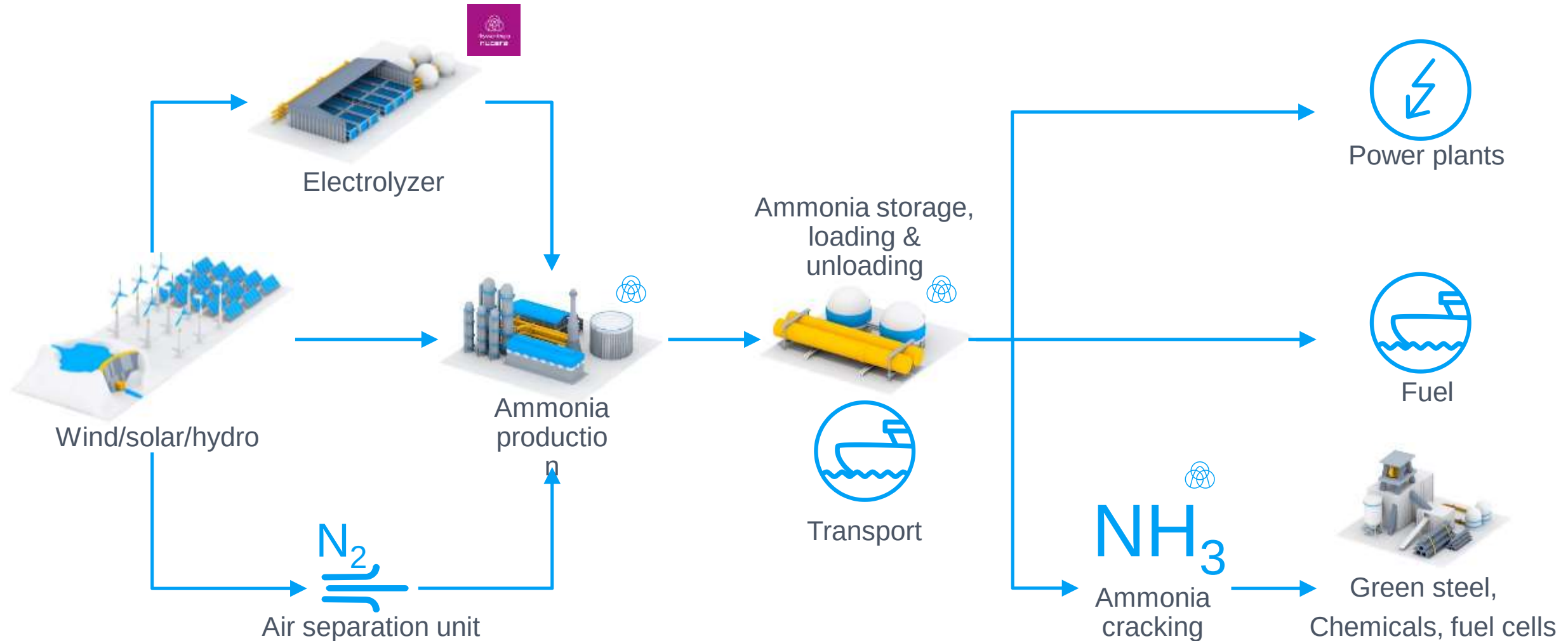
Renewable
energy, air and
water
as feedstocks

Energy carrier,
fertilizer, CO₂-
free maritime



Green ammonia as energy carrier – Set up along the whole energy supply chain

The complete solution from one source



Ammonia usage for energy transport, utilization as energy carrier or re-conversion to hydrogen



A overview of today's program

Time	Presentations		Presenter
12:00	Registration open		
13:00	Welcome		Tobias Birwe
14:35	Break		
	Room 1 – New Developments	Room 2 – New Services	
~ 16:00	Round tables		
17:00	Closing Address		
18:00	Departure to Dinner and Evening Event – We go together with a bus that picks us up in front of the hotel		
18:30	Arrival BMW World & aperitif - we meet on the terraces (3 rd Floor)		
19:00	Exclusive guided tours		
19:45	Dinner		
~ 22:00	Return to the hotel with our bus		



Uhde Ammonia Technology Users' Group Meeting

Introduction | Agenda

- 1 Uhde Fertilizer Projects Update
- 2 Uhde Ammonia Innovations Update
- 3 Uhde Revamp and Services Portfolio Update
- 4 Catalyst Optimization in Uhde Ammonia Plants
- 5 Introduction Workshops Topics



Uhde Ammonia Projects Update

Uhde Ammonia Technology Users' Group Meeting

Munich, August 22nd 2023 | Dr. Klaus Nölker | thyssenkrupp Uhde



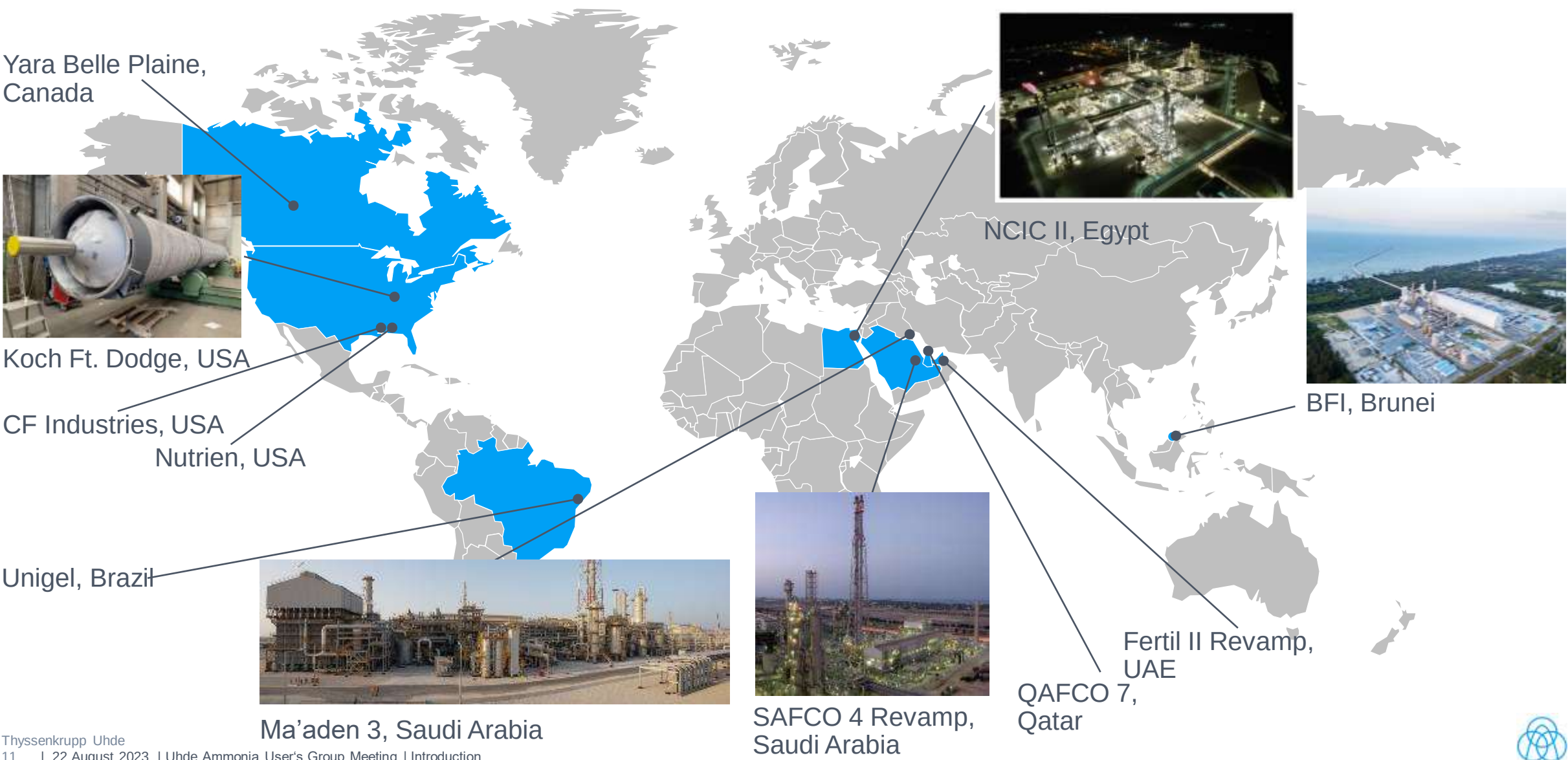
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thyssenkrupp Uhde Projects Update

Project Update for Ammonia



thyssenkrupp Uhde Projects Update

Project Update for Ammonia

Ma'aden 1 – 3

Location: Ras al Khair, Saudi Arabia

Capacity: Ammonia: 3 x 3,300 mtpd

Contract: Engineering, procurement and commissioning assistance to main contractor

Highlights: Ma'aden 1: started up in 2011

Follow-up contracts:

Ma'aden 2: in operation since 2016

Ma'aden 3: in operation since 2022



thyssenkrupp Uhde Projects Update

Project Update for Ammonia and Urea

Brunei Fertilizer Industries, Brunei

Location: Sungai Liang, Brunei Darussalam

Capacity:

- Ammonia: 2,200 mtpd
- Urea synthesis: 3,900 mtpd (Stamicarbon license)
- Urea granulation: 3,900 mtpd (tkFT license)

Contract: Engineering, procurement, construction, commissioning (EPC)

Status:

- Engineering start: Oct. 2017
- Basic engineering finished
- Detail engineering and construction works finished
- Start-up in 2021
- First ammonia December 2021



Highlights:

- Low limits on emissions of ammonia and dust:
- Acidic scrubbing of urea granulation exhaust and synthesis vent
- Recovery of spent acid (Ammonia Convert Technology by tkFT)



thyssenkrupp Uhde Projects Update

Project Update for Ammonia and Urea

NCIC II

Location: Ain Soukna, Egypt

Capacity:

Ammonia: 1,200 mtpd

Urea: 1,050 mtpd

Nitric Acid: 500 mtpd

Ammonium Nitrate: 635 mtpd

CAN: 826 mtpd

Contract: Engineering, procurement and construction lump sum (in consortium with Petrojet)

Status:

- Engineering start: June 2019
- Construction works finished
- Ammonia, urea, nitric acid: first production achieved in 2023
- Ammonium nitrate and CAN: under precommissioning (August 2023)



thyssenkrupp Uhde Projects Update

Project Update for Green Ammonia

UNIGEL, Brazil



The screenshot shows a news article on the thyssenkrupp website. The headline is "Brazil's first electrolysis-based ammonia plant takes shape" by Julian Atchison on August 1, 2022. The article text states that Brazil's largest fertiliser producer Unigel (Portuguese language) has launched the country's first industrial-scale electrolytic hydrogen & ammonia project. The initial phase of the project entails \$120 million of investment and 60 MW of thyssenkrupp nucera electrolyzers, to be installed in three 20 MW units. Operational by 2023, the plant (located within the existing Camaçari Industrial Complex in Bahia province) will produce 60,000 tonnes per year of ammonia, with production to "quadruple" in the second phase, which is due in 2025. There is a small image of the Unigel logo and a caption: "Click to learn more about Unigel's new electrolytic hydrogen & ammonia project in Camaçari, Brazil (Portuguese language)." The Unigel logo text reads: "UNIGEL A MAIOR FÁBRICA DE INÍVULGENDO VERDE DO BRASIL ESTÁ AQUI".

Capacity: 60 MW eq. 150 t/d of NH_3

CF Industries, USA



The screenshot shows a news article on the thyssenkrupp website. The headline is "Kick-off to decarbonizing ammonia production: thyssenkrupp awarded green hydrogen plant by CF Industries". The article text states that thyssenkrupp has entered into an engineering and supply contract with CF Industries to deliver a green hydrogen plant for the production of green ammonia at the Donaldsonville manufacturing complex in Louisiana. Under this contract thyssenkrupp will engineer and deliver a 20 MW hydrogen production unit based on their alkaline water electrolysis as well as all necessary utilities. There is a small image of the thyssenkrupp logo and a caption: "Click to learn more about thyssenkrupp's new electrolytic hydrogen & ammonia project in Donaldsonville, Louisiana (English language)." The thyssenkrupp logo text reads: "thyssenkrupp engineering. tomorrow. together." The article also includes a list of bullet points: "20 MW green hydrogen installation to kick-off the decarbonization of the world's largest ammonia production facility" and "CF Industries will start production of 20,000 tons per year of green ammonia by 2023".

Capacity: 20 MW eq. 50 t/d of NH_3



thyssenkrupp Uhde Projects Update

Project Update for Blue Ammonia

QAFCO 7, Qatar

- Location:** Mesaieed, Qatar
- Capacity:** Ammonia: 3,300 mtpd
- Contract:** Engineering, procurement and construction lump sum (in consortium with CCC), effective from September 2022
- Status:** Basic engineering completed, detail engineering, procurement, and construction ongoing
- Highlights:** Carbon dioxide export for emission reduction



Source: www.thyssenkrupp.com/en/newsroom/press-releases/pressdetailpage/thyssenkrupp-uhde-to-build-world-scale-blue-ammonia-plant-in-qatar-138369, 31 Aug. 2022

Thyssenkrupp Uhde

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thyssenkrupp Uhde Projects Update

Project Update for Blue Ammonia

CF Industries and Mitsui, USA

Home > News > thyssenkrupp Uhde selected by CF Industries and Mitsui for blue ammonia project

thyssenkrupp Uhde selected by CF Industries and Mitsui for blue ammonia project

12/15/2022



thyssenkrupp Uhde has been selected as technology provider for a new "Blue Ammonia" plant in the United States by Mitsui & Co., Ltd. (Mitsui), one of the leading ammonia marketers in the world, and CF Industries Holdings, Inc. (CF), the world's largest producer of ammonia.

The new greenfield facility will produce blue ammonia by leveraging carbon capture and sequestration processes to reduce carbon emissions by more than 60% compared to conventional ammonia. As a first step, thyssenkrupp Uhde will conduct a front-end engineering and design (FEED) study for the proposed joint venture of CF and Mitsui.

Location: Ascension Parish, Louisiana, USA

Capacity: Ammonia: 3,300 mtpd

Contract: FEED, effective from October 28th, 2022

Highlights: Carbon dioxide compression for export to sequestration

Source: Hydrocarbon Processing: www.hydrocarbonprocessing.com/news/2022/12/thyssenkrupp-uhde-selected-by-cf-industries-and-mitsui-for-blue-ammonia-project

Thyssenkrupp Uhde

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thyssenkrupp Uhde Projects Update

Project Update for Blue Ammonia

Nutrien Geismar, USA



Location: Louisiana, USA

Capacity: Ammonia: 3,300 mtpd, single train

Contract: Basic engineering, awarded 2022

Highlights: Carbon dioxide capture rate >90%, ATR process, single pressure process



thyssenkrupp Uhde Projects Update

Project Update for Ammonia

Koch Ft. Dodge Revamp, USA

Location: Ft. Dodge, Iowa, USA

Capacity: Ammonia: capacity increase by 180 stpd

Contract: Basic engineering, proprietary equipment

Status: Basic engineering started in Nov. 2020
Installation of converter cartridge: June 2022
Revamp capacity reached: Sept. 2022

Highlights: Capacity increase by insertion of a once-through synthesis into a vintage plant

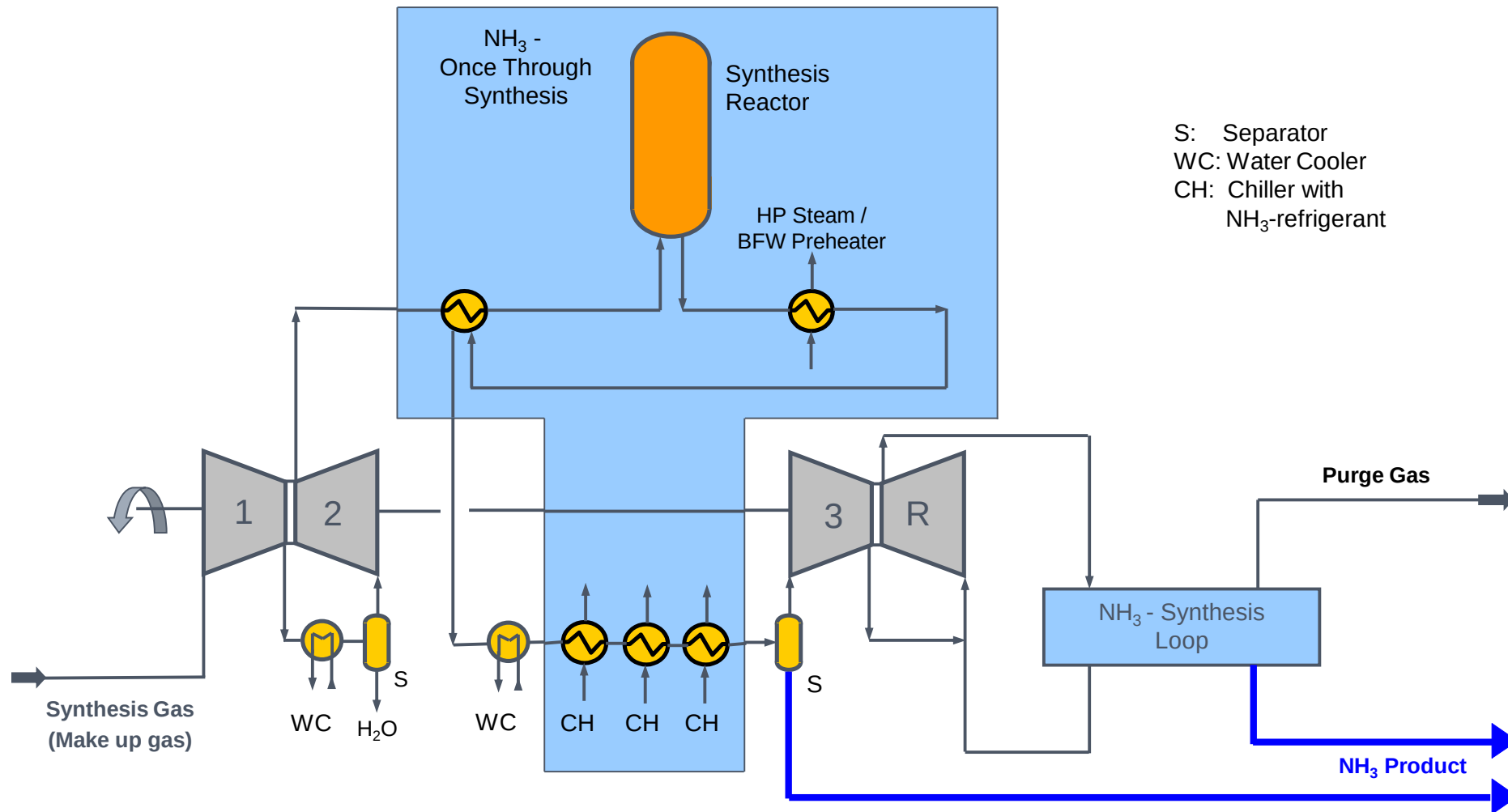
Use of Johnson Matthey Katalco 74-1 catalyst for ammonia synthesis at low pressure

Converter cartridge with axial-radial catalyst beds and modular design, maximum use of available volume



Uhde Dual Pressure Ammonia Process

General Process Scheme



thyssenkrupp Uhde Projects Update

Project Update for Ammonia

Fertil II Projects

Location: Abu Dhabi, United Arab Emirates

Project 1: Extension of ammonia recovery unit, addition of a hydrogen recovery unit for capacity increase of 120 t/d

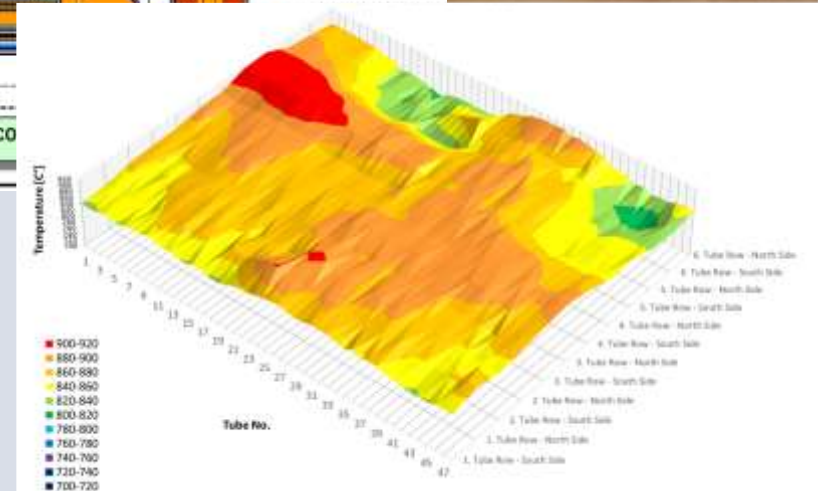
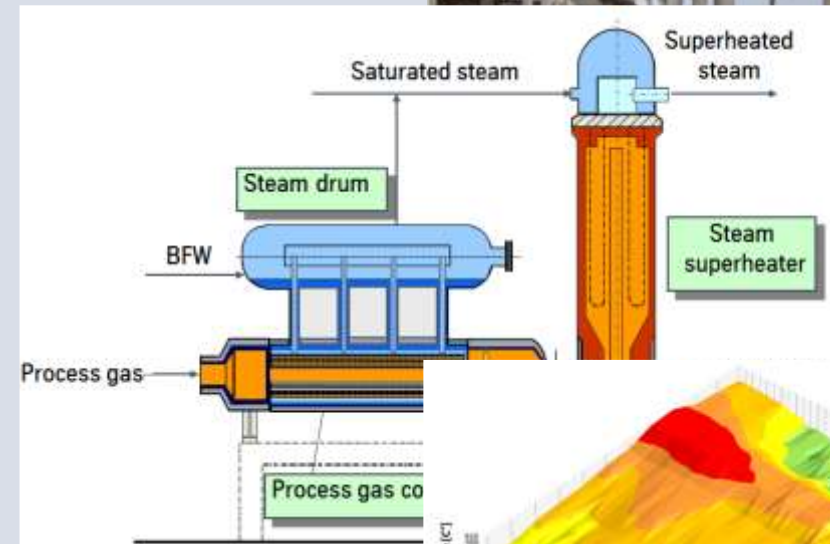
Status: Basic engineering completed, Tie-ins installed in 2022, Procurement ongoing, Installation scheduled for 2024

Project 2: Replacement of process gas cooler with new patented bypass flap design

Status: Procurement, site support, successful start-up in Oct. 2022

Project 3: Reformer tube temperature scan

Status: Finished Feb. 2023



QAFCO CO₂ Removal Project

Location: QAFCO 3 and 4 ammonia plants,
Mesaieed, Qatar

Project: Debottlenecking of CO₂ removal units

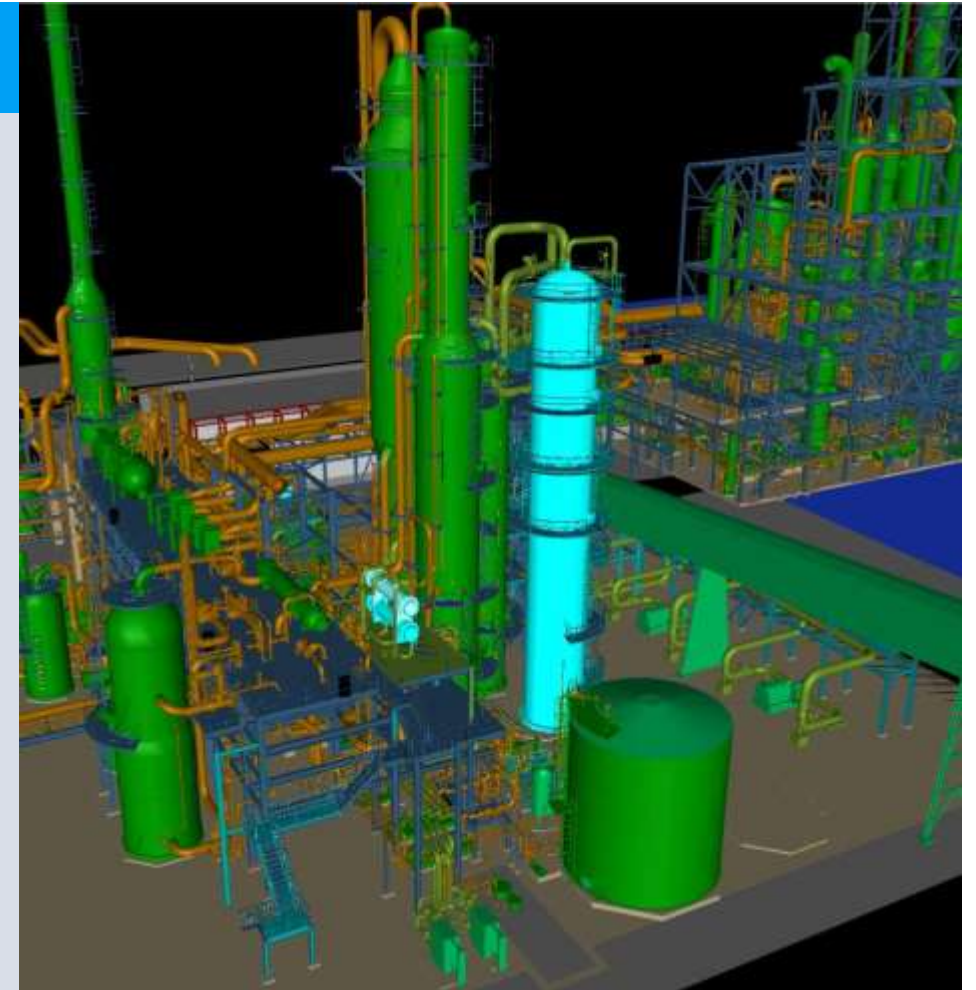
Phase 1: Study for ammonia plants 3 and 4, equipped with BASF OASE® CO₂ removal technology, to increase throughput, including:

