

New Developments

Uhde Ammonia Technology Users' Group Meeting

Munich, August 22nd 2023 | thyssenkrupp Uhde



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All around Modularization and Execution

Uhde Ammonia Technology Users' Group Meeting

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



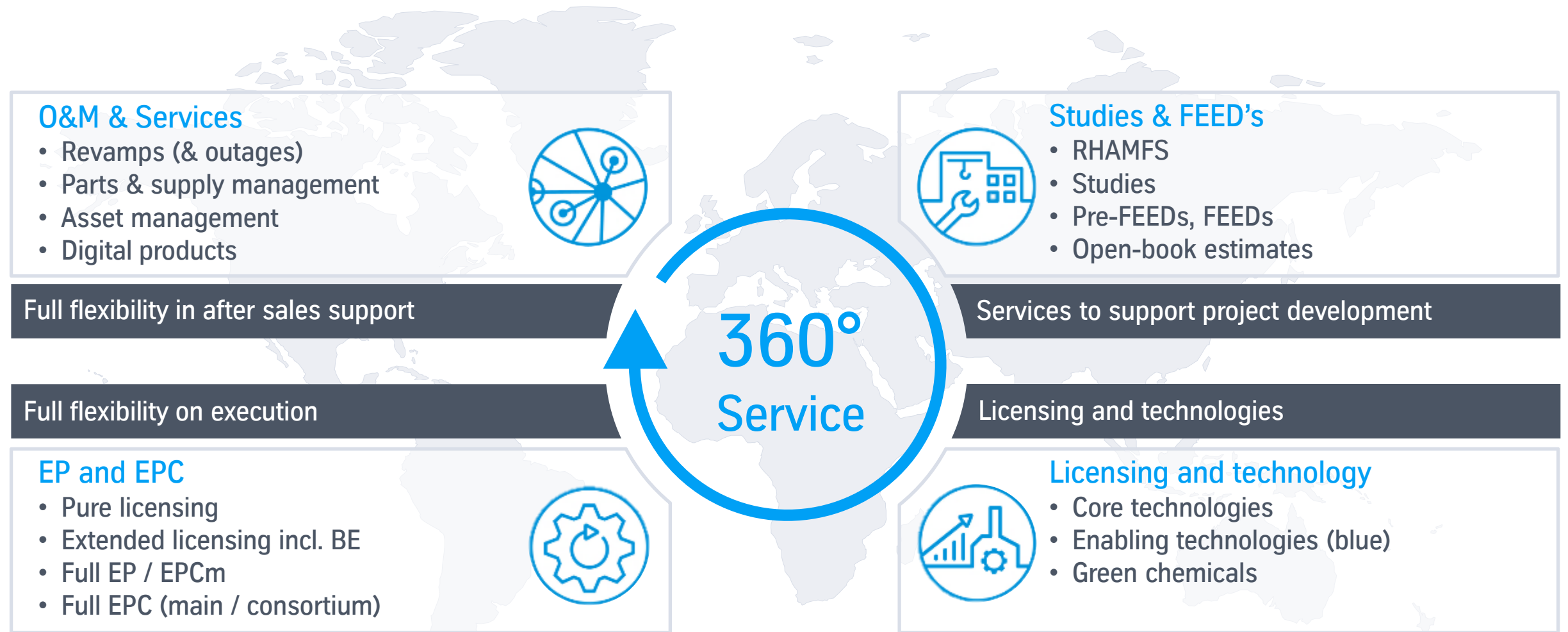
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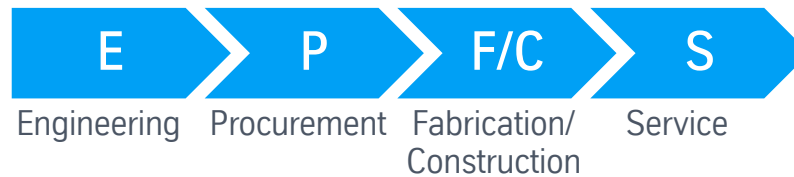
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That's what we call 360° Service.