- evaluation of addition of “vacuum flash”,
- layout considerations in existing plants

Phase 2: Further engineering and implementation

Status: Phase 1: Completed

Phase 2: Ongoing



Typical 3D model of CO₂ removal unit with “vacuum flash” in light blue

thyssenkrupp Uhde Projects Update

Project Update for Ammonia

Yara Belle Plaine Projects

Location: Yara Belle Plaine, Saskatchewan, Canada

Project 1: Ammonia synthesis loop:

Bigger loop separator to cover the actual conditions above nameplate capacity, design supported by 3D scan of surrounding area

New converter cartridges

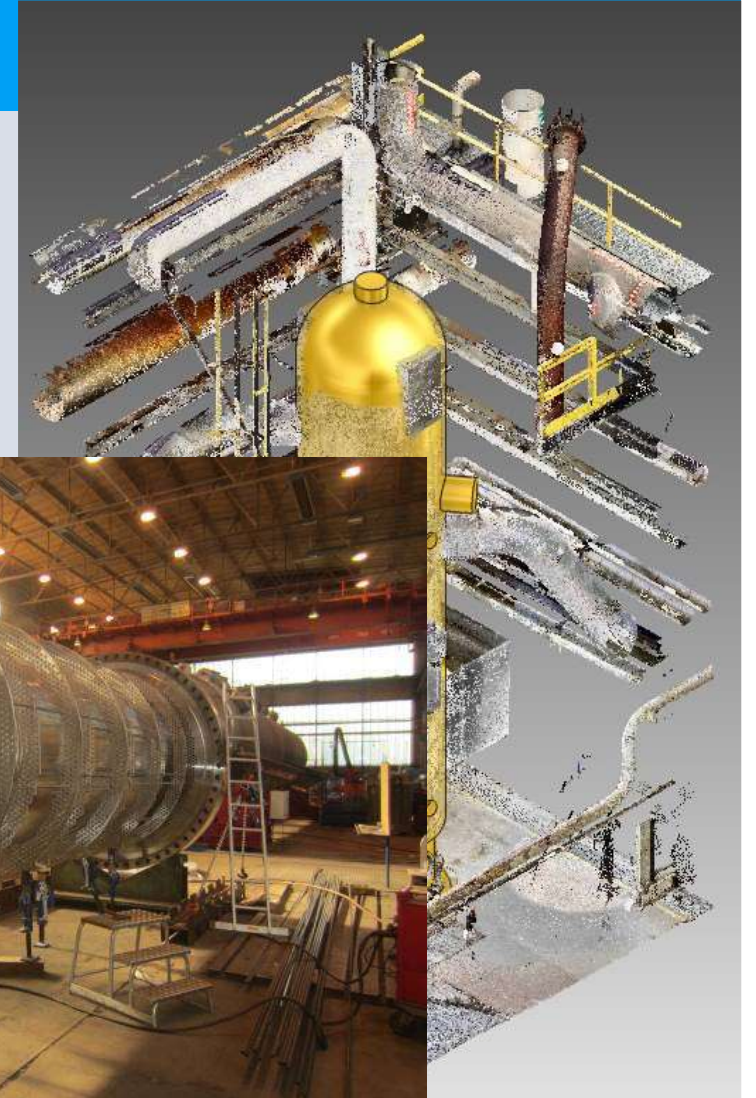
See separate presentation

Status: Separator: Installed, start-up in Aug. 2022

Cartridges: to be installed 2026

Project 2: Installation of new process gas cooler and superheaters for higher capacity, design supported by 3D scan of surrounding area

Status: Procurement, site support, successful start-up in Aug. 2022



Ammonia Production Pathways

From Grey to Green and Blue Ammonia

Current situation

Grey ammonia

- Ammonia production accounts for approx. 1.8% of the world's CO₂ emission, equal to 500 MM t CO₂/year ¹⁾
- Use of ammonia as chemical feedstock, but mostly for fertilizer production (85%)

Expectation:

- Requirement to reduce CO₂ emissions in all industry sectors, will also threaten existing producers
- Increasing use of ammonia also as fuel because it does not emit any CO₂ during combustion and as transport medium for hydrogen

additional efforts
for producers

new markets
for producers

Future requirement

Green ammonia

delayed
implementation

- Production of ammonia without CO₂ emissions:
 - based on hydrogen from electrolysis of water, using renewable energy

Blue ammonia

immediate
implementation

- Production of ammonia with significantly reduced CO₂ emissions:
 - using fossil feedstocks (natural gas)
 - utilizing CO₂ for other purposes (CCU) or storing it under ground (CCS)

Ammonia: Market growth and new production pathways



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Ongoing Developments

- Various projects on optimization of ammonia plants
- Adapting the ammonia synthesis to the requirements of a green ammonia plants:
 - Clean hydrogen at low pressure
 - Fluctuating availability of power and hydrogen
- Ammonia plants for the energy market:
 - Large Plants: projects call for 3,500 mtpd and more in single train } ⇒ ATR-based process, basic engineering finished
 - High degree of CO₂ capture: >95% possible
- Optimization of ammonia converter cartridge:
 - Converter cartridge with axial-radial catalyst beds and modular design, maximum use of available volume
- Ammonia cracking: Decomposition of ammonia to hydrogen

See separate presentation

See separate presentation

See separate presentation



Thank you for your attention



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Uhde Ammonia Innovations Update

Uhde Ammonia Technology Users' Group Meeting

Munich, August 22nd 2023 | Bernd Mielke | thyssenkrupp Uhde



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Uhde Ammonia Innovations Update

Agenda

- 1 Steam reformer innovations
- 2 ATR introduction and innovations
- 3 Ammonia synthesis innovations
- 4 Green ammonia innovations
- 5 Operations innovations
- 6 Conclusion



Steam methane reformer

Innovations

- The steam methane reformer – and especially the Uhde reformer – is a well referenced and reliable item
- Although the technology is mature, there is still room for improvement
- Uhde's recent innovations took place in:
 - Improvements in burner management system (BMS): more stringent flame monitoring
 - Modularization of reformer penthouse: take construction work away from the site
 - Simplified way to evaporate ammonia-water for SCR applications: use MP steam instead of hot air as a carrier
 - Mitigation of hot spots in outlet headers: new material for casted refractory
 - Active cooling of reformer bottom
- For details, please refer to presentation “Updates on Equipment Design” held by Thorsten Brakhane this afternoon in Room 2



CO₂ recovery from SMR flue gas

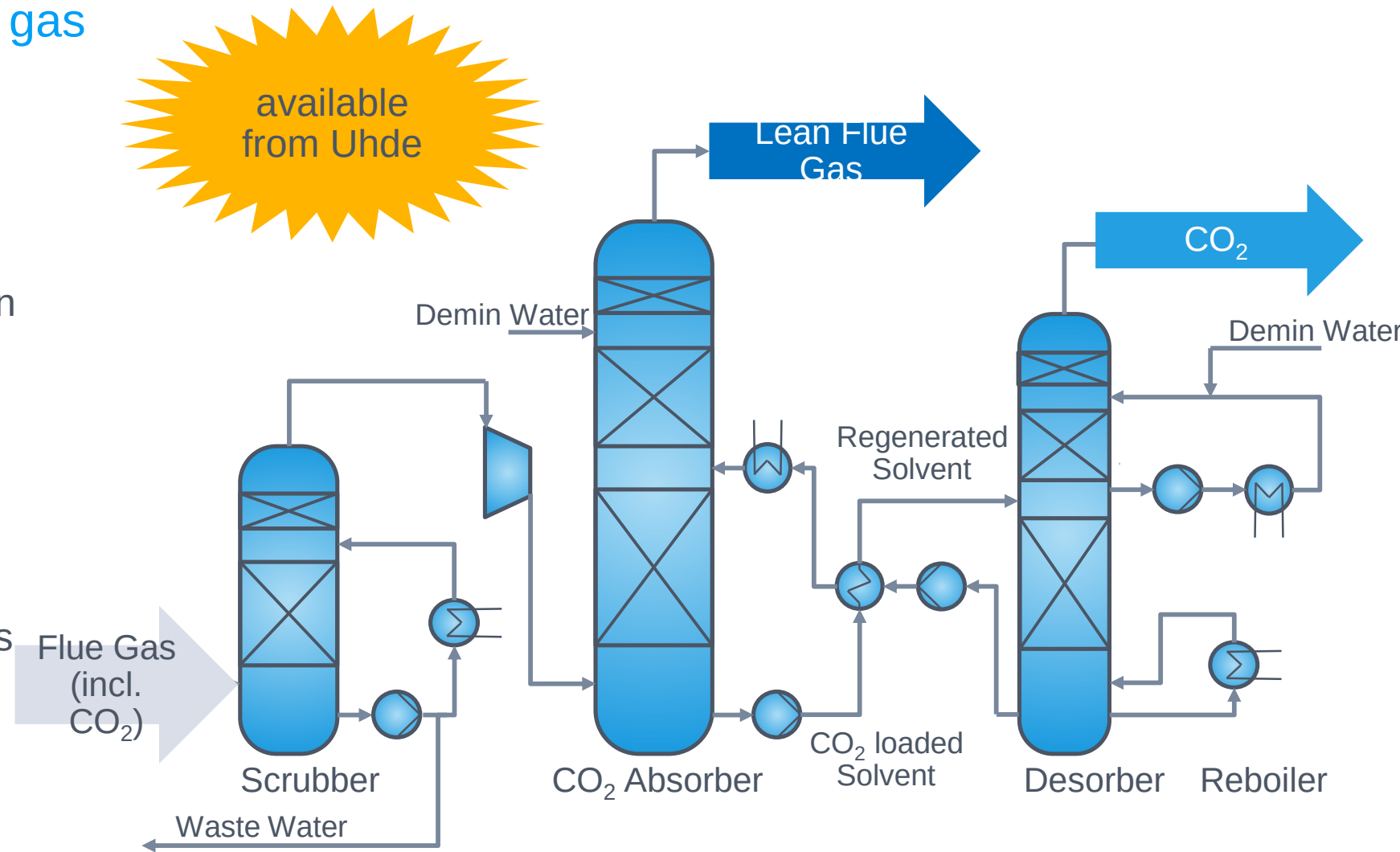
Process – design constraints

Process:

- Process based on CO₂ removal with liquid aqueous amine solution
- Composition of amine solution developed by Uhde

Design Constraints:

- Flue gas composition & quantity
- Quality requirements lean flue gas
- Quality requirements CO₂ stream
- Energy availability and cost (Reboiler)

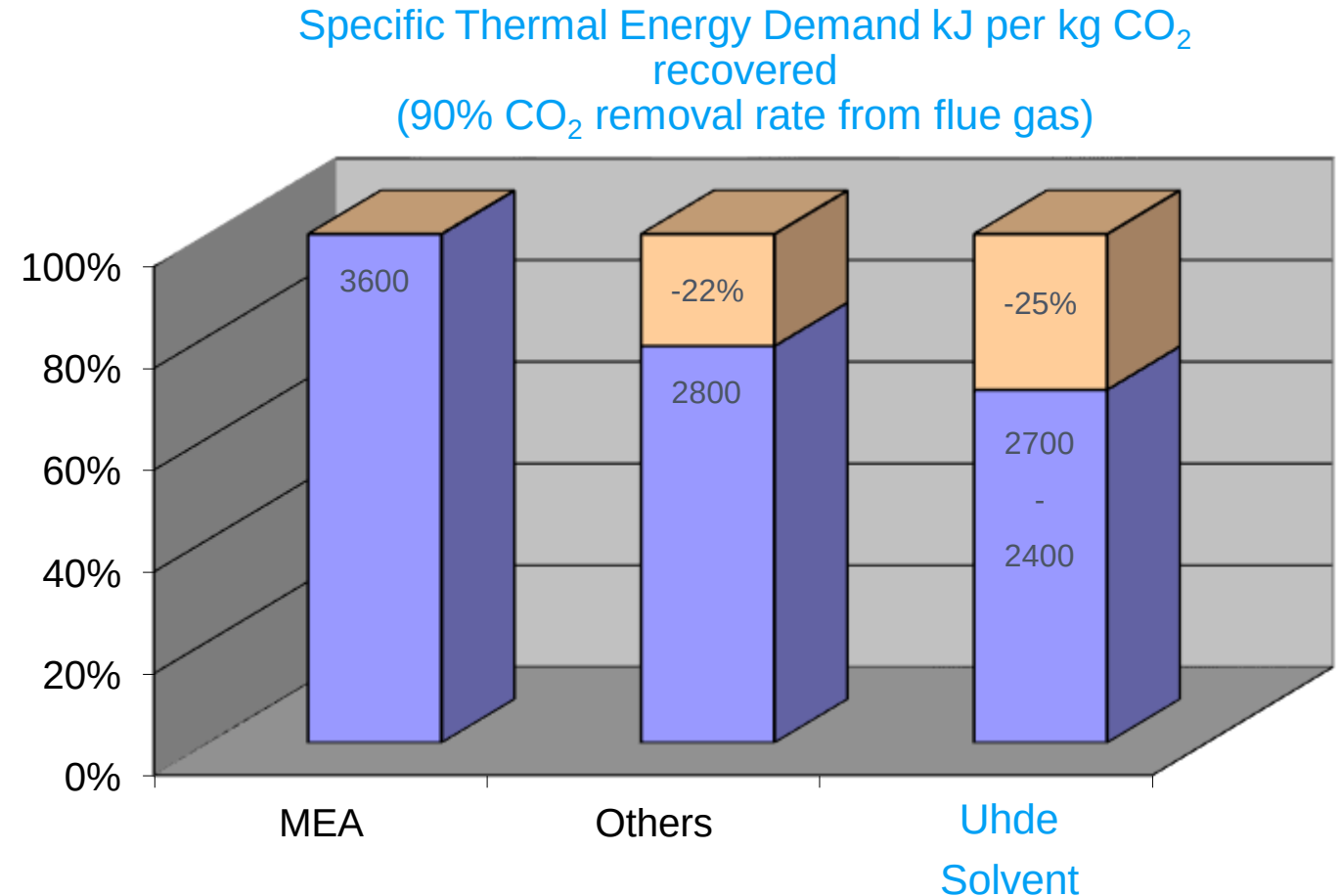
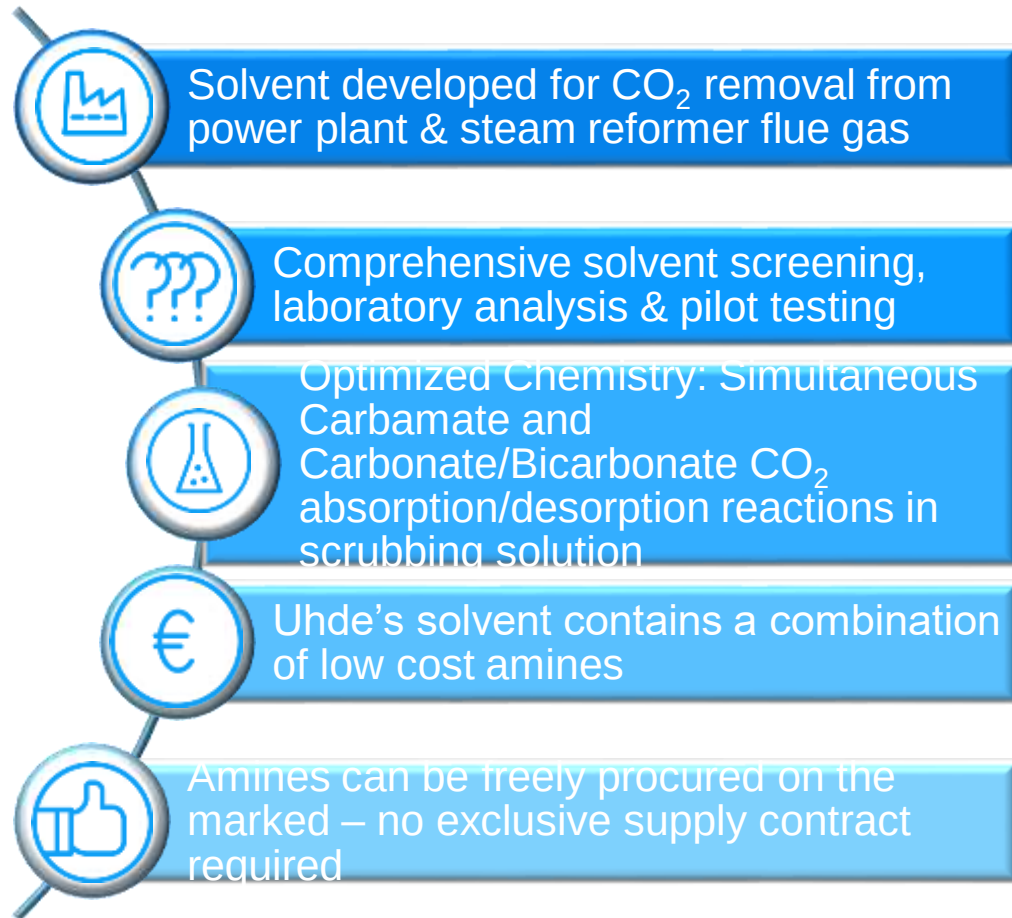


Uhde has developed its own solvent recipe based on standard chemicals



CO₂ recovery from flue gas – How?

Solvent



Uhde solvent offers low energy demand and low solvent consumption for cost effective CO₂ Recovery



CO₂ recovery from flue gas – Where?

CO₂ recovery from flue gas – mobile pilot plant

Pilot plant features

Operating pressure:	ambient up to 1.1 barg
Feed gas flow:	30 m ³ /h (STP)
CO ₂ feed gas content:	8 - 33 vol%
CO ₂ product gas flow:	equivalent to 90% CO ₂ removal
Absorber diameter:	100 mm
Height (total packing):	2 x 3,000 mm
Desorber diameter:	100 mm
height (packing):	2,500 mm
Solvent circulation	260 l/h

Gas exhauster for active feed gas flow included,
modular and fully transportable



Pilot plant at thyssenkrupp Steel Duisburg
Co-operation with Technical University of Berlin



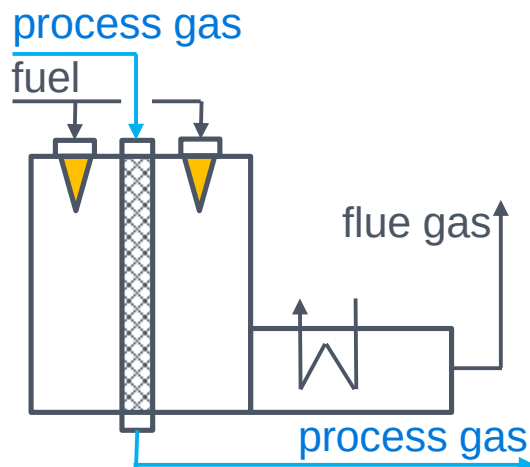
ATR introduction

Two alternative process steps for production of hydrogen from natural gas

Steam reformer (SMR):

the classic way

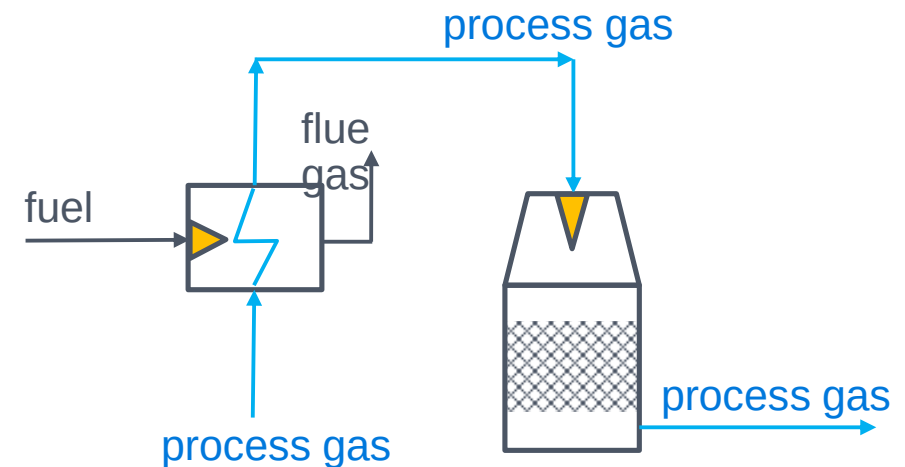
- Heat for **reforming** is supplied by combustion and **heat transfer** into the process equipment (reformer tubes)
- High amount of flue gas for preheating of inlet streams and steam superheating



Autothermal reformer (ATR):

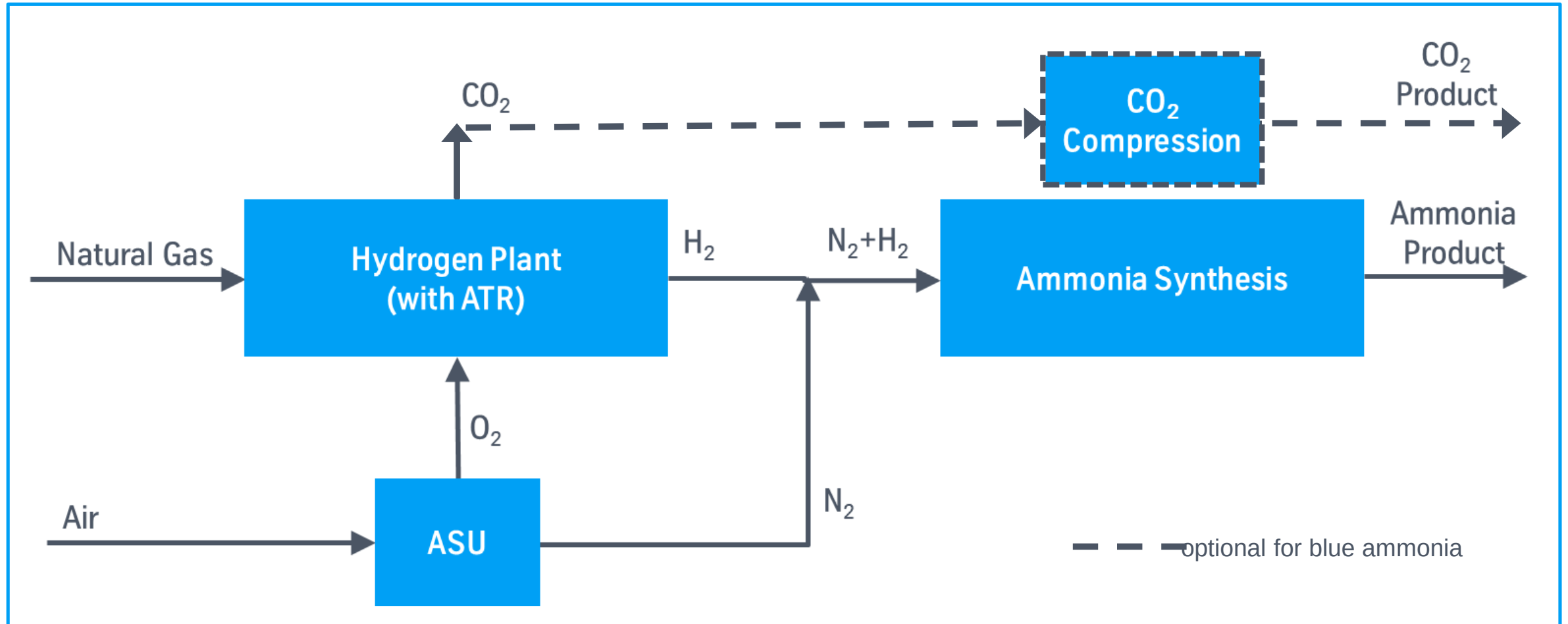
the alternative way for ammonia production

- Heat for reforming is supplied by **combustion** of a portion of the feedstock **inside the process vessel**
- Separate fired heater for preheating of ATR inlet streams



ATR introduction

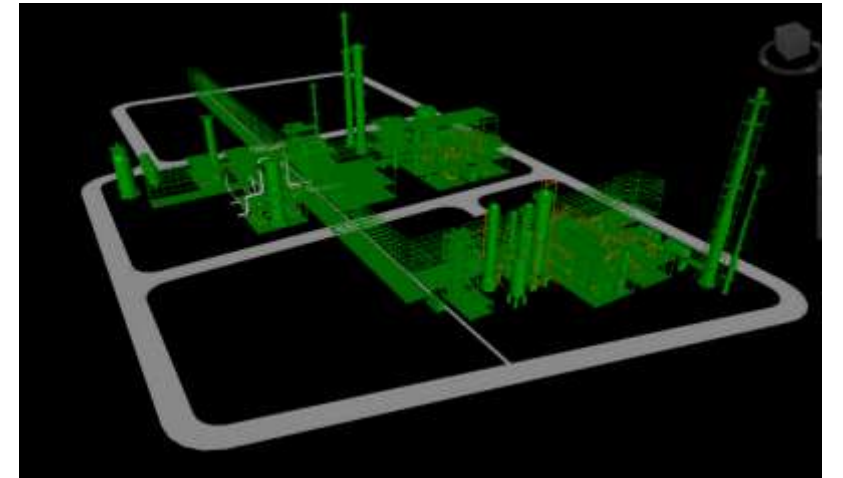
Block diagram of blue ammonia plant



ATR introduction

Process particularities

- Preheating of feedstock will be done in dedicated fired heater
- A pre-reformer is employed to pre-treat heavy hydrocarbons
- The ATR will be fired with pure oxygen
- Steam to carbon ratio can be lower than in SMR process
- Steam superheating will be done in dedicated fired heater
- Nitrogen will be added to the syngas after CO₂ bulk removal
- Synthesis makeup gas contains less inerts
- For blue ammonia applications the fuel composition becomes an essential parameter



Uhde 3D model of reference ATR project

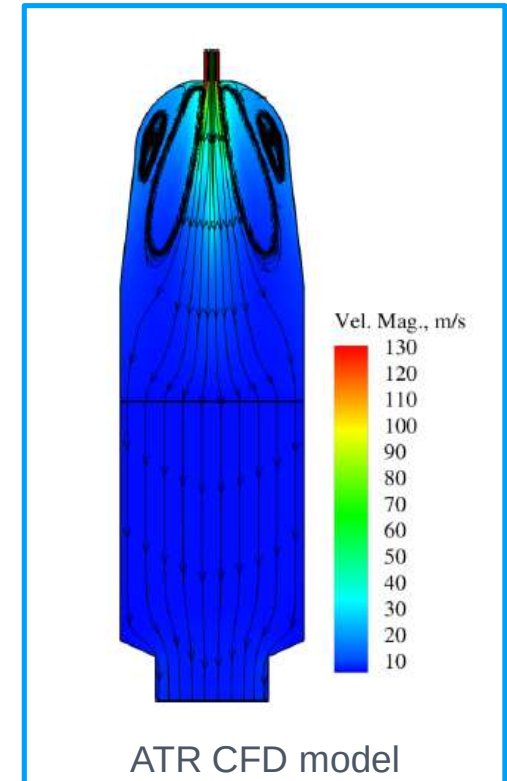
ATR process offers advantages for large capacities and high CO₂ capture rates



ATR innovations

Uhde's experiences and improvements

- The engineering works conducted during contract execution revealed a lot of challenges and pitfalls
- Solutions developed for:
 - Heat integration within the process
 - Special measures to compensate for differences in SOR and EOR conditions
 - Process startup/shutdown considerations
 - Extensive internal reuse of process condensate
 - CO₂ removal performance improvement
 - Closing the steam balance
 - Modularization and site implementation issues



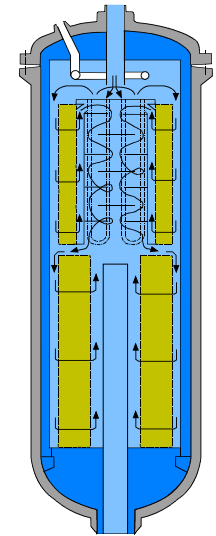
Uhde and its partner GasConTec have refined ATR burner design based on constantly validated CFD models



Ammonia synthesis

Recent Uhde innovations

- In 2022 an add-on Uhde dual pressure synthesis at Koch Fertilizer's, Fort Dodge, Iowa (USA) was commissioned successfully
- The reactor is located between the stages of the syngas compressor, operated at only 66 barg / 960 psig
- Uhde designed the cartridge to fit into a very slim existing converter shell
- High-performance catalyst Katalco™ 74-1 from Johnson Matthey is utilized
- Installation was done with the existing plant still in operation
- A contract was awarded by ISGAS/Turkey to Uhde in 12/2022 to engineer and supply a new cartridge
- Key features of the new cartridge design are:
 - Conversion from axial to radial flow, producing less pressure drop
 - Modular design: two separate beds
 - No central pipe, thus more room for high-performance catalyst Katalco™ 74-1
 - Details will be reported to you by Johannes Distler at a later presentation



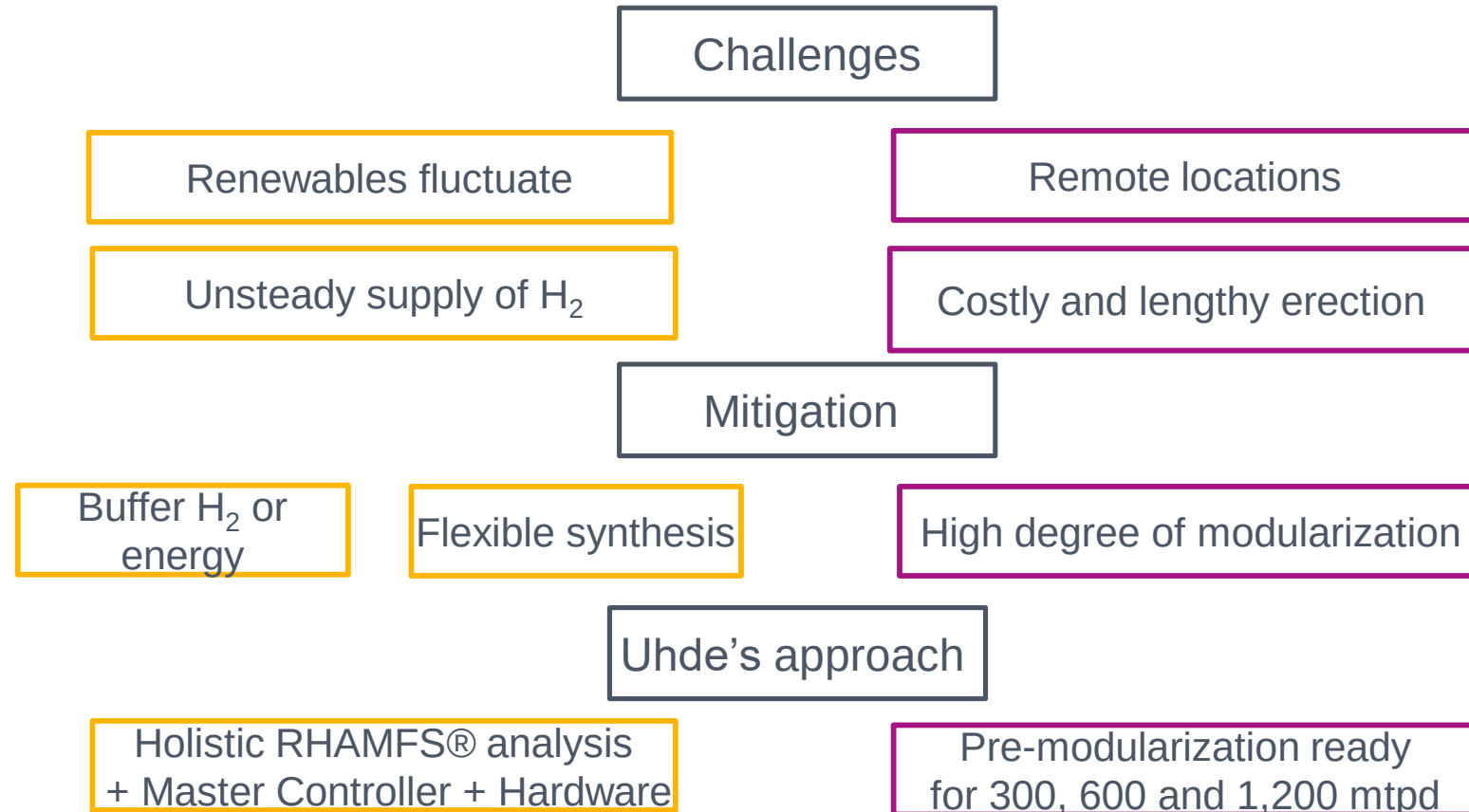
Typical Uhde 2 bed converter



Green ammonia

Recent Uhde innovations

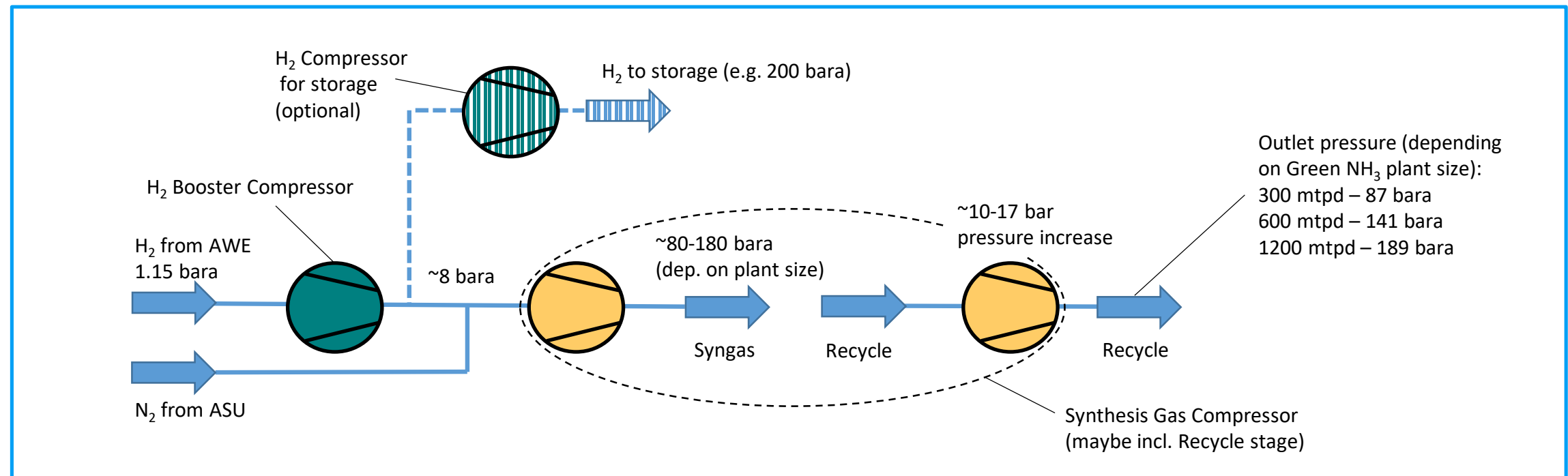
- Since 2017 Uhde is exploring the opportunity of green ammonia production by R&D and engineering activities
- Green ammonia: H₂ from renewable powered electrolysis + N₂ from ASU to Haber-Bosch-loop



Green ammonia

Compressor setup optimization: starting point

- Hydrogen from electrolysis is available at compressor inlet at 1.15 bara – H₂ Booster Compressor required (H₂ from AWE)
- Nitrogen is available after Air Separation Unit (ASU) in the range of 7-9 bara - no additional N₂ Booster Compressor required
- Synthesis gas discharge pressure / Recycle gas pressure will increase with higher plant capacities
- H₂ compressor for storage might be required depending on fluctuation of electricity – probably reciprocating type



Green ammonia

Compressor setup: investigating the options

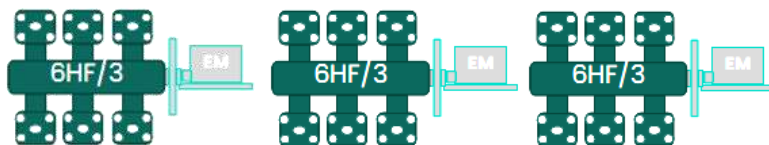
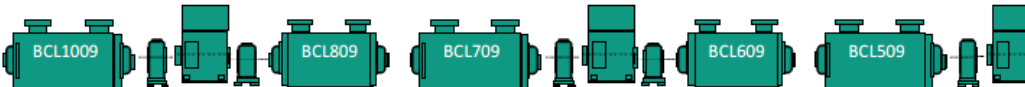
- By launching an internal R&D project Uhde investigated different compressor configurations for green ammonia plants

TON / Designation	Description	Type of machine	Vendors	Plant capacity / Project						Remark
				300 mtpd	600-675 mtpd	1200 mtpd	2200 mtpd	3300-3500 mtpd	5000 mtpd	
				Standard / Grashoek	FMG Tiger	Origin	---	3400 stand. / CIP Murch.	Study FMG Rhamfs	
1071K002 Hydrogen Booster Compressor	- H2 - In: 1,15 bara - Out: 8-11 bara	centrifugal; 2 x gear type comp. in series	MAN		high CAPEX / OPEX		1x100% or 2x50%	2x50% or 3x33%	3x33% or 4x25%	MAN design: 2 gear type compressors with 1 motor (double-end drive)
		centrifugal; inline; 3 casings	NP, (MHI from 2023, Siemens 2024)		high CAPEX / OPEX	2 casings for 1st stage / double suction?	2-3 trains in parallel	3-4 trains in parallel	5-6 trains in parallel	HPRC design (NP) or conventional with 3 casings
		reciprocating	NP, Howden, BCA, NEA	in case of redun- dancy: higher CAPEX	2 (3)x 50% (depends on redundancy)	high CAPEX				10-14 days maintenance after appr. 12,000 hours
		screw (water injected)	MAN	very high OPEX	poor references; very high OPEX					MAN design alternative
1071K001 Synthesis Gas Comp.	- Synthesis Gas - In: 8-11 bara - Out: 80-200 bara	centrifugal; inline; 3 casings	NP, MHI, MAN	investigation possible			2 e-motors / trains?	2 e-motors / trains	1 motor per casing 3 separate trains	e-motor power limited; higher capacity -> higher discharge pressure
		reciprocating	NP, Howden, BCA, NEA		less OPEX; redun- dancy -> high CAPEX					
1071K003 Recycle Compressor (or Recycle stage)	-H2/N2/NH3 - In: 80-200 bara - appr. 10-20 bar diff. pressure	centrifugal	NP, MHI, MAN	investigation possible	included in HP Casing of 1071K001 Synthesis Gas Compressor (1 impeller only)					no separate compressor
		reciprocating	NP, Howden, BCA, NEA	independent or incl. in 1071K001	independent or incl. in 1071K001					maybe included in 1071K001 (depending on vendor); suction pressure depending on capacity
1071K004 / 9561K001 Hydrogen Comp. (for storage)	- H2 - In: 8-11 bara - Out: ...	reciprocating	NP, Howden, BCA, NEA	not necessary in every project; volume flow and storage pressure depending on project requirements						
1091K001 (+ 1091U002) Refrigeration Comp.	- NH3 - LP: 1 -> 4,5 bara - HP: 4,5 -> 13-17 bara	LP + HP centrifugal	NP, MHI, MAN							1 train with 2 casings
		LP screw / HP centrifugal	JCI, Aerezener / NP, MHI, MAN							
		LP + HP screw	JCI, Aerezener		HP: 2 x 50%					oil injected screws
8851MT01 Generator Turbine	Condensing Turbine with small extraction	Steam Turbine (mfr standard, if accepted by client)	Siemens -> package NP -> Turb. / package MHI -> Turbine only	appr. 2 MW; API design not competitive	appr. 5 MW; API design not competitive	appr. 10 MW	appr. 20 MW	appr. 30 MW	appr. 50 MW	full package with generator, condenser, oil system... possible; < 10 MW: NP and MHI (API design) not competitive
	possible									
	possible, but restrictions									
	not possible or not competitive									



Green ammonia

Compressor setup: results for H₂ Booster Compressor (Example)

1:	 600 mtpd: 3x50% reciprocating	+ low power consumption for 600 mtpd + very good turndown capability + low CAPEX for 600 mtpd	- high maintenance costs – 5% / year - 15 days shutdown after 8,000 hours -> redundancy required	
2:	 600 mtpd: 4x33% reciprocating	+/- similar comments as for 3x50% reciprocating, but + modularization as pre assembled unit (PAU) possible ➤ possible concept for smaller plants / based on fluctuating energy (wind/solar)	- special e-motor design – low speed - no modularization possible	
3:	 conventional centrifugal design 1x100% (5 casings), min. 600 mtpd	+ less maintenance / high availability (4-5 years uninterrupted operation)	- higher power consump. (600 mtpd) - limited turndown (85% with VFD) - very high CAPEX	
4:	 new and exclusive design 1x100% (3 casings), min. 600 mtpd	+ less maintenance / high availability + modularization as PAU possible + lowest overall costs for 1200 mtpd ➤ possible concept for larger plants / based on constant hydropower (from 2023 on)	- higher power consump. (600 mtpd) - limited turndown (85% with VFD) - available from 2023	

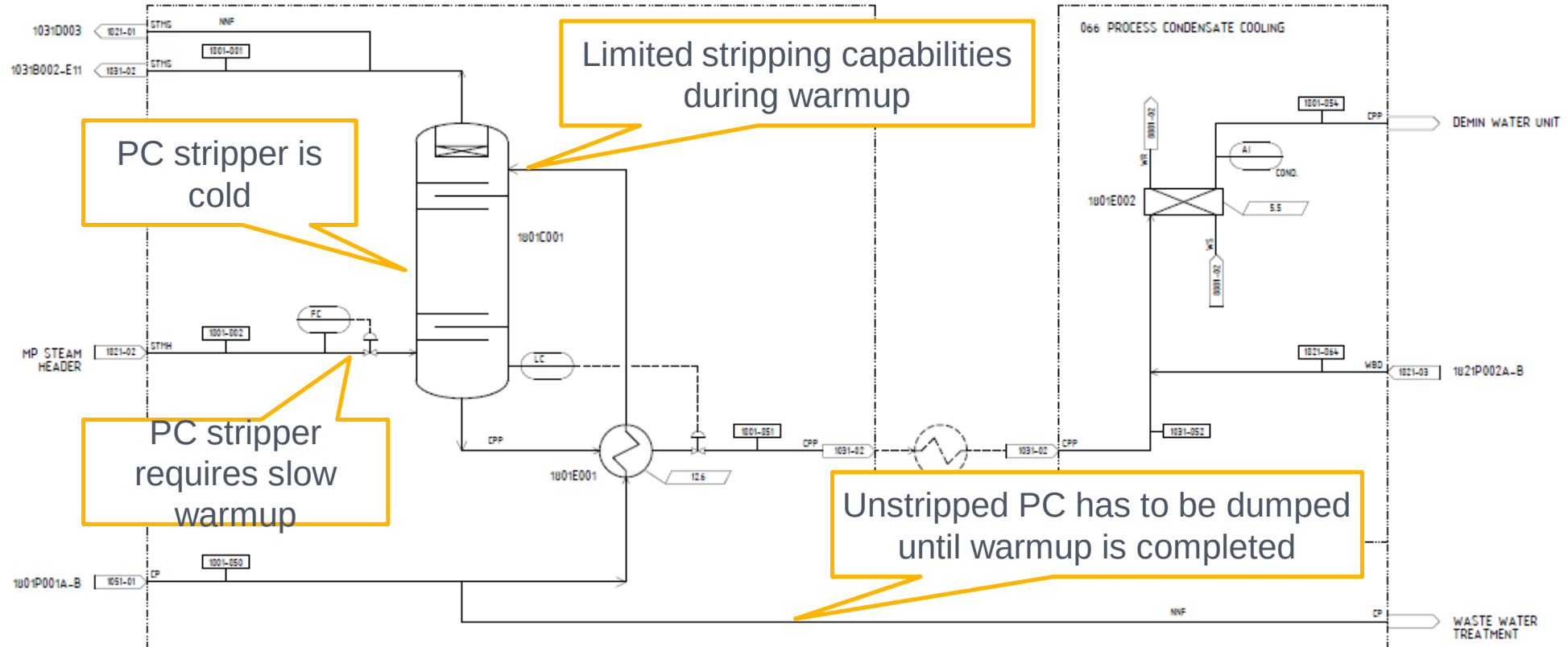
In close collaboration with a compressor manufacturer the optimum setups were developed, considering plant capacity, reference situation, efficiency, cost and modularization capabilities



Operations innovation

Solving operational problems

- A well-known problem: Startup of the process condensate stripper



PC: Process Condensate

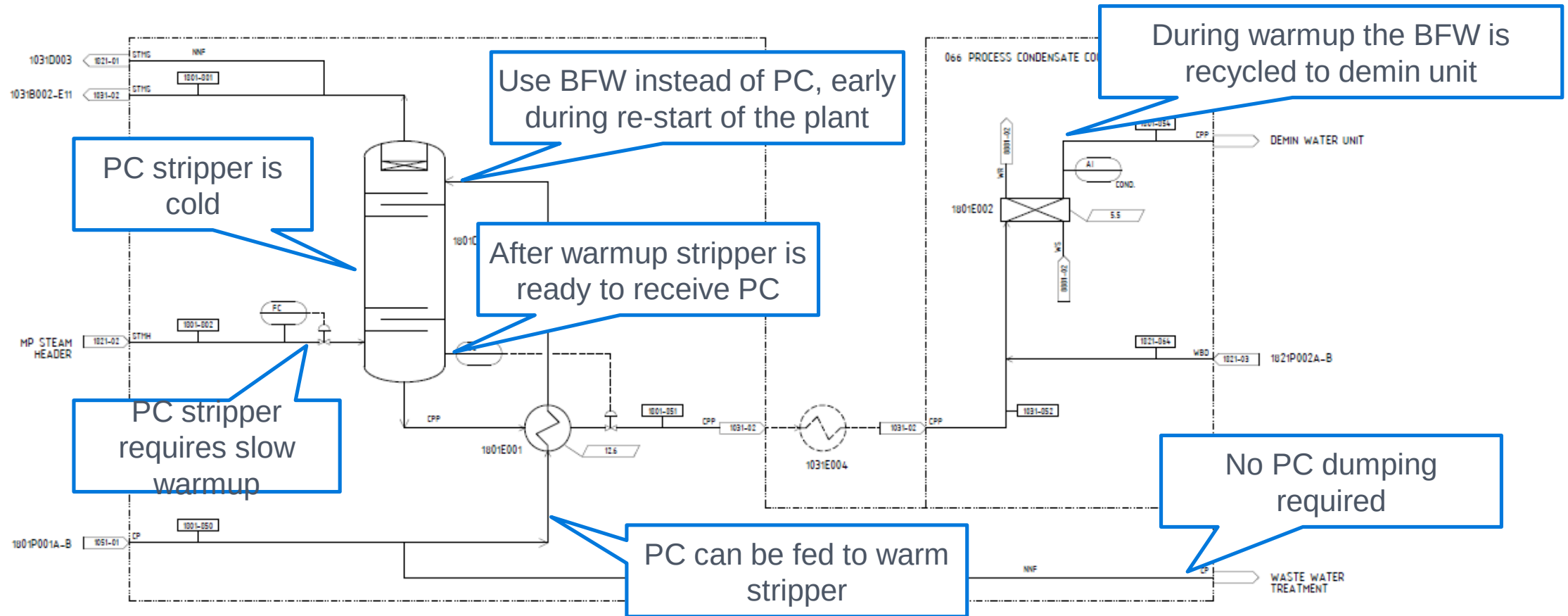


Operations innovation

Solving operational problems

- An innovative way for startup of the process condensate stripper

Uhde patent
pending:
EP 4 129 894 A1
US 2023/0044089
A1



Thyssenkrupp Uhde as a supplier – Benefits for customers

Access to the global procurement organisation of Uhde:

The SMR process is very mature.
However, there is still room for
improvements

thyssenkrupp Uhde has
technology available for CO₂
recovery from SMR flue gas

Blue ammonia projects based on
ATR are under execution and the
technology will gain importance
in the near future

Green ammonia technology has
some challenges that needs to
be tackled

Through experiences gained at
site combined with intensive
R&D thyssenkrupp Uhde
develops real benefit for the
customer

thyssenkrupp Uhde is your
partner for conventional, blue
and green ammonia and for
tailor made technical solutions



Thank you for your attention



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www.linkedin.com/company/uhde-gmbh/

Uhde Services Portfolio Update

Uhde Ammonia Technology Users' Group Meeting

Munich, August 22nd 2023 | Guenter Voelker | thyssenkrupp Uhde



engineering.tomorrow.together.

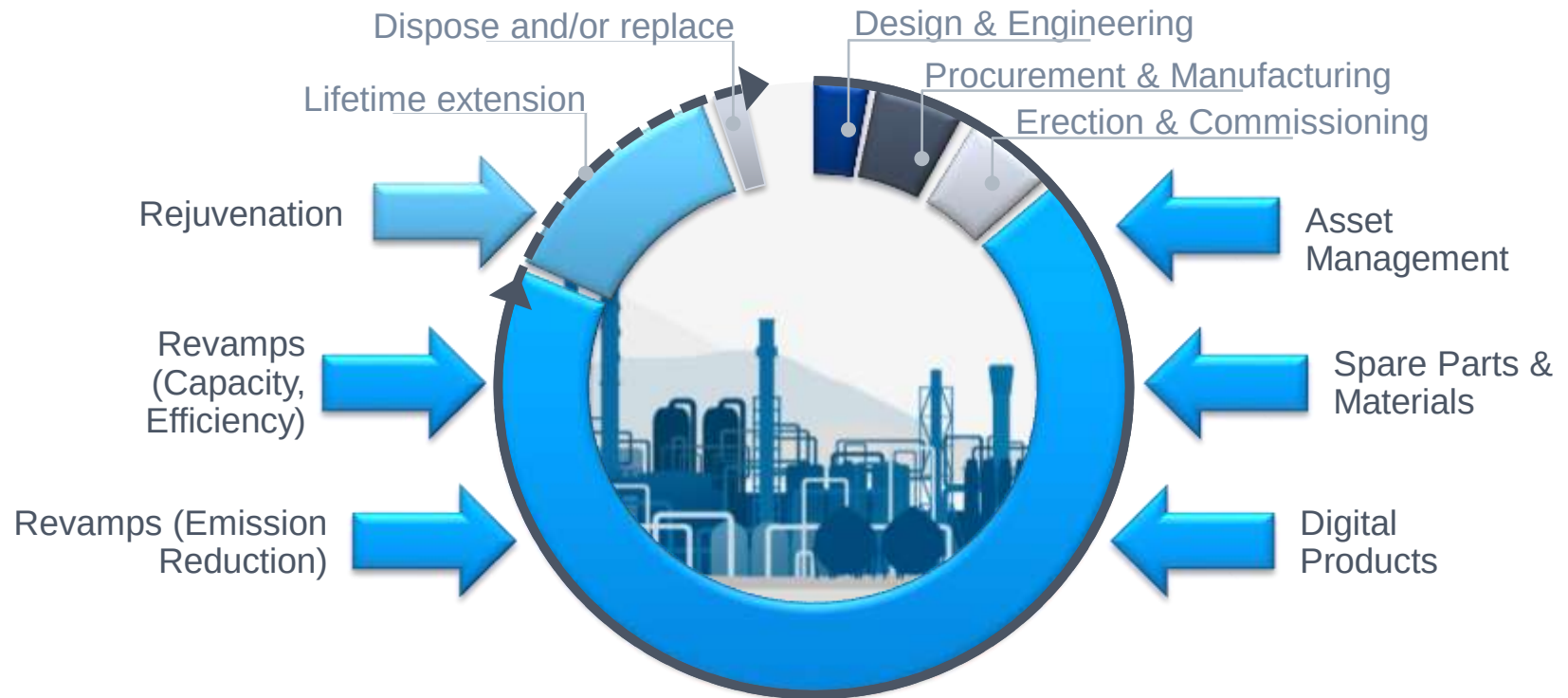


thyssenkrupp

Uhde Services Portfolio Update

Lifecycle Services by Uhde's global Service & Operation Team for existing Fertilizer plants

- Our Service teams deliver technical solutions over the complete plant lifecycle to improve our customers' competitiveness - that's what we call 360° Service.
- Worldwide more than 100 experts are dedicated to Service Fertilizer.
- Our focus is on optimizing our customer's profit and risk – creating a win-win situation and trustful partnership



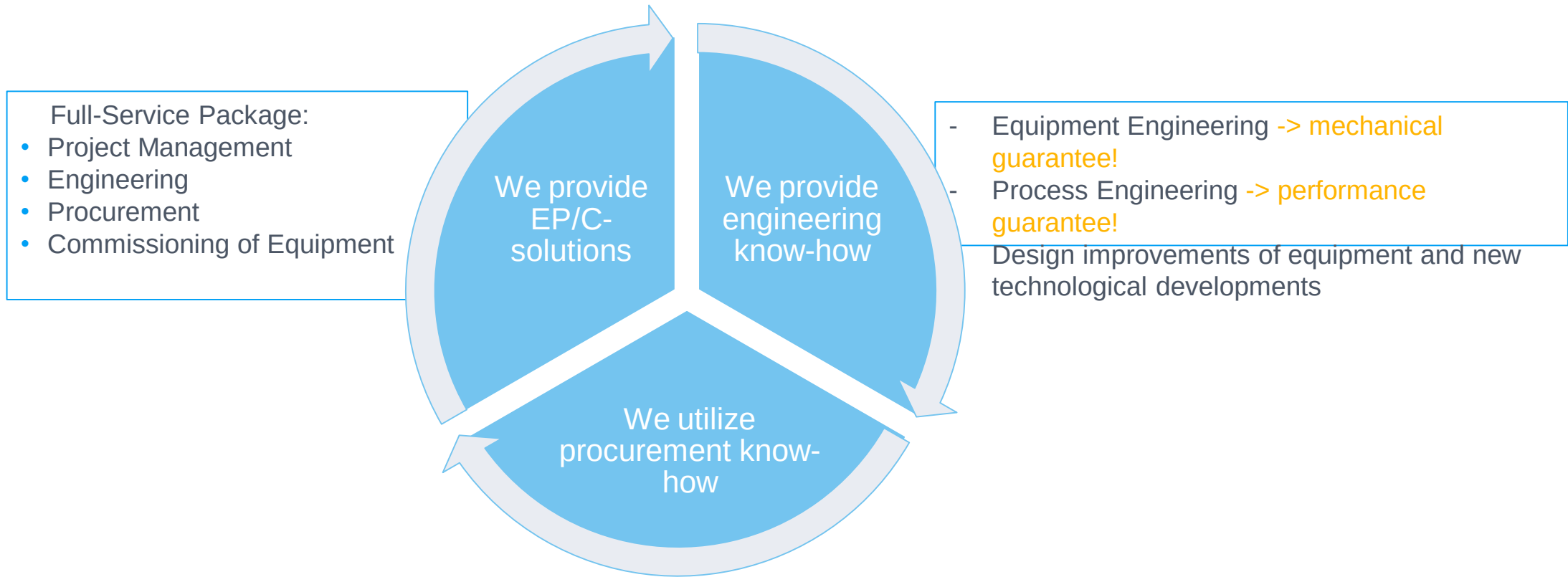
Service solutions along the entire plant life cycle to enhance our customers' competitiveness

That's what we call 360° Service



Engineering and Supply of Equipment and Spare Parts

thyssenkrupp Uhde as a Supplier – Benefits for Customers



Customers benefit from Uhde's design know-how and experience



Thyssenkrupp Uhde as a supplier – Benefits for customers

Access to the global procurement organisation of Uhde:



Professional buyers, quality inspectors and logistics experts ensure reliable, quality-conscious, global, just-in-time sourcing



Extensive expediting and inspection → Guaranteed delivery time and quality !



Long-term relationship with manufacturers for critical equipment



Emergency supplies due to excellent contacts with suppliers



Favourable purchase conditions due to huge purchasing volume

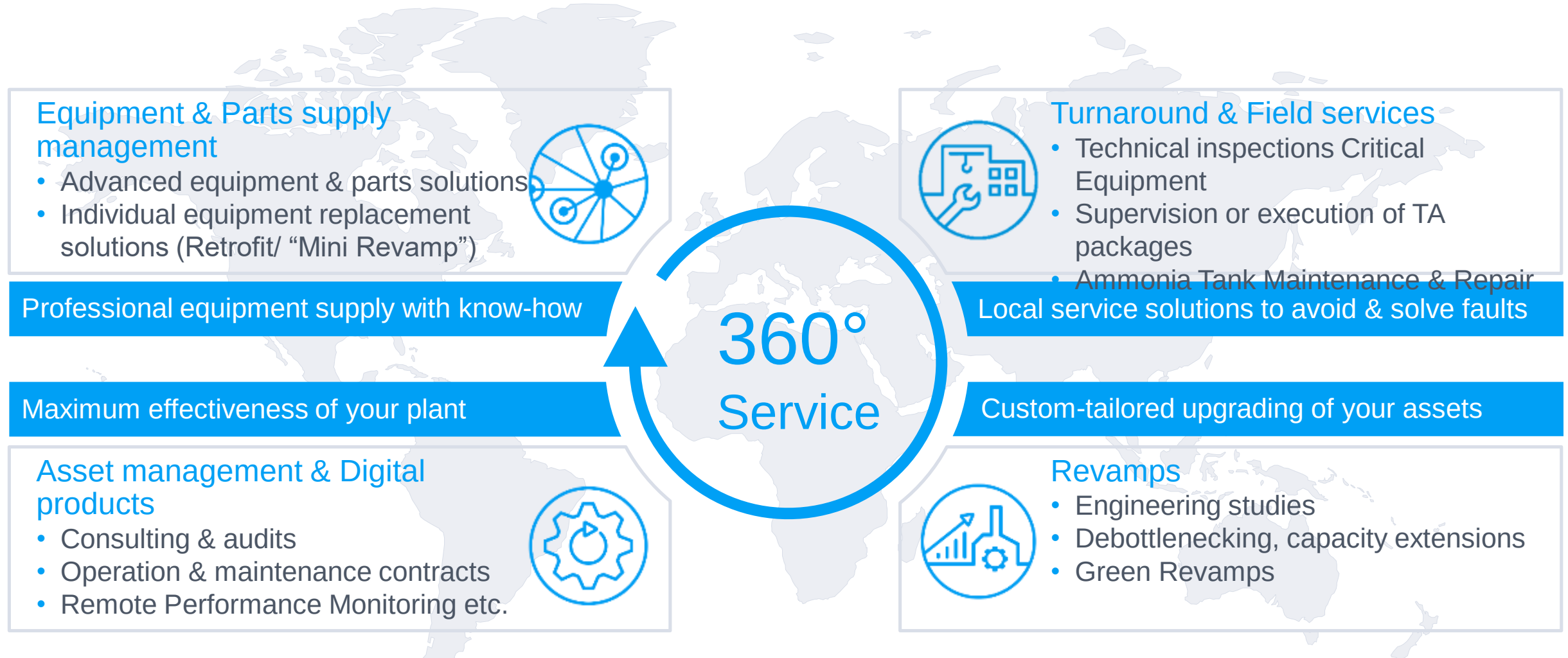


Knowledge of strengths and weaknesses of manufacturers



Service solutions along the entire plant life cycle to enhance our customers' competitiveness

That's what we call 360° Service



Plant digitalization

Portfolio of digital products to improve operation & maintenance of chemical plants



Data Analytics & Consulting

- Connectivity set-up & remote expert support
- Report & consulting/remote performance monitoring



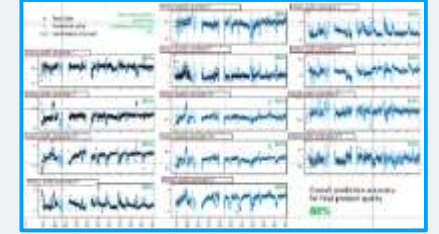
Digitalized Maintenance

- Remote inspection
- (thermal) drone inspections
- Plant scan 3D
- Digital service sticker
- Professional spare part navigator
- Remaining lifetime prediction
- Workflow automation app
- Automated machine monitoring
- Computer vision



Predictive Operation

- AI assistant (open-loop)
 - Maximization of production
 - Reduction of energy and raw materials consumption
 - Product quality enhancement
 - Emission reduction
- Operator training simulator



Performance Optimization

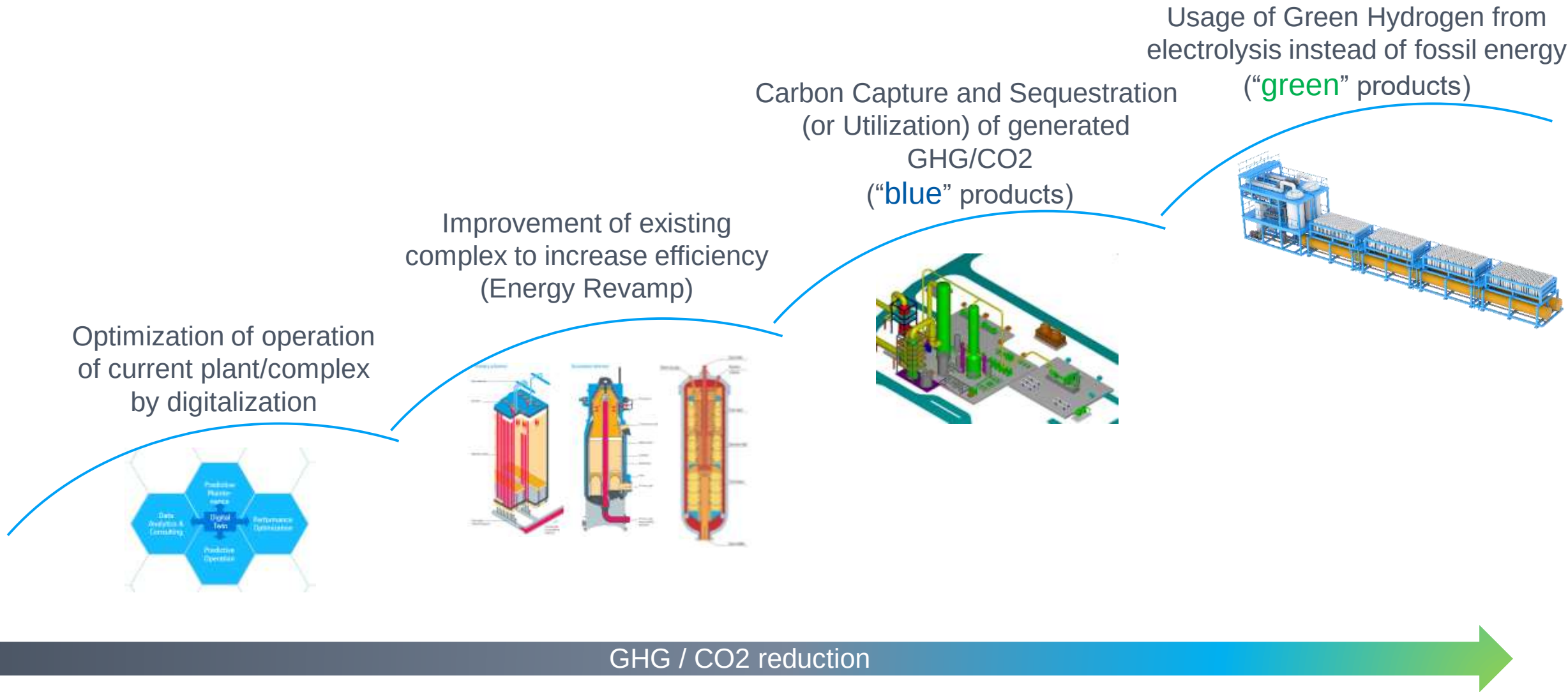
- AI controller (closed-loop)
 - Similar functionality as for AI assistant
- Advanced process control

DIGITAL TWIN



Transition from conventional (gray) to sustainable (blue and green) Ammonia and Fertilizers

Different revamp options for existing plants to reduce GHG/CO2 emissions



Uhde Services Portfolio Update

Today's focus: New Service Products in Workshop Room 2

- Optimize fertilizer production by plant digitalization incl live demo
 - Remote Performance Monitoring
 - Digital Twin
- Proprietary Equipment Designs to improve energy efficiency / Updates on Equipment Design
 - New Ammonia Converter Design
 - New Design Features in Reforming Section
- Ammonia Process Revamp Options
 - Revamp with Green Hydrogen
 - Revamp to reduce CO2 emissions





Thank you for your
attention



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Johnson Matthey
Inspiring science, enhancing life

Catalyst performance optimisation tk Uhde users meeting

John Brightling

23rd August 2023 – Munich

1998 – 2023 celebrating JM-uhde collaboration

Silver Anniversary



Plant	Country	Ammonia, tpd	Start-up
EFC 1	Egypt	1200	1998
Abu Qir 3	Egypt	1200	1998
QAFCO 4	Qatar	2000	2004
Tecen	Turkmenistan	600	2004
SAFCO 4	Saudi Arabia	3300 (3670)	2006 (2017)
EFC 2	Egypt	1200	2006
Alexfert	Egypt	1200	2006
Helwan	Egypt	1200	2007
MOPCO	Egypt	1200	2009
ENPC	Egypt	2x1200	2016
Ma'aden	Saudi Arabia	3300	2011
SORFERT	Algeria	2x 2200	2012
Fertil	UAE	2200	2013
CF Donaldsonville	USA	3300	2016
CF Iowa	USA	2200	2016
Ma'aden 2	Saudi Arabia	3300	2016
BFI	Brunei	2200	2021
Ma'aden 3	Saudi Arabia	3300	2022
NCIC	Egypt	1200	2023
QAFCO 7	Qatar	3500	2026



Ammonia expertise

- **Reliable performance products supported with deep technical know-how**

KATALCO catalyst & absorbent technology support



Experience:

Deep understanding of catalysts in uhde® ammonia process.
>100 years ammonia expertise



Global:

Regional offices networked to share best practice and experience
Range of engineering skills within team pool



Catalysis:

Proven robust catalysts on all process duties.
Tailored solutions for uhde® process design



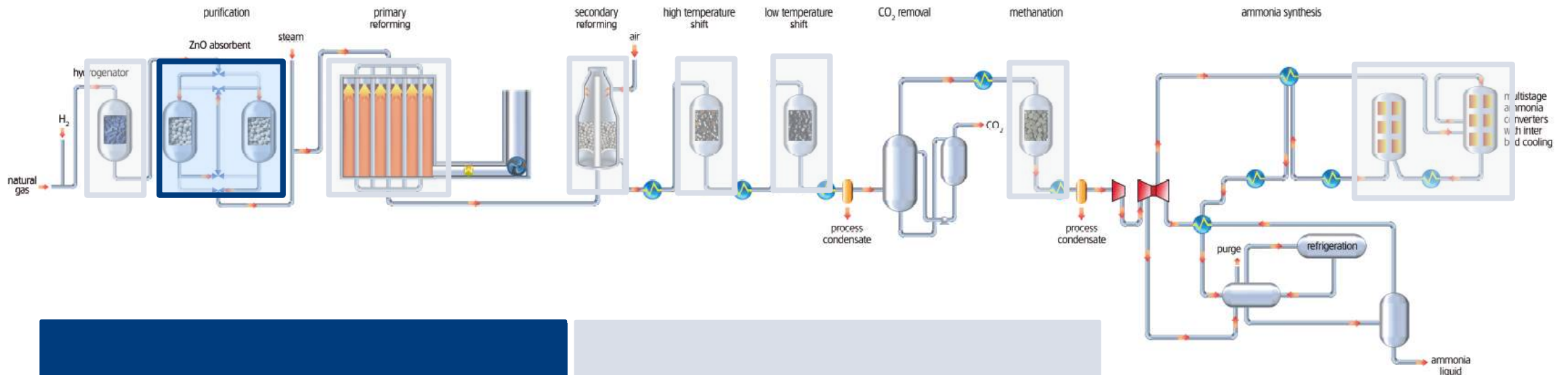
Technical support:

On-site/remote SME troubleshooting; technical training; plant optimisation & start-up support

Underpinned by catalyst science, engineering and relevant operations knowledge



KATALCO absorbents and catalysts within uhde® flowsheet



Absorbents



Hg removal (if present)
S removal (ZnO)

Catalysts

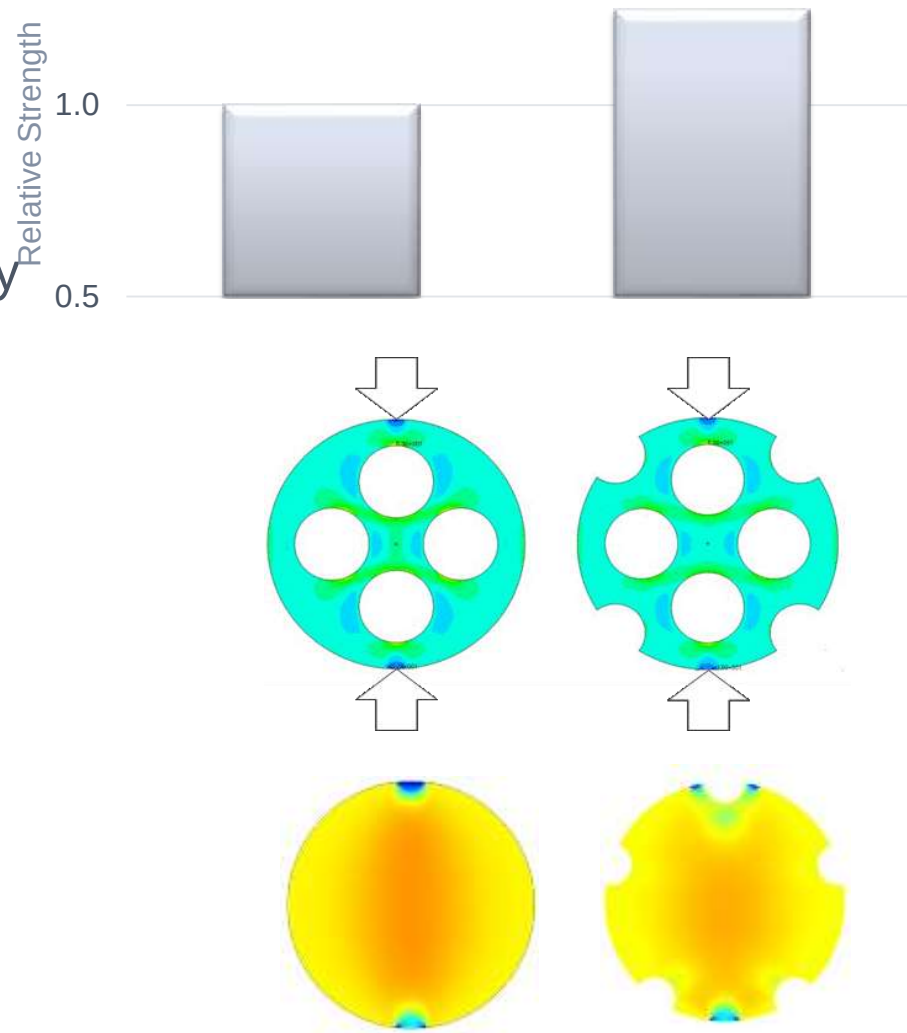


Hydrogenation
Reforming
High & low temp. shift
Methanation
Ammonia synthesis



KATALCO product developments/improvements over 25 years

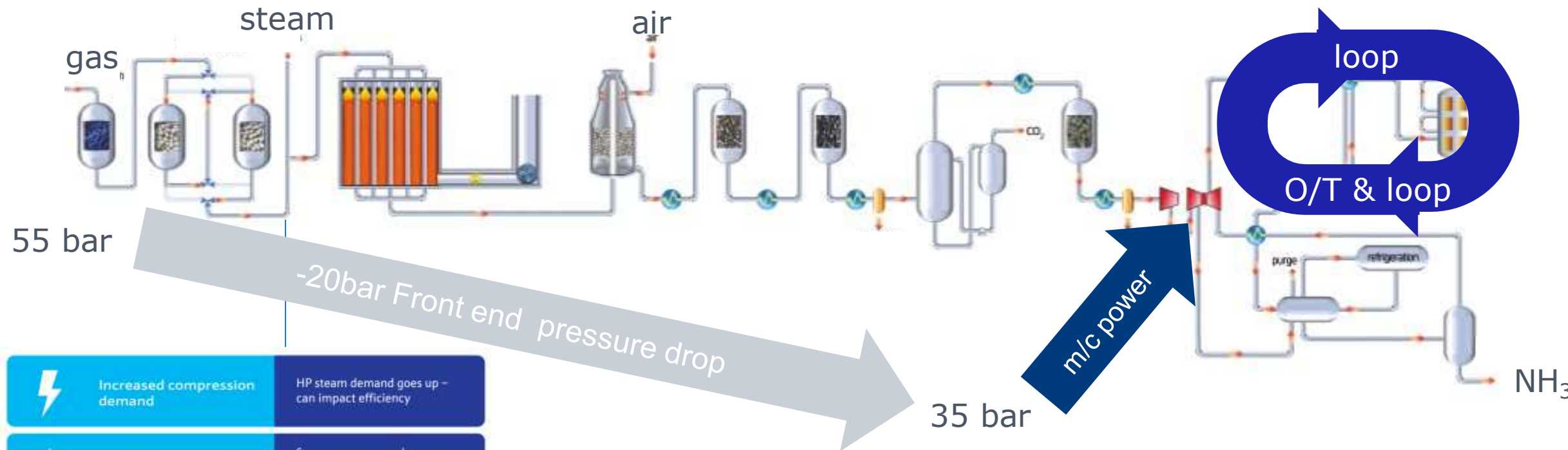
- Improvements in
 - pellet design
 - manufacturing technology
- Resultant catalyst shapes provide
 - strength increase
 - lower pressure drop



Duty	Change
HDS	Shaped
Primary	Q-shape
Secondary	Q-shape
HTS	F-shape
Methanation	MC-shape



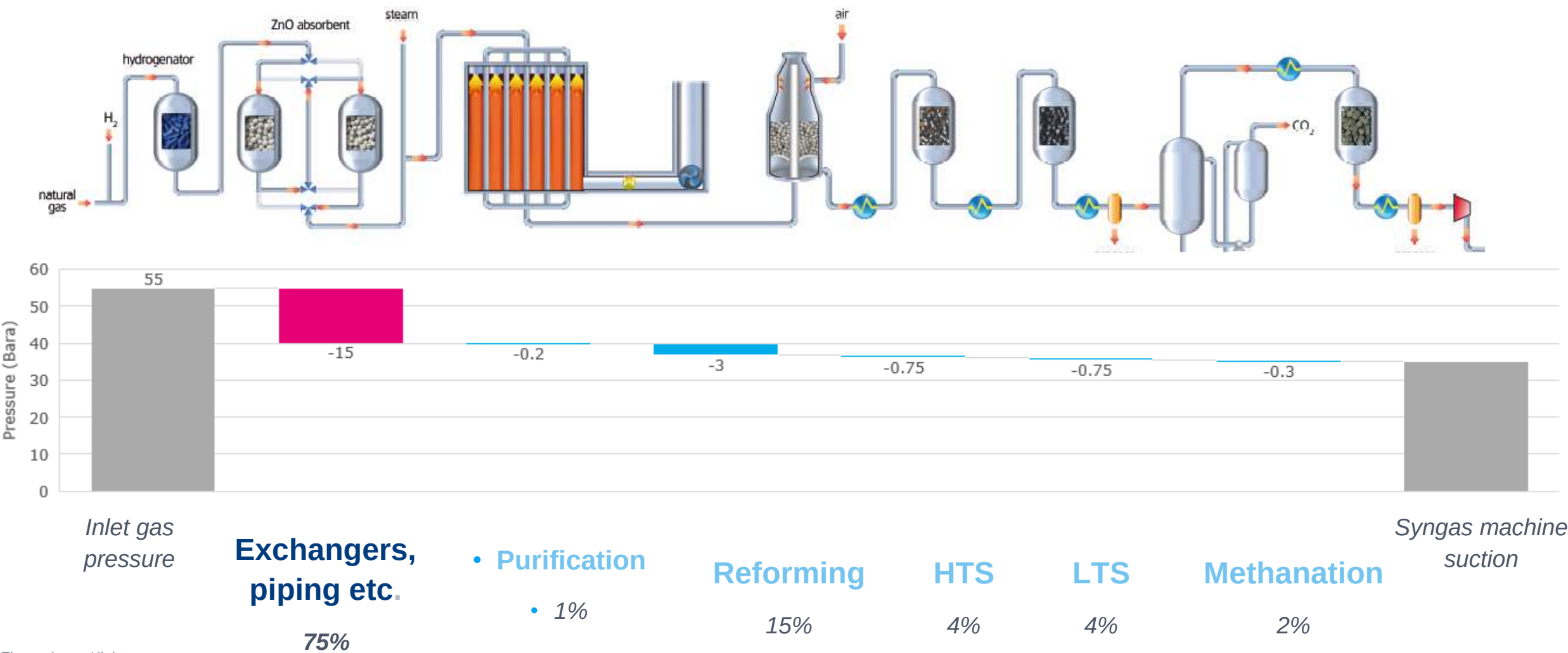
Pressure drop across the front end of uhde® flowsheet



⚡	Increased compression demand	HP steam demand goes up – can impact efficiency
💧	Ammonia production decreases	Syngas compressor becomes maxed out and ammonia loop pressure decreases
⚠️	Upstream relief valves	Increasing upstream pressure limited by RV set point

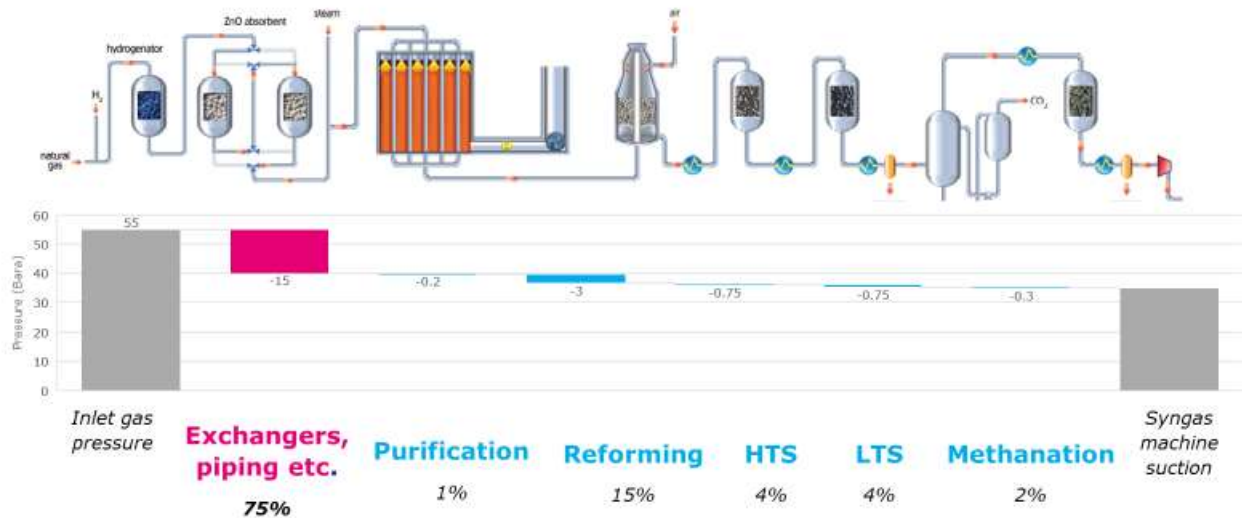


Pressure drop across the front end of uhde® flowsheet

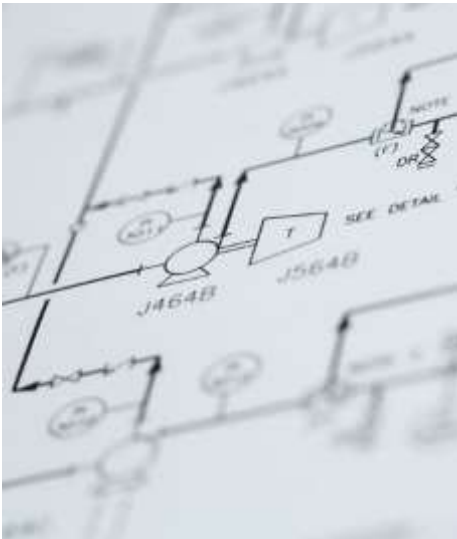


Pressure drop consideration at plant design stage

Front end pd	%
Exchangers, piping etc	75%
Purification	1%
Reforming	15%
HTS	4%
LTS	4%
Methanation	1-2%



- Focused a specific **fixed throughput**
- Exchangers and line sizing matter most - they have biggest **impact on CAPEX**
- **Reforming p.d. useful** for to achieve even distribution, achieve good heat & mass transfer
- **Other catalyst p.d.** has only a **minor impact** on flowsheet



Pressure drop considerations in operation

- **Maximise return on asset; pressure drop is a restriction**
- **Increase plant rate** is as much as possible
- Push until **rate limited** by relief valve or compressor power
- Without a revamp **catalyst p.d.** is **only variable** and is **easy to measure**
- *Therefore plant is always **limited by catalyst p.d.***



Pressure drop – catalyst important

Range of tools and types to optimise

- **Catalysts** must satisfy both **designer and operator** needs
- **Different sizes, catalyst shapes** and **loading options** - available to **reduce catalyst p.d.**
- **Design tools** for **value adding solutions**
- **Catalyst p.d.** reduction – **throughput impact** for constant p.d. through front end of plant

Catalyst p.d	Flowrate
100%	100%
50%	104%
0%	109%

Assuming air compressor limit, matching 9bar p.d. from primary to Syngas machine suction



Catalyst p.d. desired characteristics

Start as low as possible , increase as little as possible

Start of run p.d.

- Catalyst shape
- Strength at loading
- Loading care/control
- Start-up/reduction
- Support media loading
 - e.g **STREAMLINE™**

Rate p.d. change

- Strength in-service
- Breakage characteristics
- Operational stability
- Transients

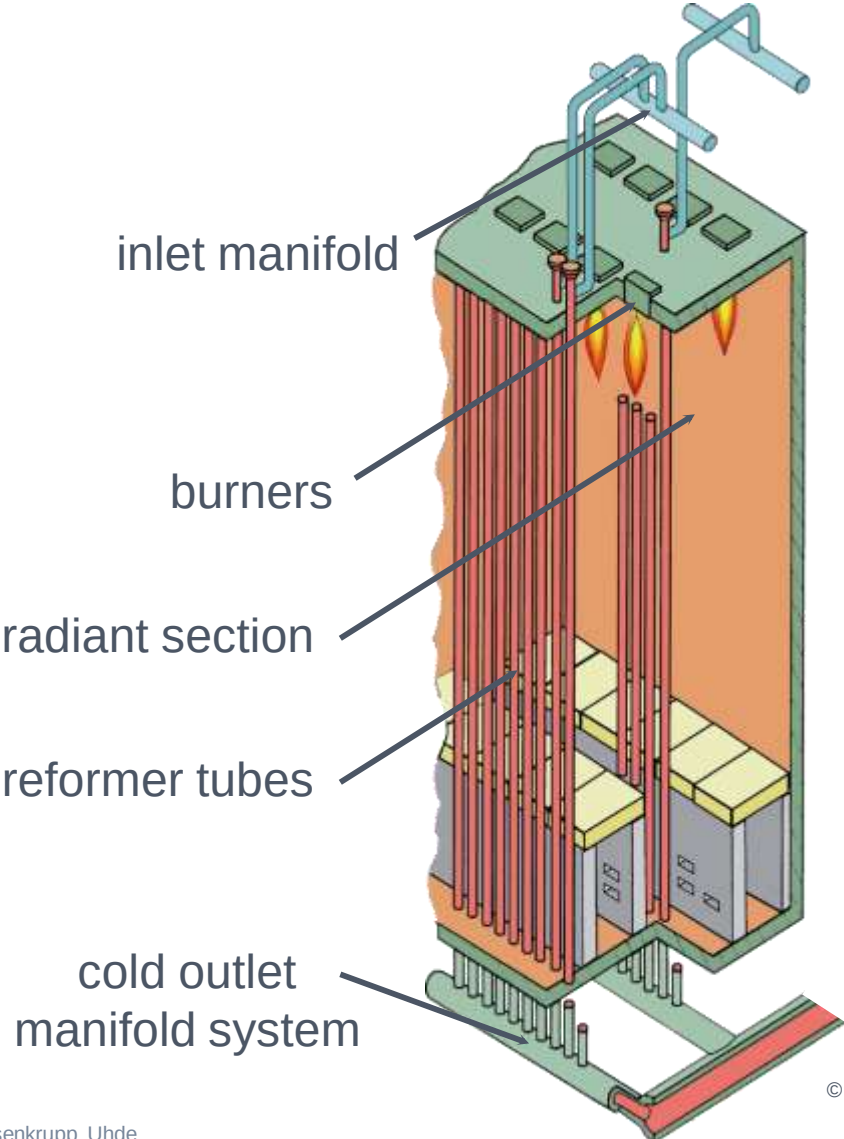




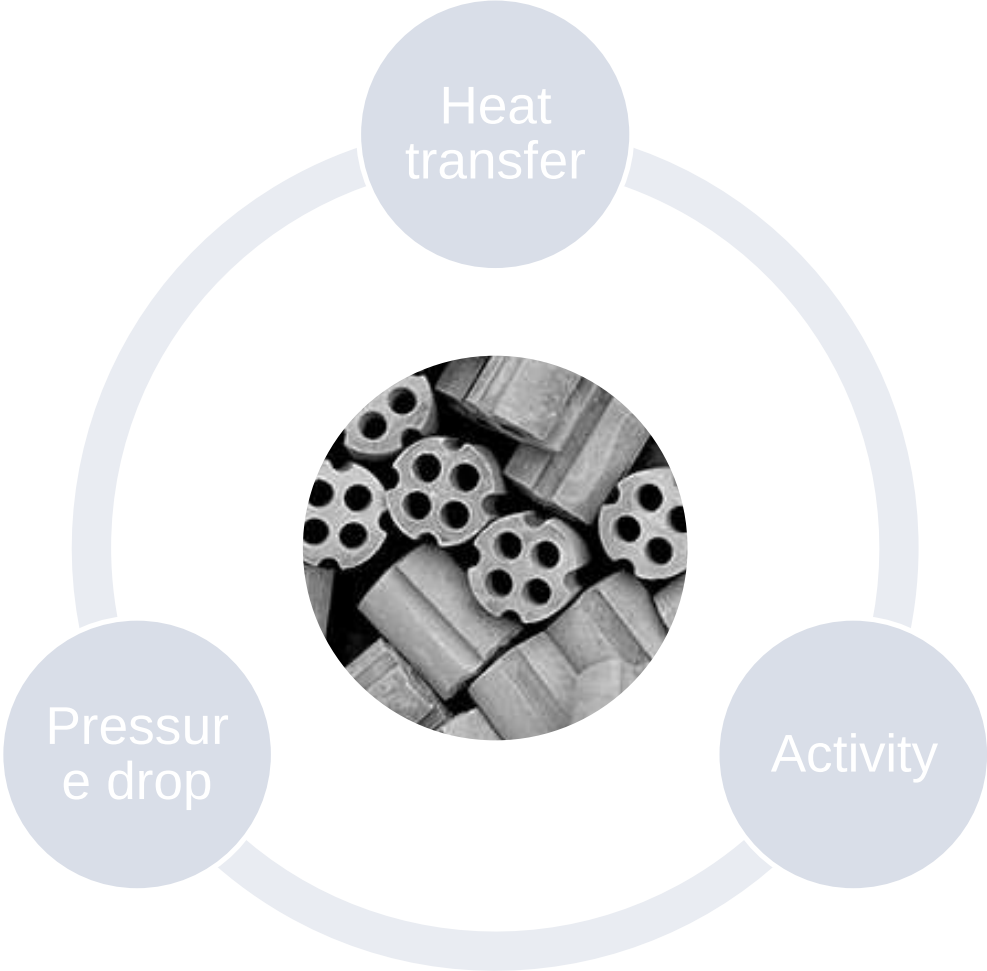
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Primary

Primary reforming catalysts

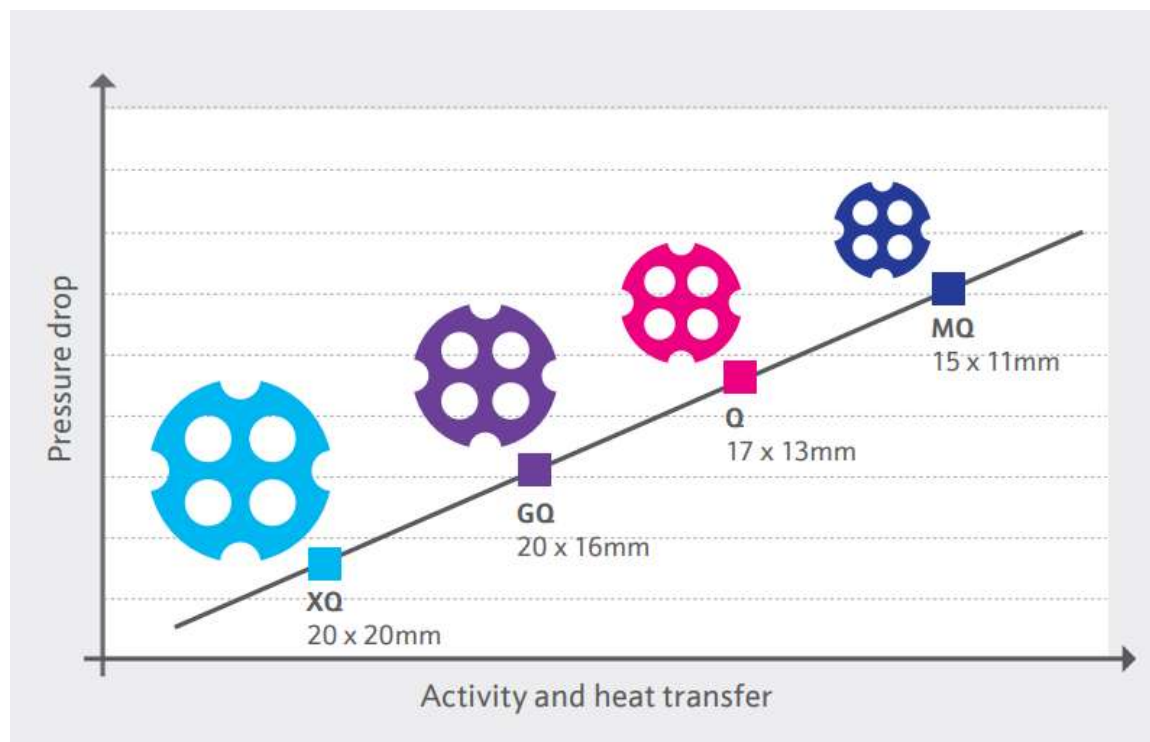


© tk uhde

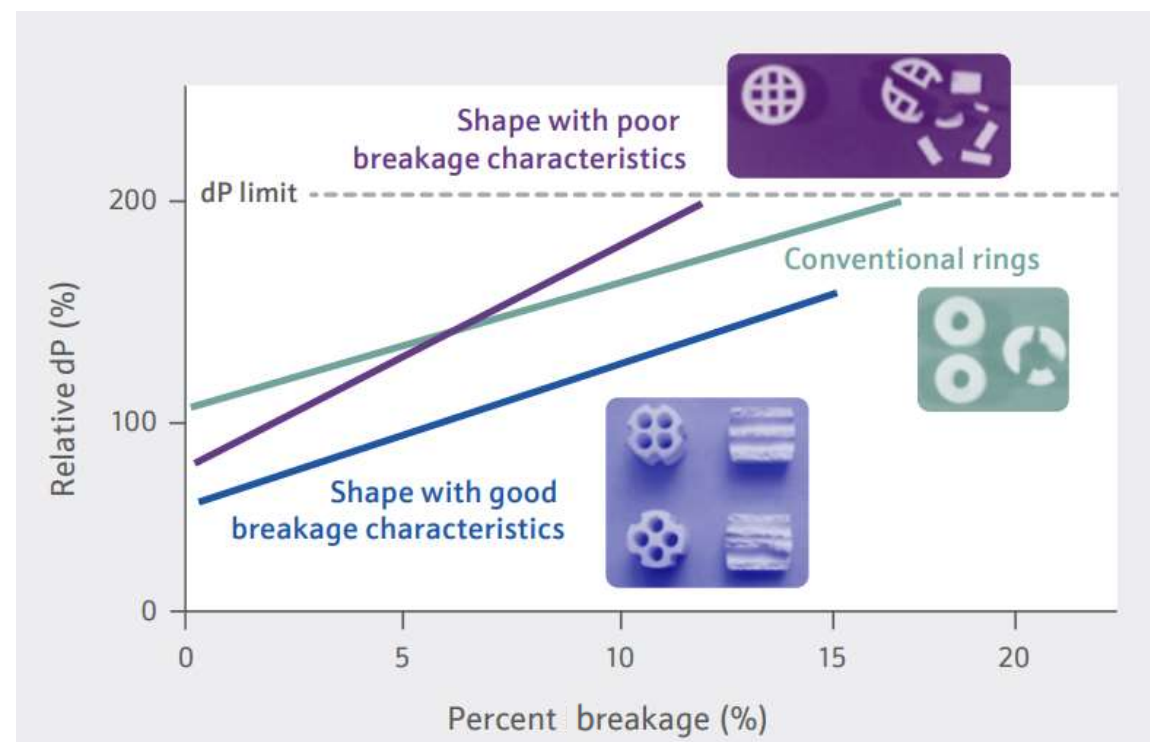


Primary reforming – KATALCO QUADRALOBE

- Widest product range of shapes
- Tailored design loadings



- Engineered pellet breakage
- Slowest rate of p.d. growth





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Shift section

Pressure drop solutions in WGS

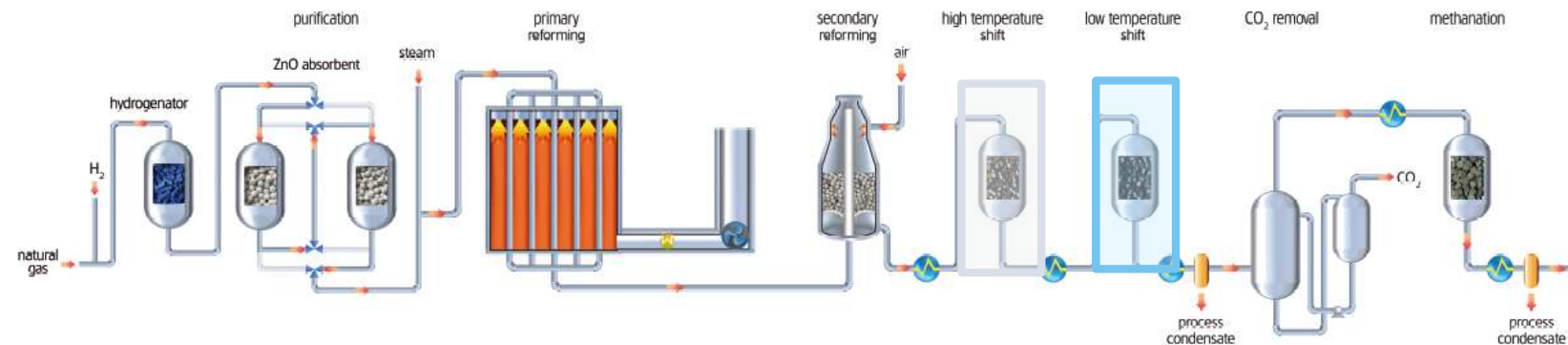
JM

Leading Water Gas Shift Solutions

Structure, sturdiness and strength



Johnson Matthey
Inspiring science, enhancing life



HTS

- Unique patented F-shape
- Strongest HTS available
- Lowest p.d. in-service

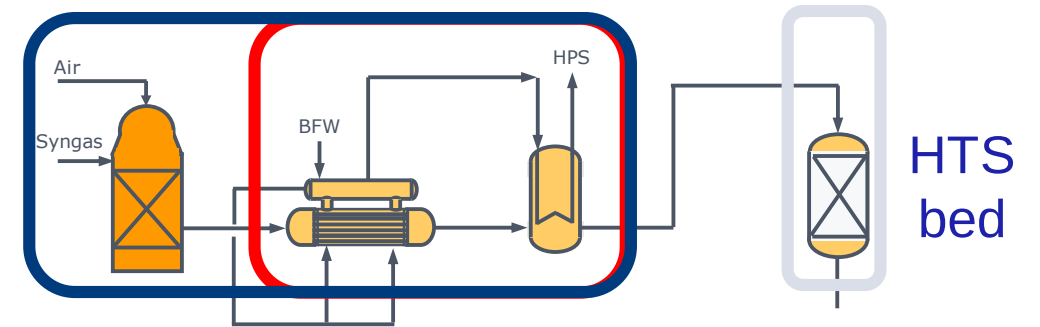
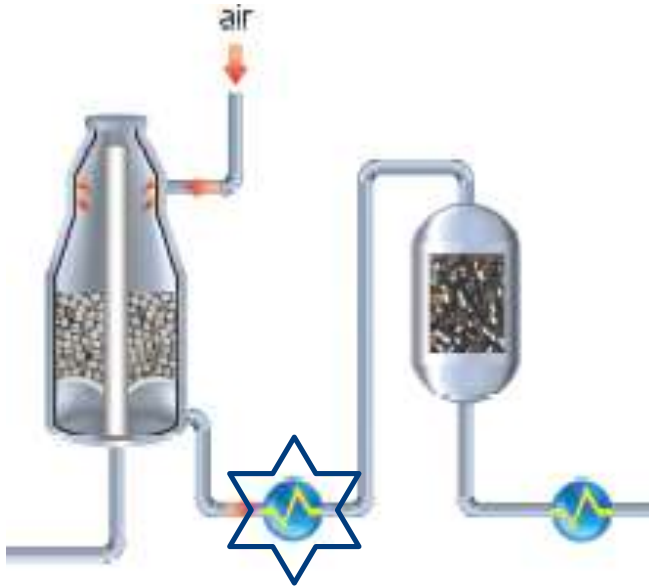
LTS

- Market leading LTS
- Strongest LTS available
- Most stable p.d. in-service



HTS challenging duty

1st reactor in line after high grade heat recovery

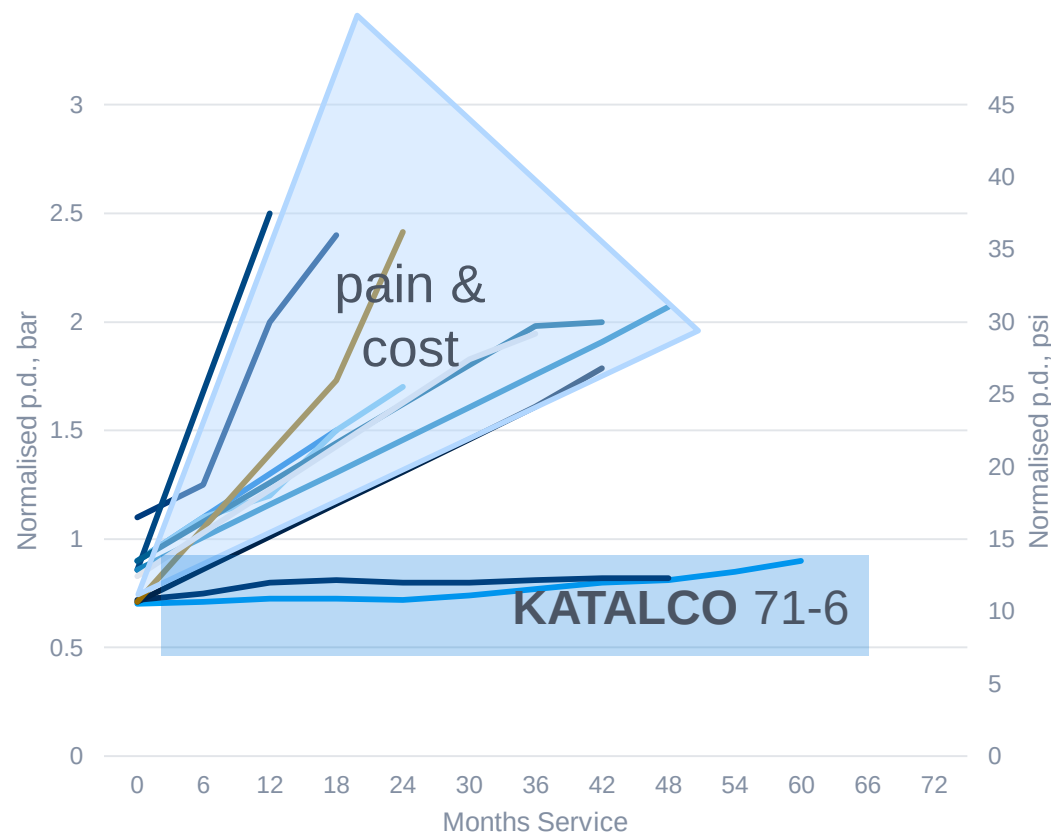


- Upstream HP boilers and superheaters
- Upstream refractory systems
- Issues
 - leaks
 - refractory/metal dusting debris
 - weakened pellet



Examples of pressure drop trends on HTS beds

- Similar products can perform very differently in-service



Need to pick right product with understanding of plant needs

KATALCO™ 71-6 premium HTS, eliminates short life due to p.d. increase - '**pain & cost**' factor

New product **KATALCO 71-7F**

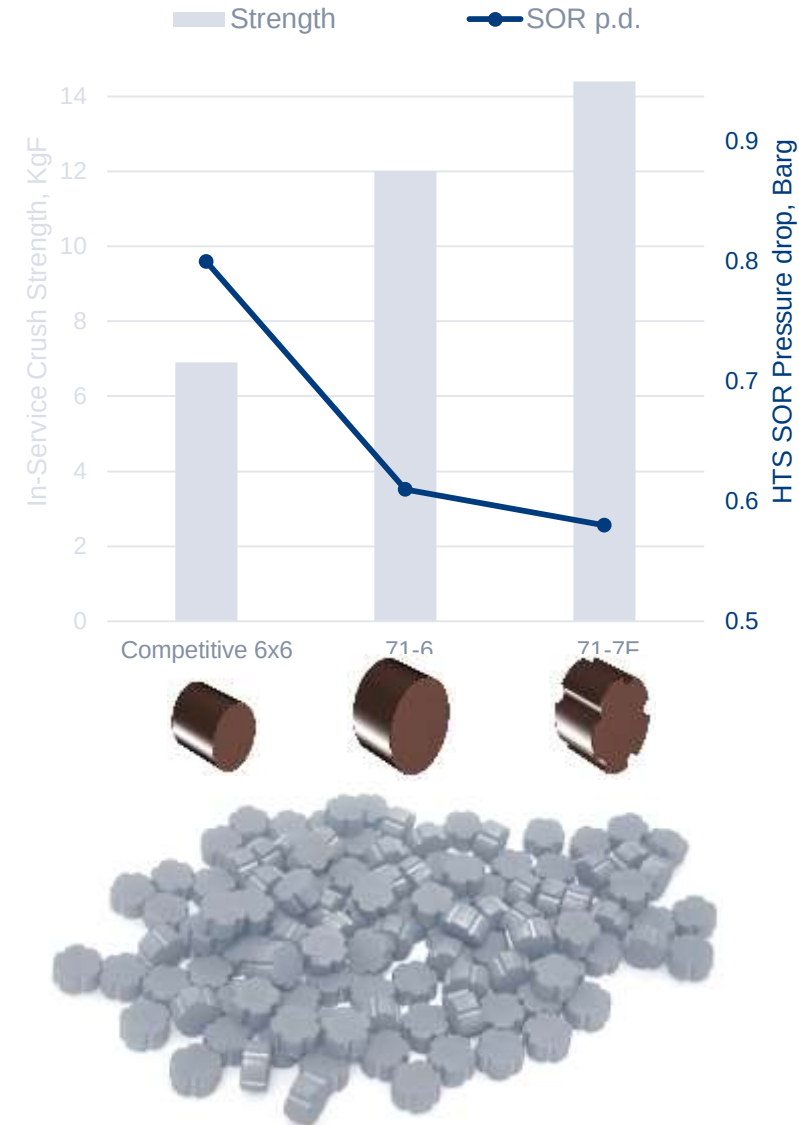
further performance advantage

- pressure drop, **lower SOR**
- **stronger**, low rate of change



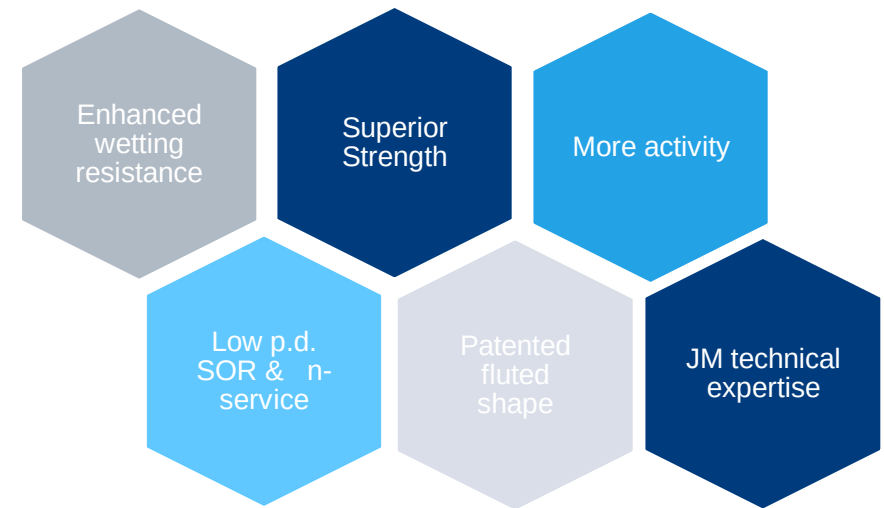
Leading HTS catalyst products

- **KATALCO 71-6**
 - For the most demanding duties
 - High activity and strength
 - Catalyst p.d., lower than competitive 6x6
 - Best survival in over-reducing conditions
- **KATALCO 71-7F**
 - Manufacturing process delivers higher strength
 - F-Shape lowers p.d.
 - 12% lower than **KATALCO 71-6**



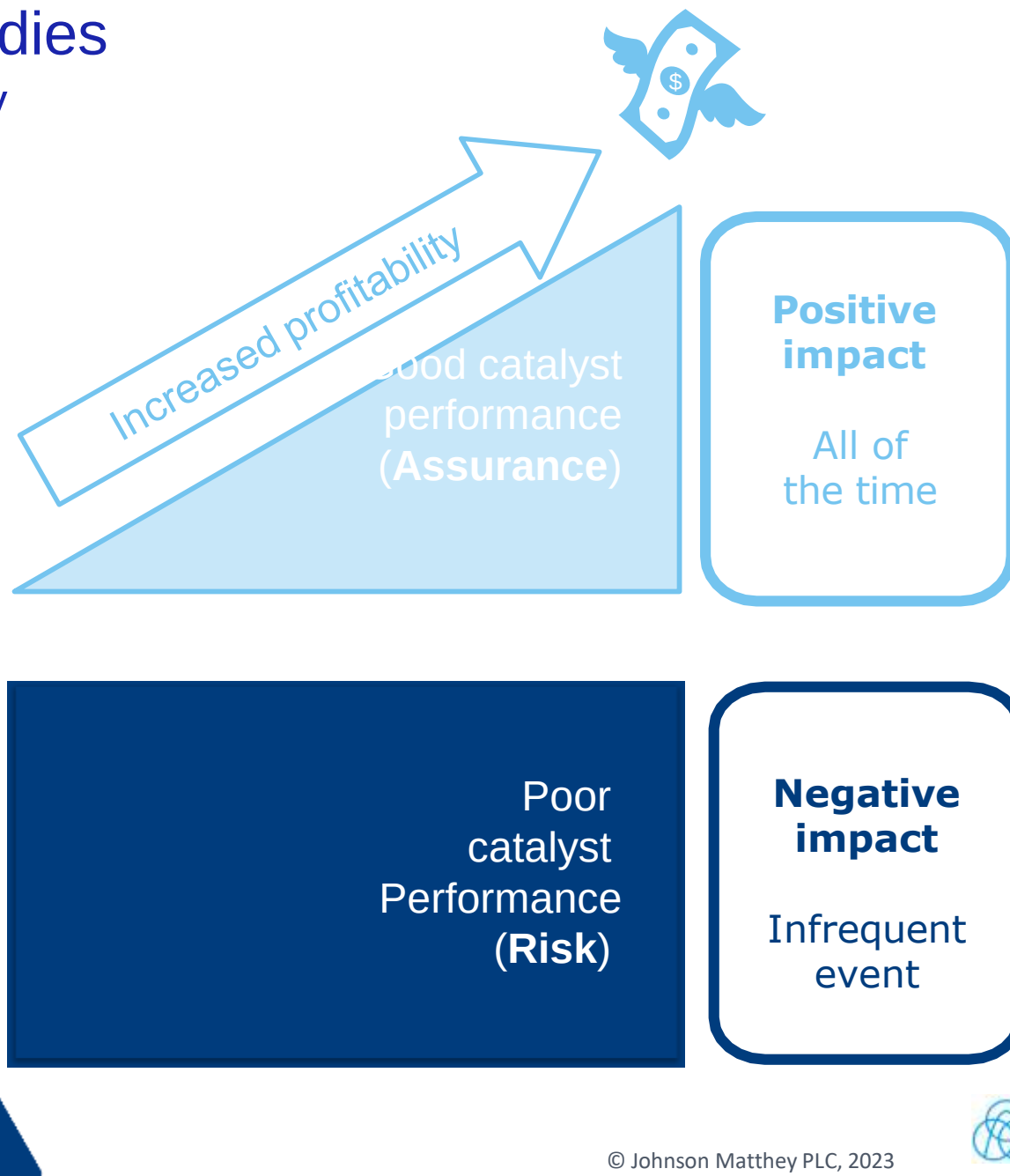
Leading HTS catalyst products

- **KATALCO 71-6** - current
 - For the most demanding duties
 - High activity and strength
 - Catalyst p.d., lower than competitive 6x6
 - Best survival in over-reducing conditions
- **KATALCO 71-7F** - new
 - Manufacturing process delivers higher strength
 - F-Shape lowers p.d.
 - 12% lower than **KATALCO 71-6**

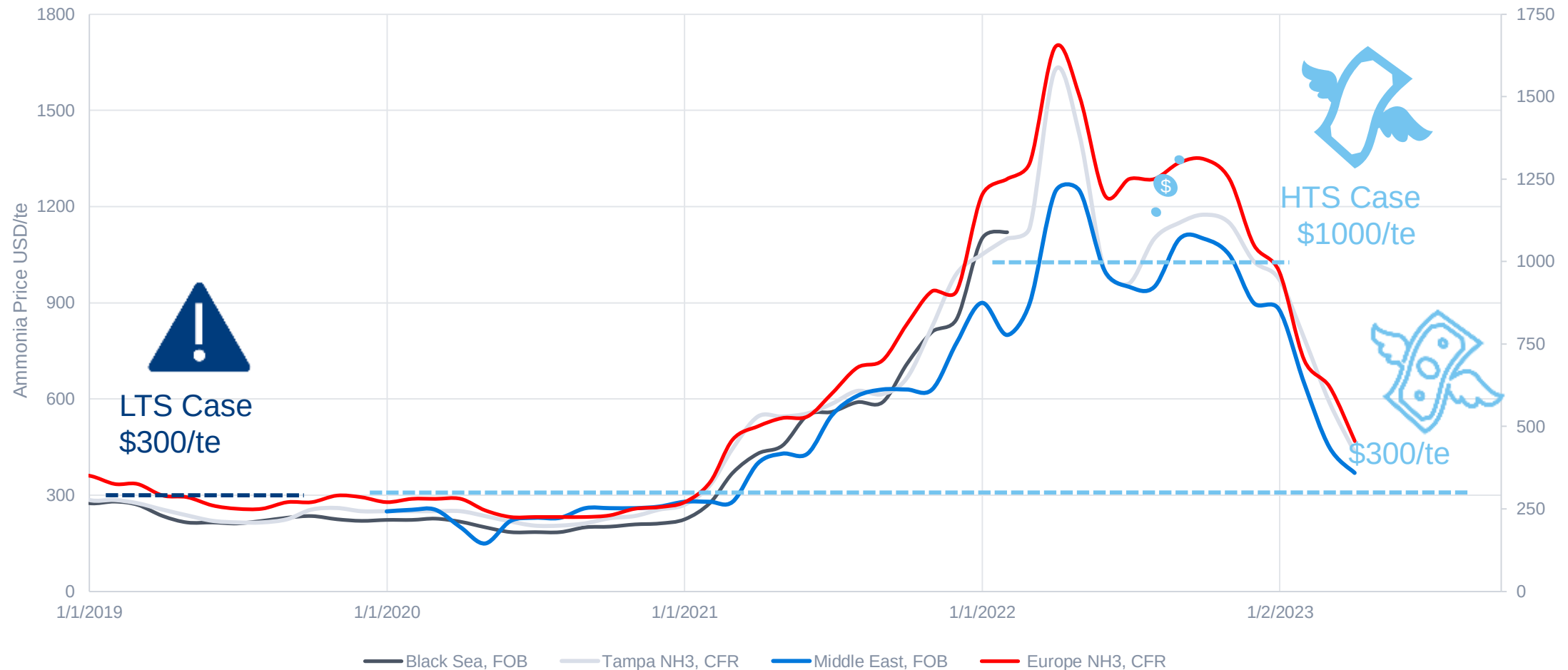


Shift catalyst – pressure drop case studies

Impacts can be + or -; increased or lost profitability

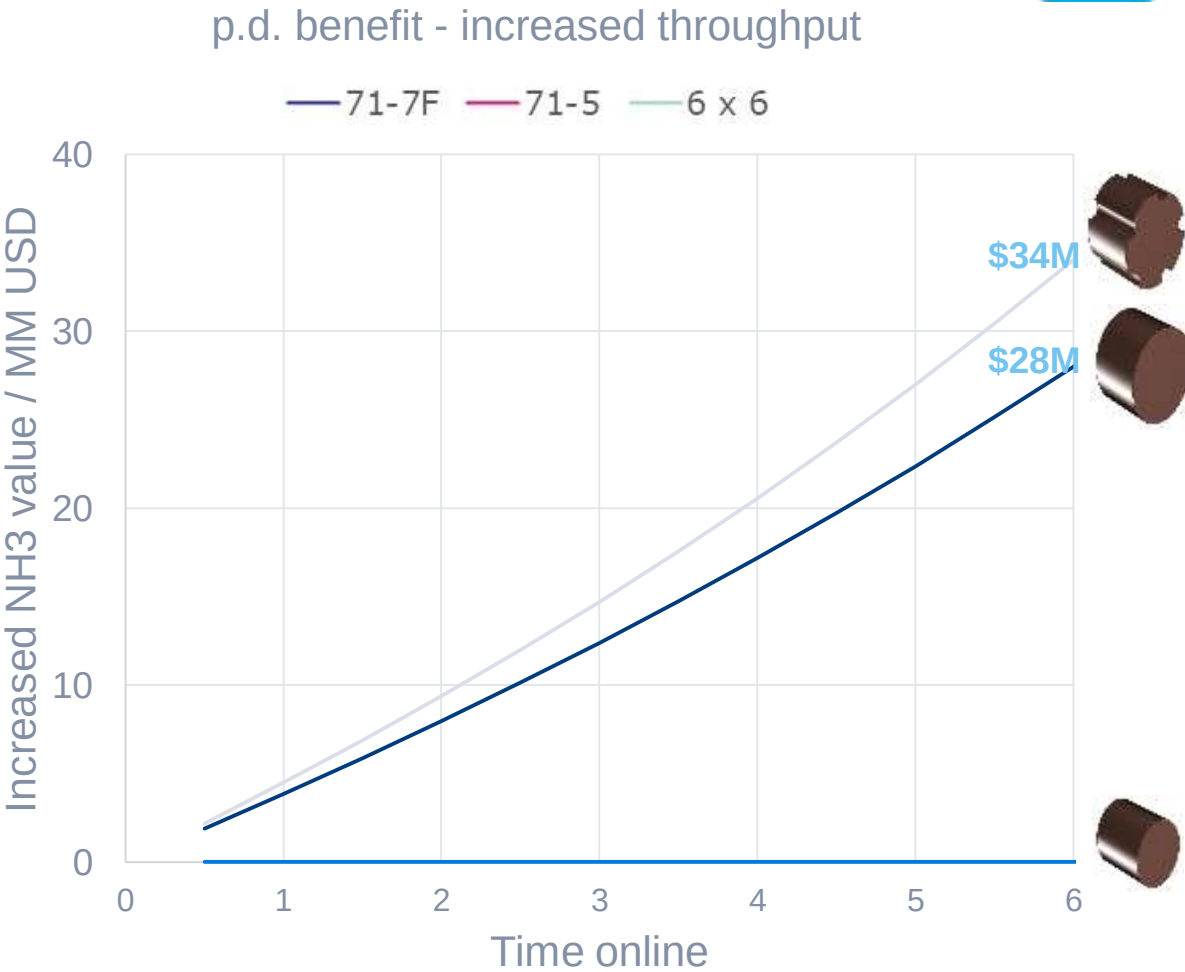
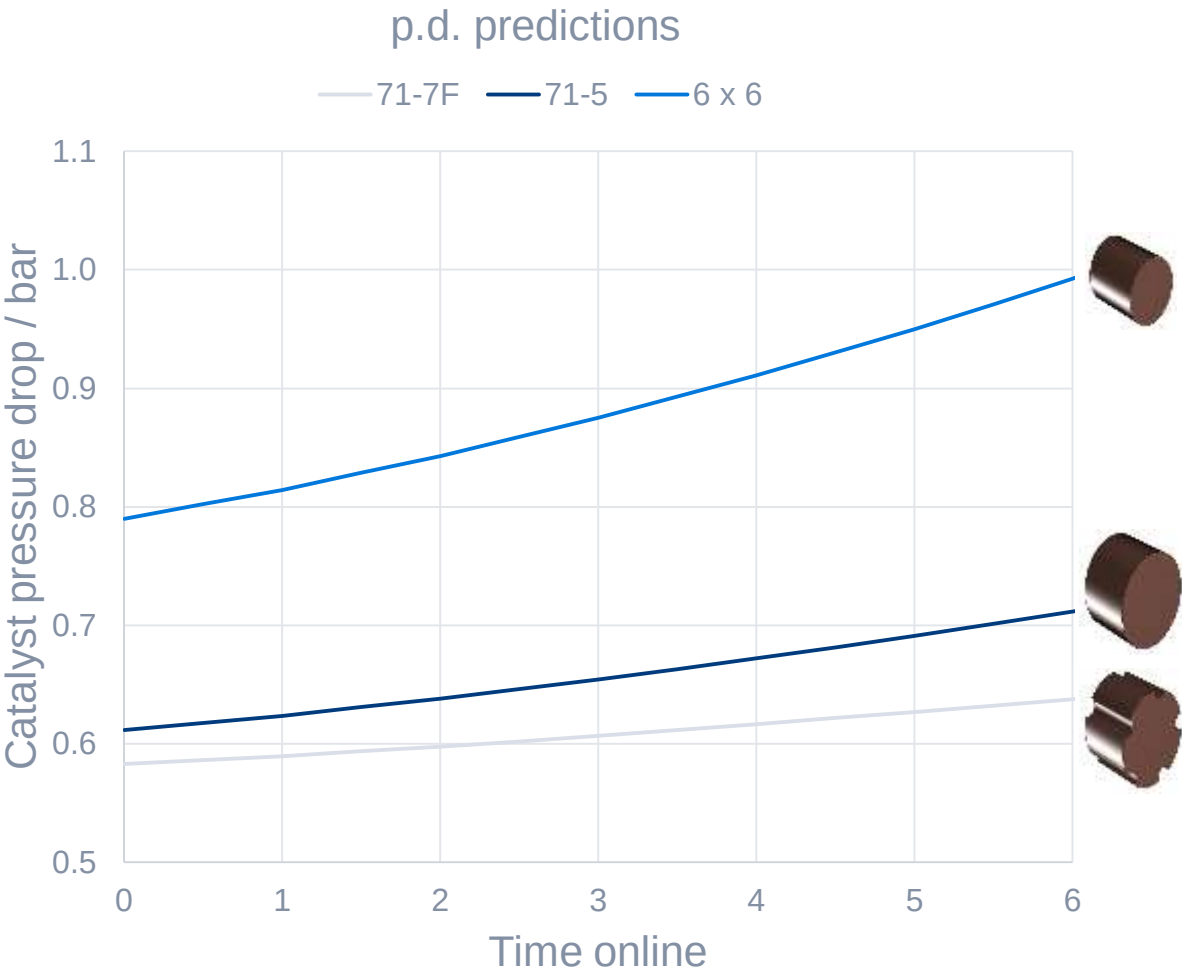


Shift catalyst pressure drop case studies, examples of positive reward HTS; negative risk on LTS



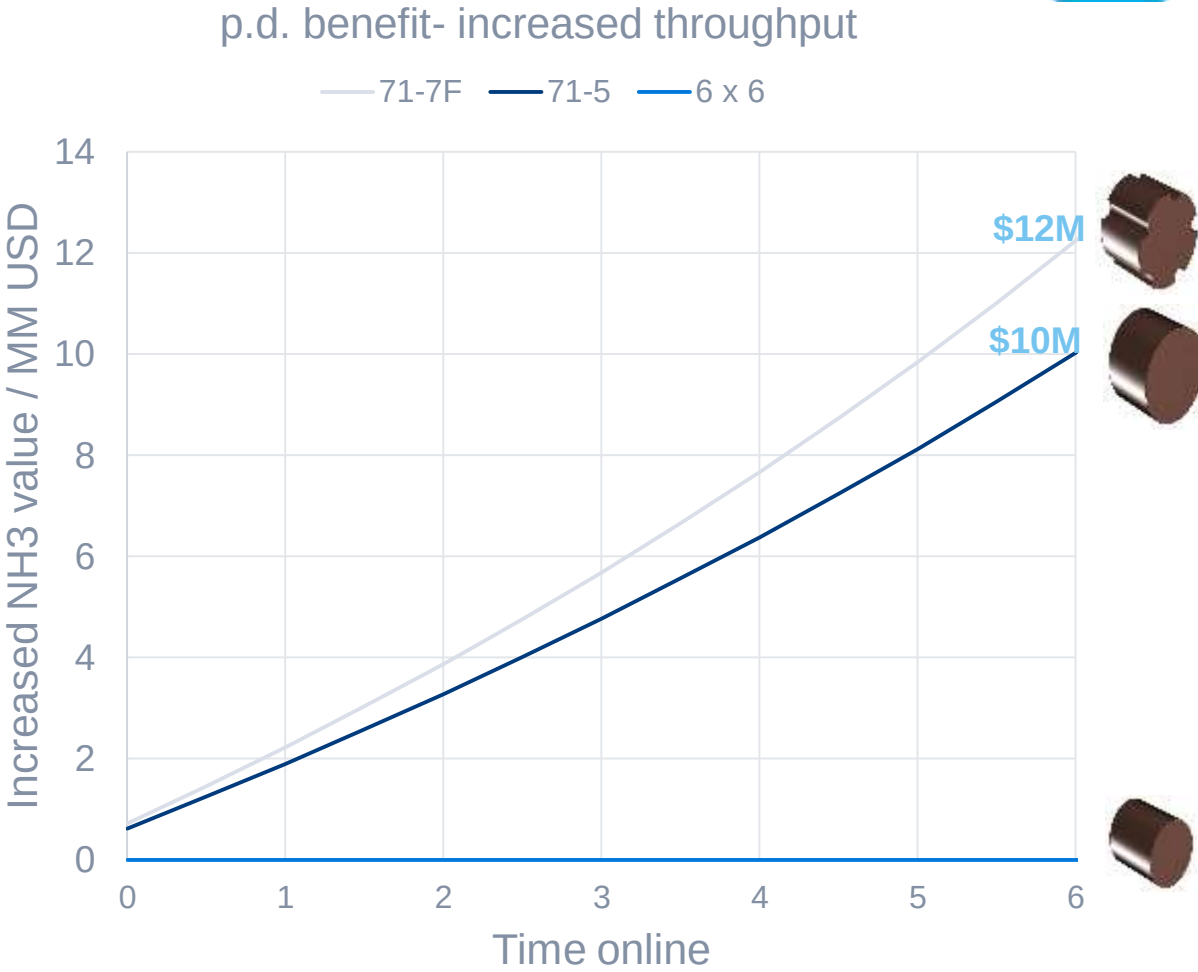
Shift catalyst – pressure drop Case Study HTS

HTS – Saudi plant scale 3,300 tpd, ammonia at \$1000/te



Shift catalyst – pressure drop Case Study HTS

HTS – Saudi plant scale 3,300 tpd, ammonia at \$300/te

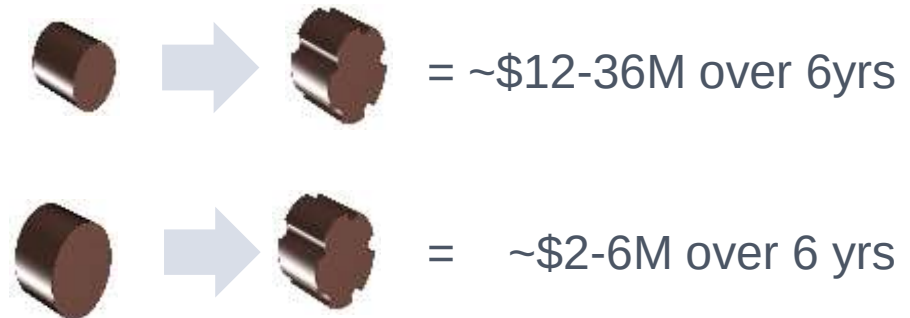


Shift catalyst – pressure drop Case Study HTS

HTS – Saudi Plant scale 3,300 tpd



- Even **relatively small d.p.** differences allow strong returns due to combination of the **plant scale** and **ammonia production margin**.
- **p.d. saving** can **increase value** production



Shift catalyst – pressure drop Case Study LTS

LTS - Plant scale 1,200 tpd; ammonia at \$300/te

- **Competitive LTS charge**

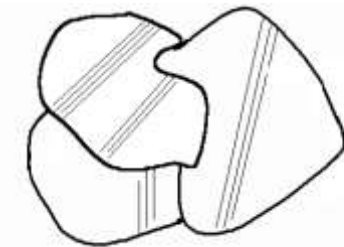
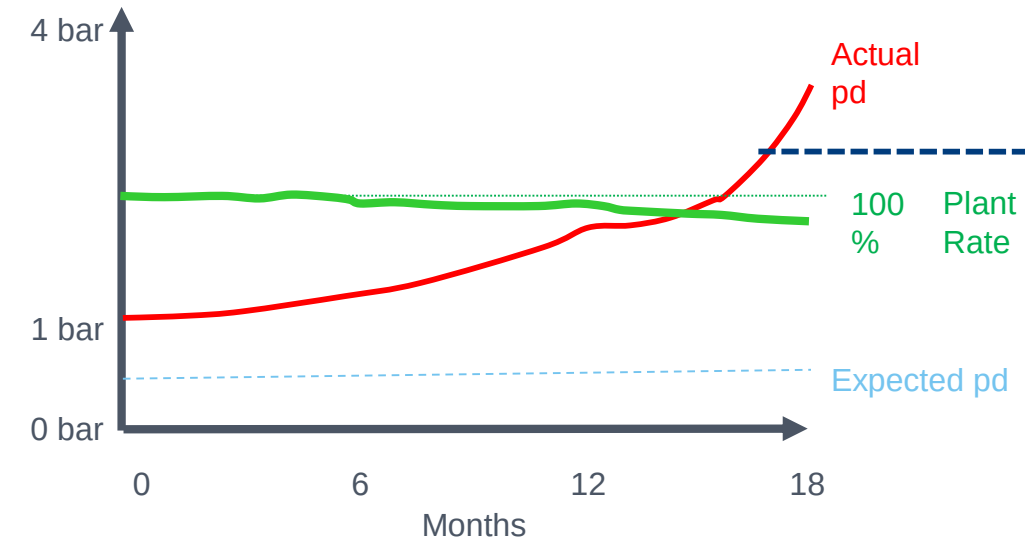
- Purchase cost saving

- **Performance issues**

- LTS pressure drop double expected SOR @ 1bar
- p.d. increased dramatically through life to 3.5bar
- Caused rate restriction, changed at 18 months
- Incident cost, estimated at \$10M

Why?

- Catalyst structural issue in reduction?
- Chloride suggested as contributor??

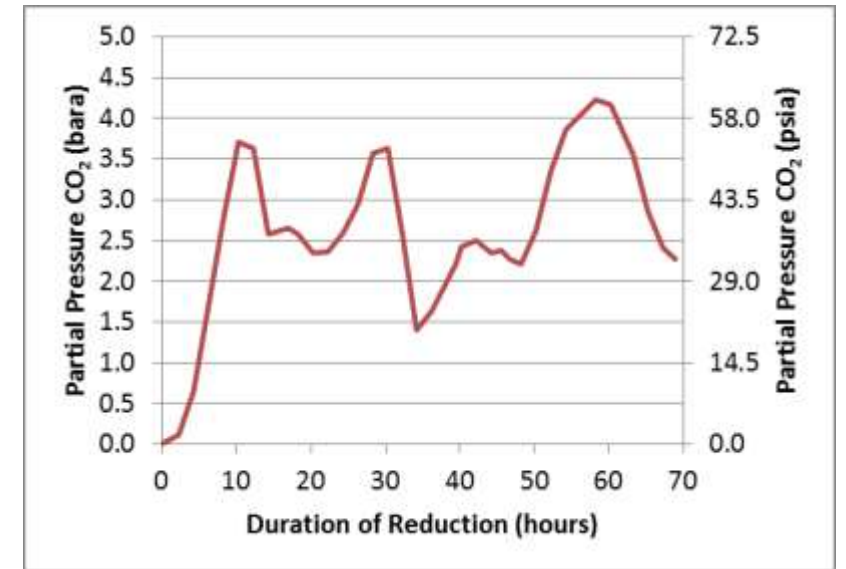


Poor pellet integrity results in fused pellets and reduced voidage



Low temperature shift – reduction transient period of operation

- Reduction is an **unavoidable transient condition**
 - Hydrogen content and exothermic temperature rise
- Transition can **impact on** LTS catalyst strength ⁽¹⁾
 - All LTS catalysts originate from Cu-Zn carbonates, these liberate CO₂ during reduction. Some catalysts are easily **weakened** by this resulting in high pressure drop
 - **Strict limits on CO₂ partial pressure** during reduction for some **competitive products**
- **KATALCO 83-3 is formulated** to avoid this issue
 - Support backbone engineered to avoid breakdown
 - Allows high levels of CO₂ during reduction



(1) Reference:

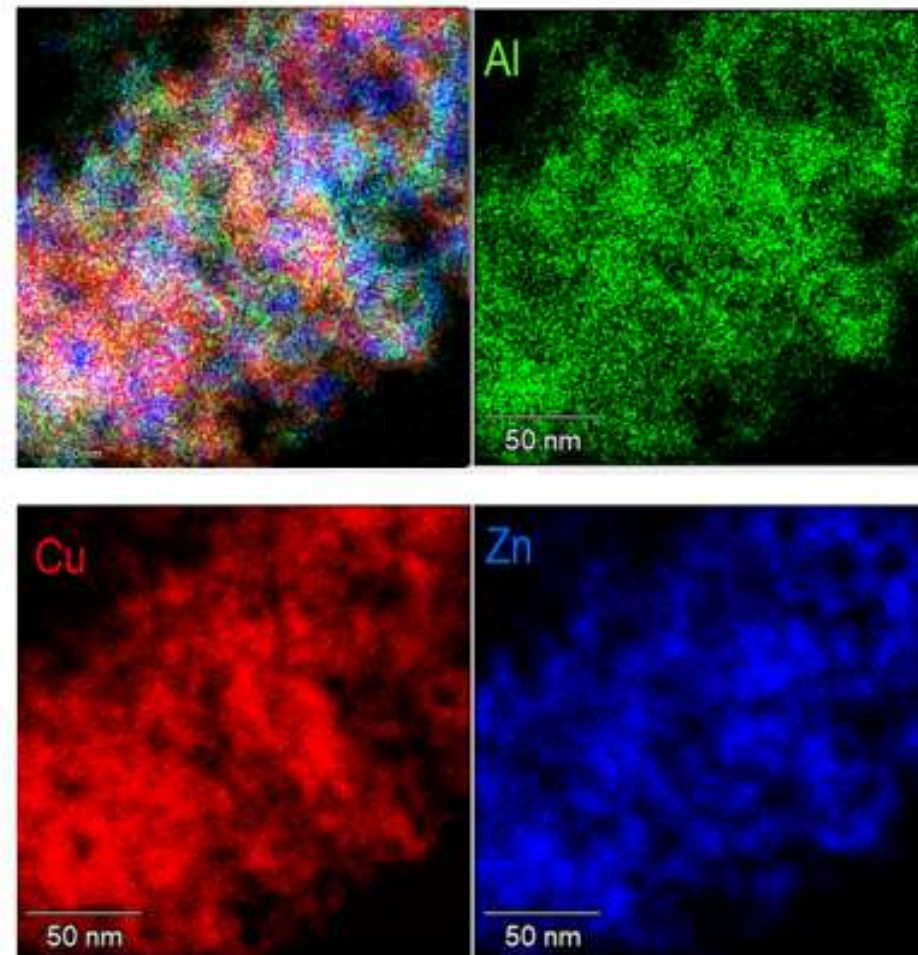
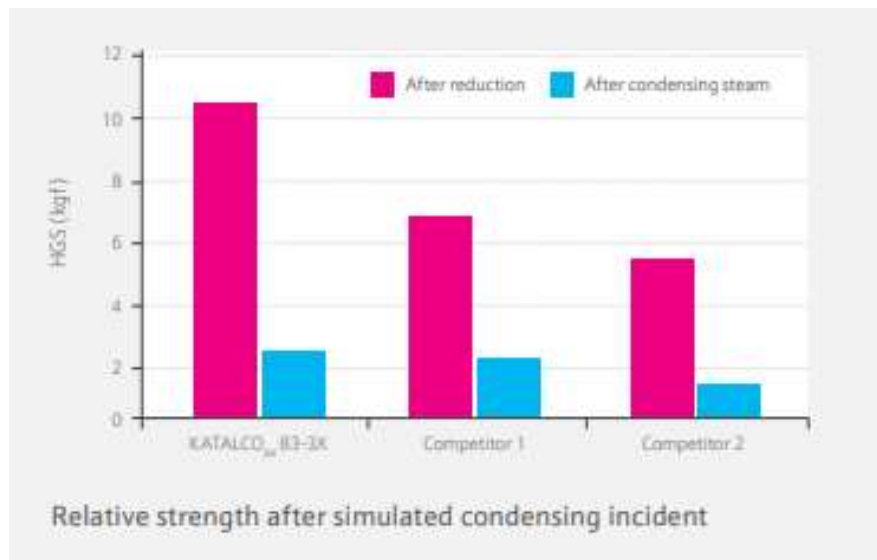
Importance of Catalyst Design in Managing the Impact of Transient Operating Conditions in Ammonia Plants - Peter Farnell, Mikael Carlsson, JM - AIChE 2014



KATALCO™ 83-3 / 83-3X LTS catalysts = robust products

Designed to be highly active, strong catalysts

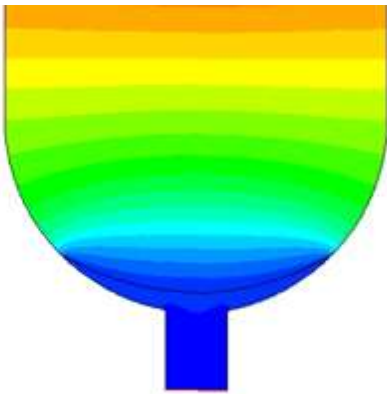
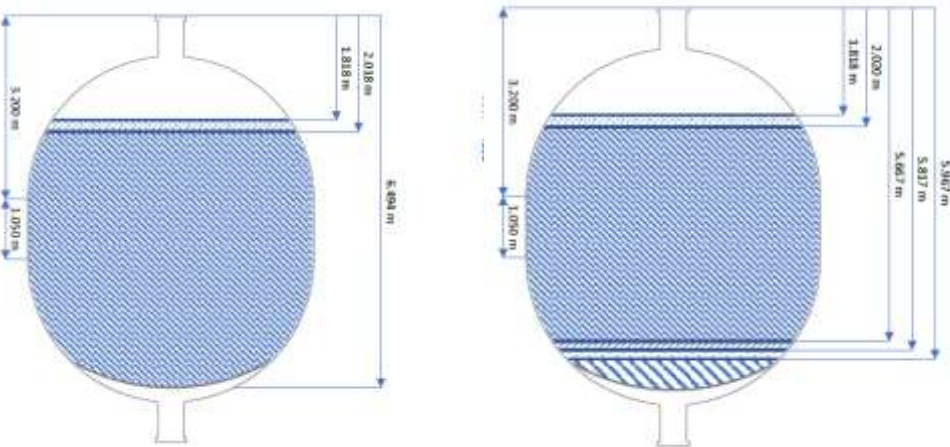
- **KATALCO 83-3 / 83-3X**
- Robust LTS - optimum catalyst structure
- ‘good skeleton’ of Zn-Al refractory crystals
- supports Cu, provides intrinsic strength



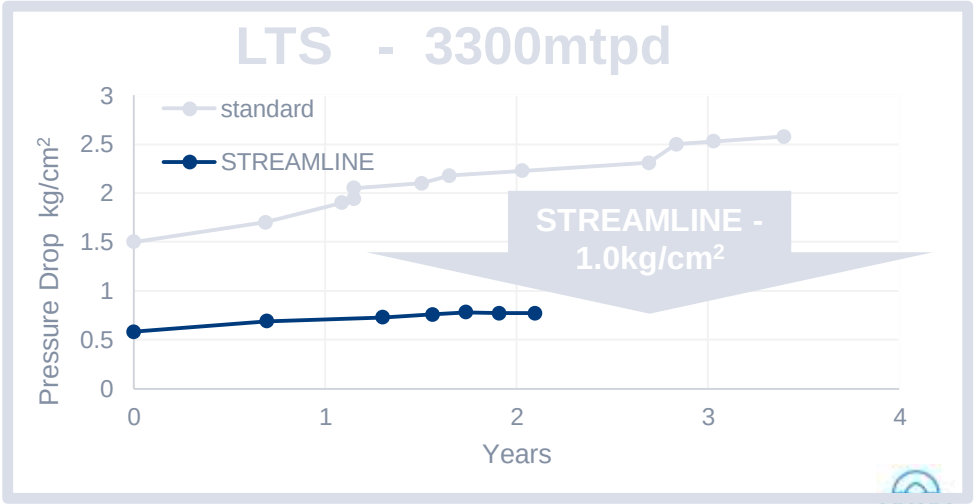
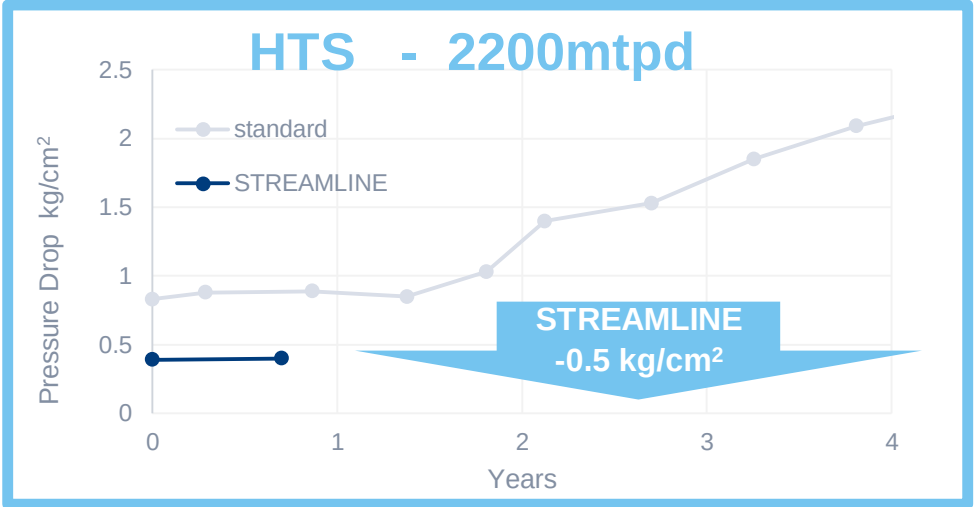
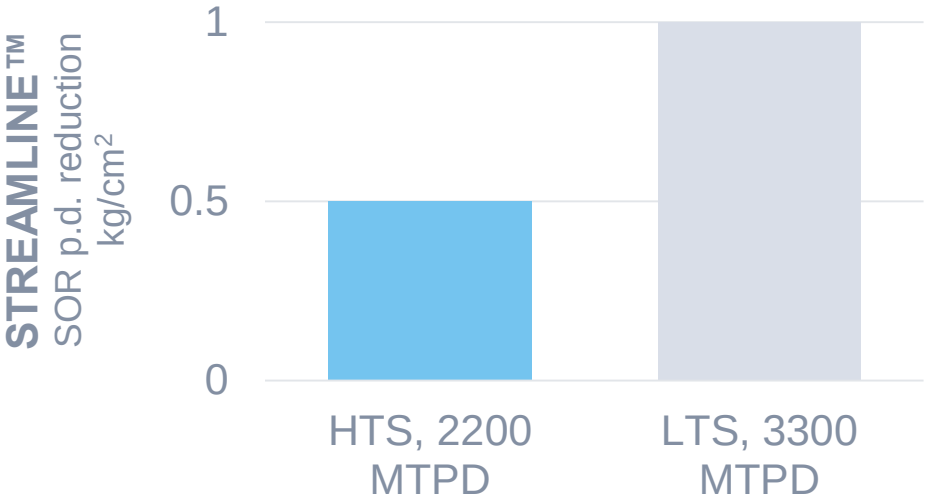
- **Strength** **Al, Zn**

STREAMLINE™ solution to lower pressure drop

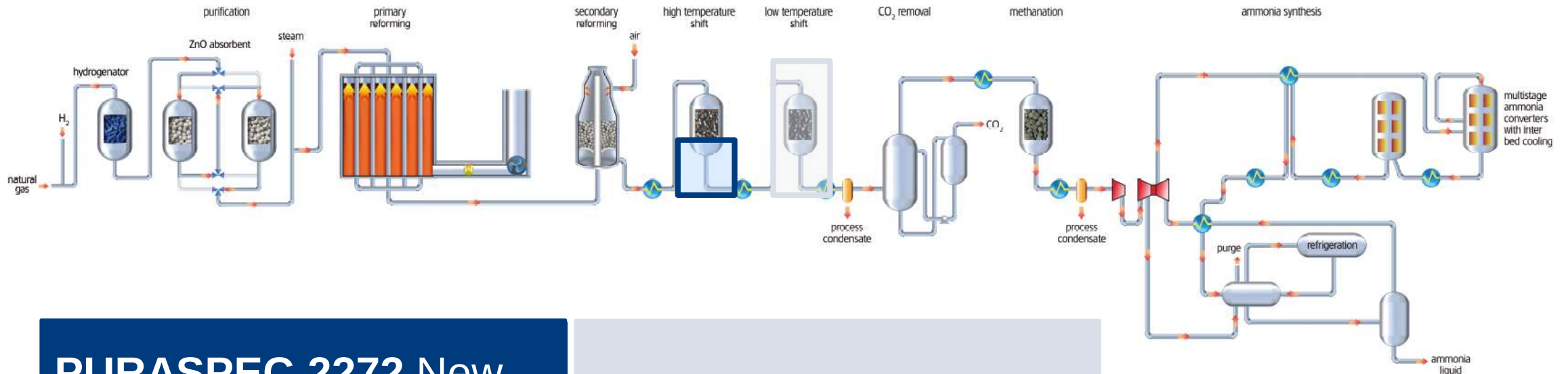
- Engineered loading of supports in reactor; case studies in both HTS and LTS



- JM's proprietary design tools used to optimise



PURASPEC™ 2272 – adds extra resilience as a new Cl-absorbent



PURASPEC 2272 New Cl-absorbent



PURASPEC™ 2272
Cl-trap for use in HTS vessel

LTS protection



Extra protection for LTS from the risk of wetting damage



New patented absorbent duty **PURASPEC™ 2272**

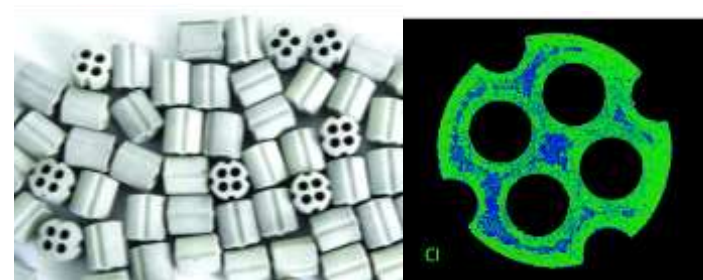
Traps Cl in base of HTS

PURASPEC 2272

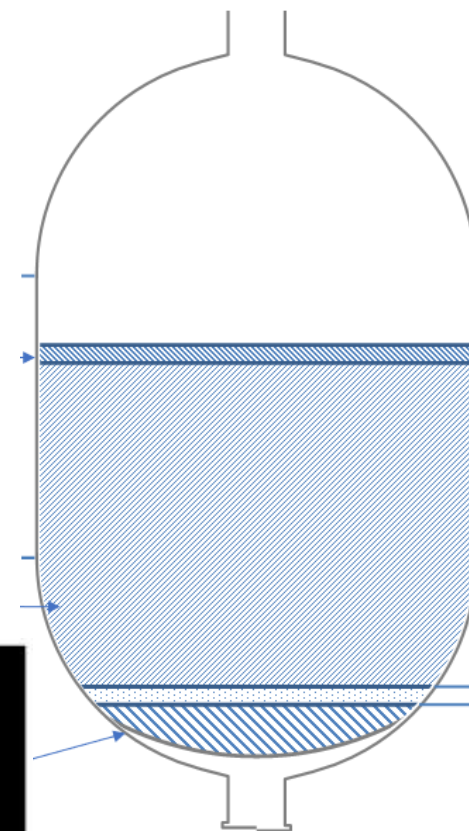
- Robust alkali promoted ceramic
- Effective trap for ppb levels Cl
- Prevents all Cl-reaching LTS bed
- Active absorbent replacing inert
- Low pressure drop shape



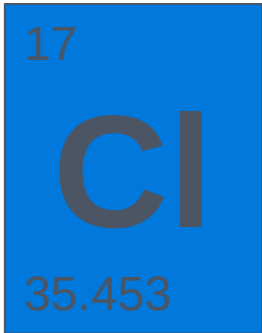
KATALCO 71-7F



PURASPEC 2272



Cl LTS catalyst poison – source and impacts



Source	• Process air • (coastal, cooling tower) • Steam
Typical levels (in syn gas)	• 1 – 10 vppb
Impact	• Blocks active site • Promotes sintering • Hi-mobility to wetting



https://upload.wikimedia.org/wikipedia/commons/b/be/Cenk_Endustri_Field_Erected_Industrial_Cooling_Tower.JPG



http://www.freeimageslive.co.uk/free_stock_image/bigsur-seamistjpg freeimageslive.co.uk - surfside



PURASPEC™ 2272 – very effective trap, 10ppb is tough thing to find



- 3,300 TPD uhde® LTS design volume, 139m³ (4,910 ft³)
- 139m³ **KATALCO™** 83-3X to fill ~1,200,000,000 pellets



Out of 838 full drums of catalyst

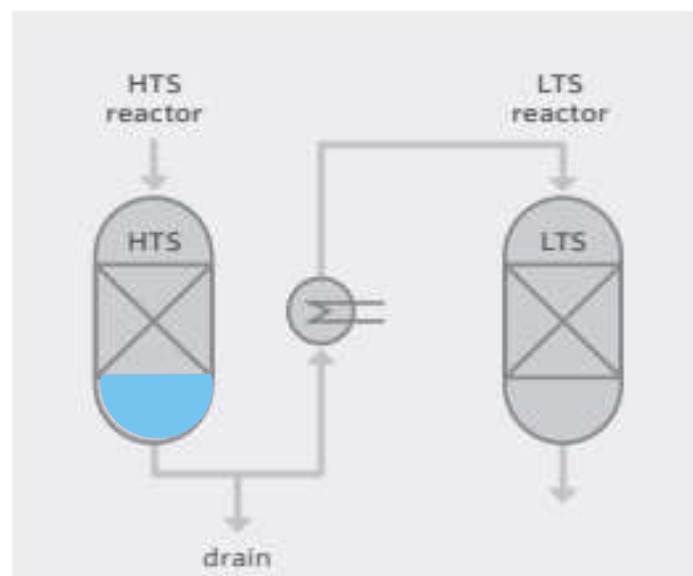
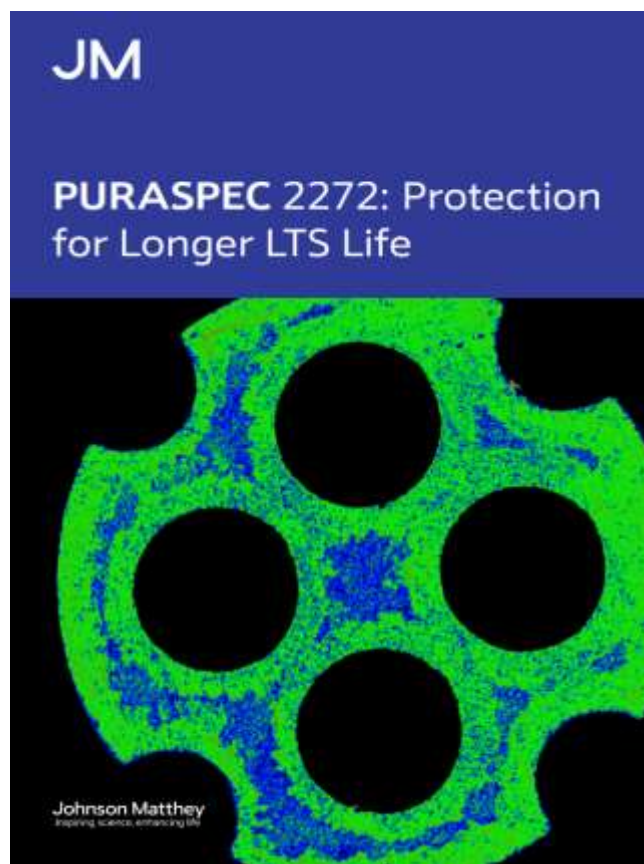


Find 10 specific pellets!



PURASPEC 2272

More protection longer LTS life; less risk from transient wetting



HTS exit PURASPEC 2272

LTS inlet - Traditional

Process 450°C / 840°F

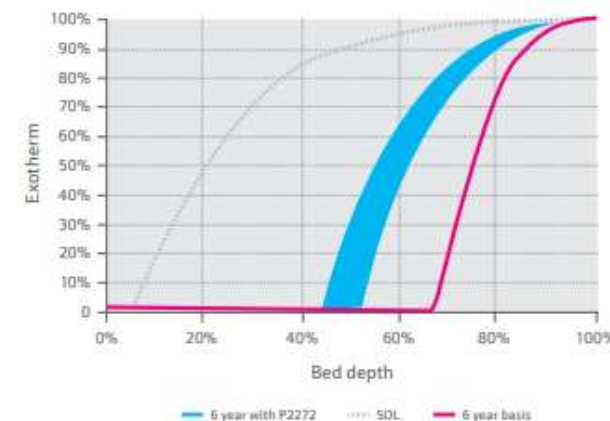
Process 195°C / 380°F

Dewpoint 180°C / 355°F

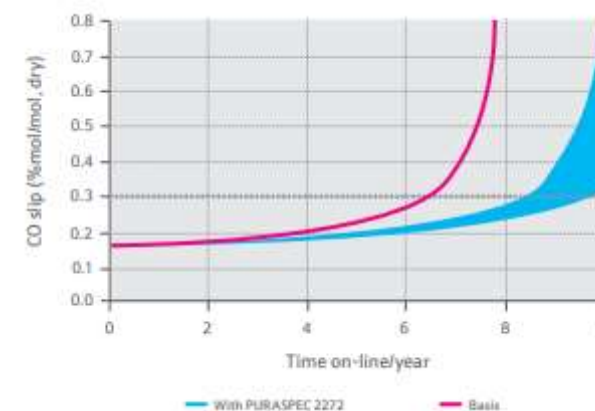
Dewpoint 180°C / 355°F

Dewpoint Margin 270°C / 484°F

Dewpoint Margin 15°C / 27°F



- Slower LTS deactivation



- LTS life extension



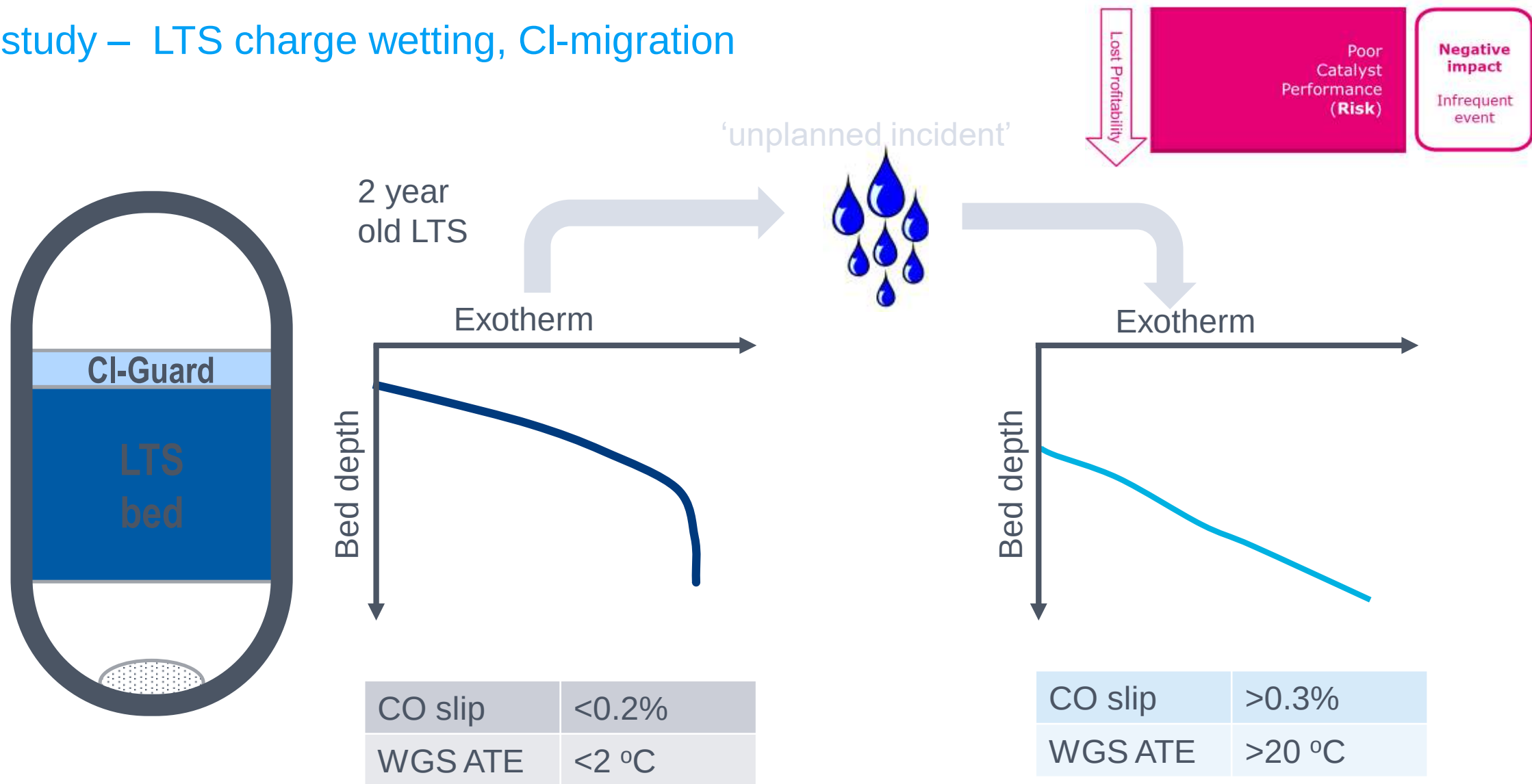
No risk CI migration



Risk of CI migration



Case study – LTS charge wetting, Cl-migration



Unplanned premature LTS change, impact ~\$2-5M



KATALCO 74-1 Koch Fort Dodge low pressure reference

- Recent North American reference

14 Jun 2023 09:00

thyssenkrupp Uhde and Johnson Matthey increase ammonia synthesis capacity at Koch Fertilizer facility



Koch Fertilizer facility, Fort Dodge, Iowa (USA)

<https://www.thyssenkrupp-uhde.com/en/media/press-releases/press-detail/thyssenkrupp-uhde-and-johnson-matthey-increase-ammonia-synthesis-capacity-at-koch-fertilizer-facility-225744>



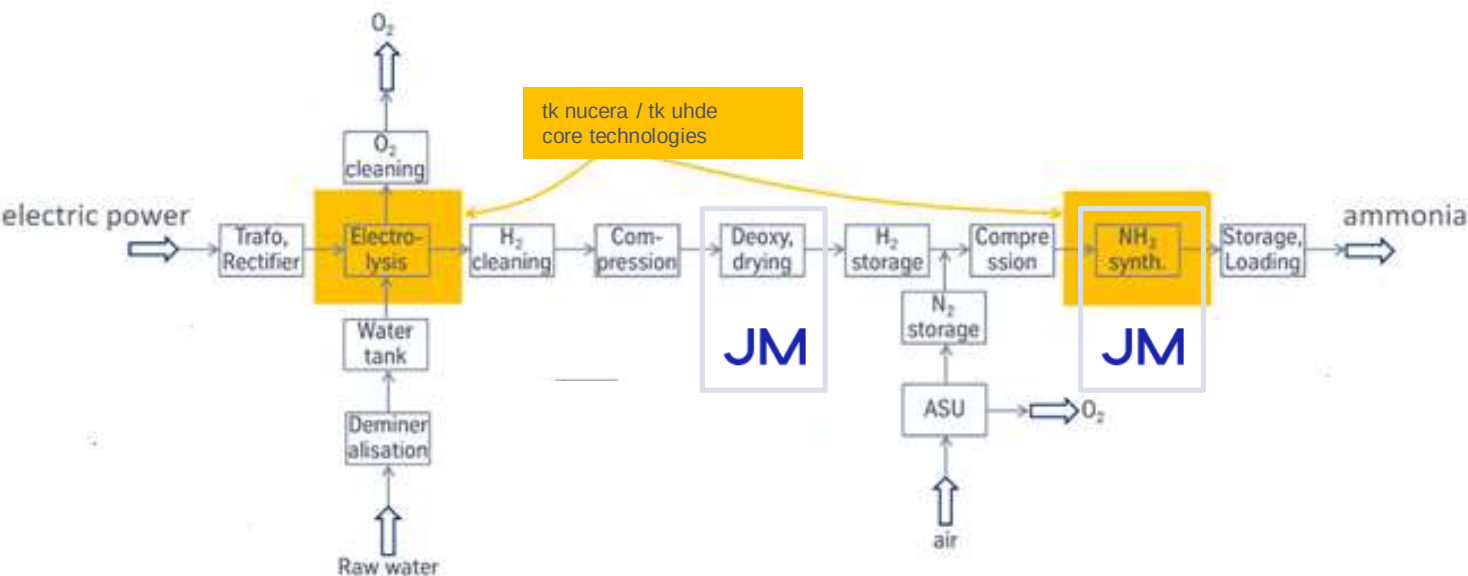
For this revamp to increase capacity a key challenge was the **very low** ammonia synthesis **operating pressure of only 960 psig/66 barg** for the ammonia synthesis converter.

Solved by combining high-performance catalyst **KATALCO 74-1** with an adapted novel process design from tk Uhde.

This joint solution has enabled the increased ammonia synthesis capacity.



GREEN Ammonia product range



PURAVOC™ GREEN 10



Johnson Matthey
Inspiring science, enhancing life

JM's PURAVOC GREEN™ purification catalysts enable green hydrogen to be used as a building block for decarbonising industry.



Renewable energy

Electrolytic (green) hydrogen production

PURAVOC GREEN™ catalysts

Building blocks for the chemical and fuel industries

KATALCO™ 74-1 GREEN



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UNIVERSITY OF CAMBRIDGE



Catalysis and Process Integration
Research and Development



KATALCO 74-1 GREEN: Green ammonia synthesis with reduced energy consumption and operating costs



Summary

JM

Trusted solutions
for the ammonia
industry

www.matthey.com



Johnson Matthey
Inspiring science, enhancing life

JM

Shaped HTS
for lowest PD &
highest strength

www.matthey.com

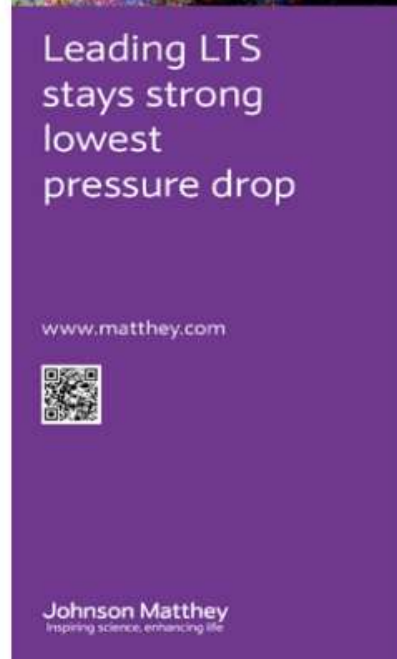


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Leading LTS
stays strong
lowest
pressure drop

www.matthey.com

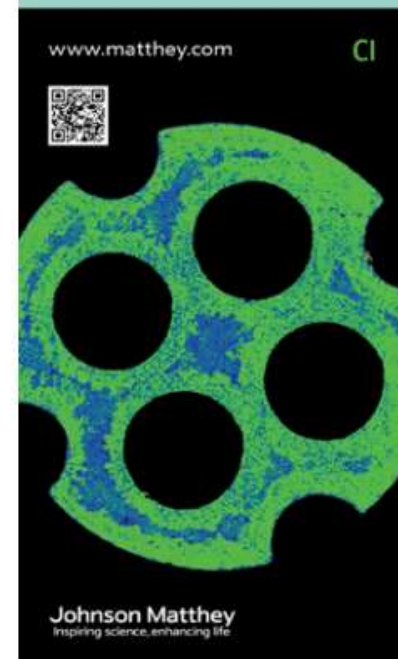


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PURASPEC 2272
patented revolutionary
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Reliable ammonia
production has
never been more
important



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Workshop Introduction

Uhde Ammonia Technology Users' Group Meeting

Munich, August 22nd 2023 | Tobias Birwe | thyssenkrupp Uhde



engineering.tomorrow.together.



thyssenkrupp

Overview

14:35	Break			
	Room 1 – New Developments		Room 2 – New Services	
Time	Workshop / Presentation	Presenter	Workshop / Presentation	Presenter
14:50	All around Modularisation & Execution	Birwe	All around Digitalization & Automation	Wenzel
15:10	Q & A (change of room possible)			
15:15	Pushing the Limits	Mielke	Proprietary Equipment Design(s)	Brakhane Distler
15:40	Q & A (change of room possible)			
15:45	New Product: Ammonia Cracking	Nölker	Ammonia Process Revamp Options	Kessler
~ 16:00	Round tables			



Uhde Ammonia Technology Users' Group Meeting

New Developments Workshop



- 1 All around Modularisation & Execution
Tobias Birwe
- 2 Pushing the Limits: : Large Ammonia Plants
Bernd Mielke
- 3 New Product: Ammonia Cracking
Klaus Nölker



Uhde Ammonia Technology Users' Group Meeting

New Services Workshops



- 1 All around Digitalization & Automation
Sascha Wenzel
- 2 Proprietary Equipment Design(s):
 - 2.1. Proprietary Equipment Design – Reformer
Thorsten Brakhane
 - 2.2. Evolution of the Uhde® Ammonia Converter Cartridge
Johannes Distler
- 3 Ammonia Process Revamp Options
Fred Kessler



Round Tables

In the foyer you will find signs with the workshop topics on the tables.

At the tables you can ask questions about the topics ..

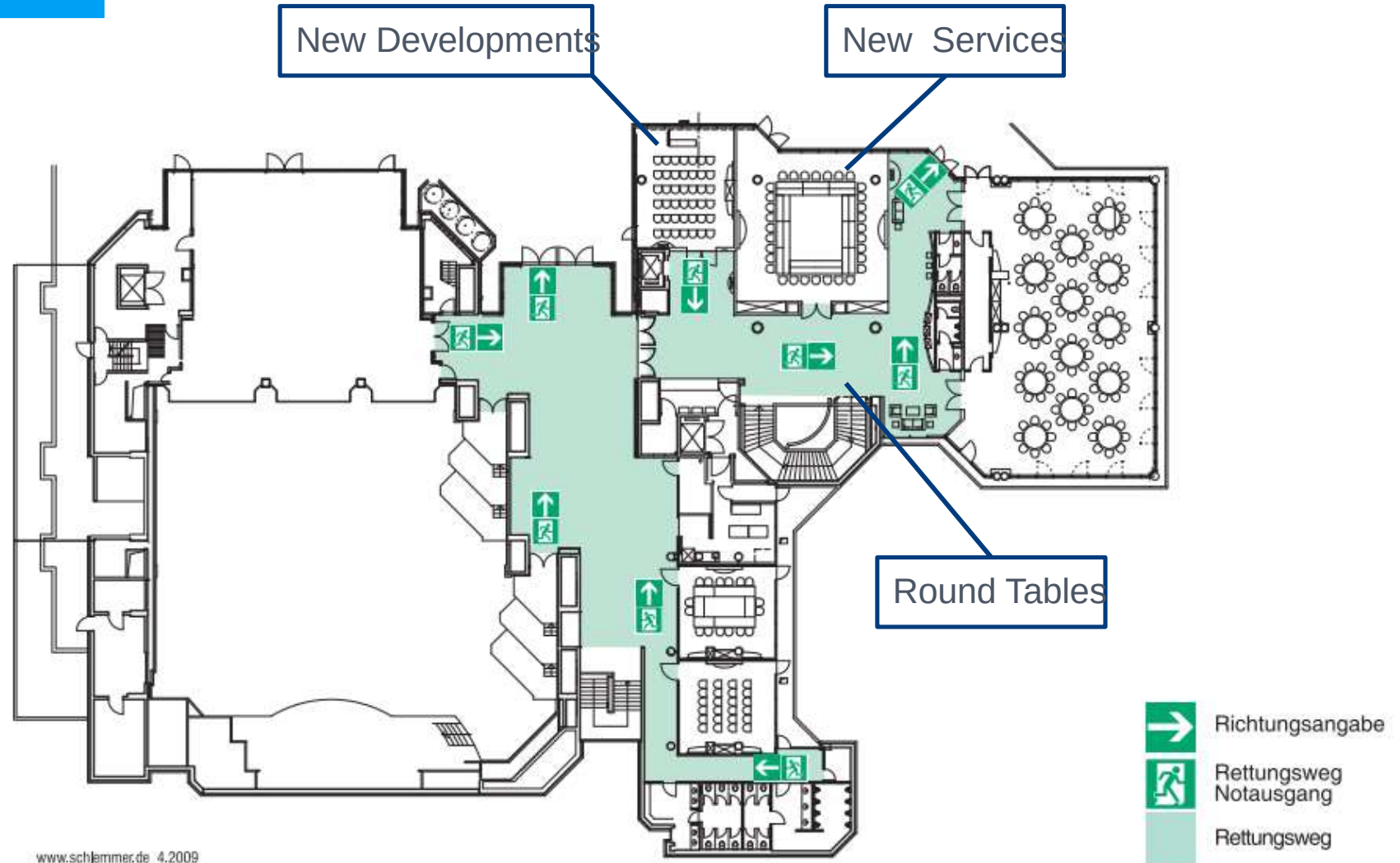
.. or just talk to our professional colleagues



We look forward to your questions!



Workshop Rooms



Coffee Break until 15:20 pm

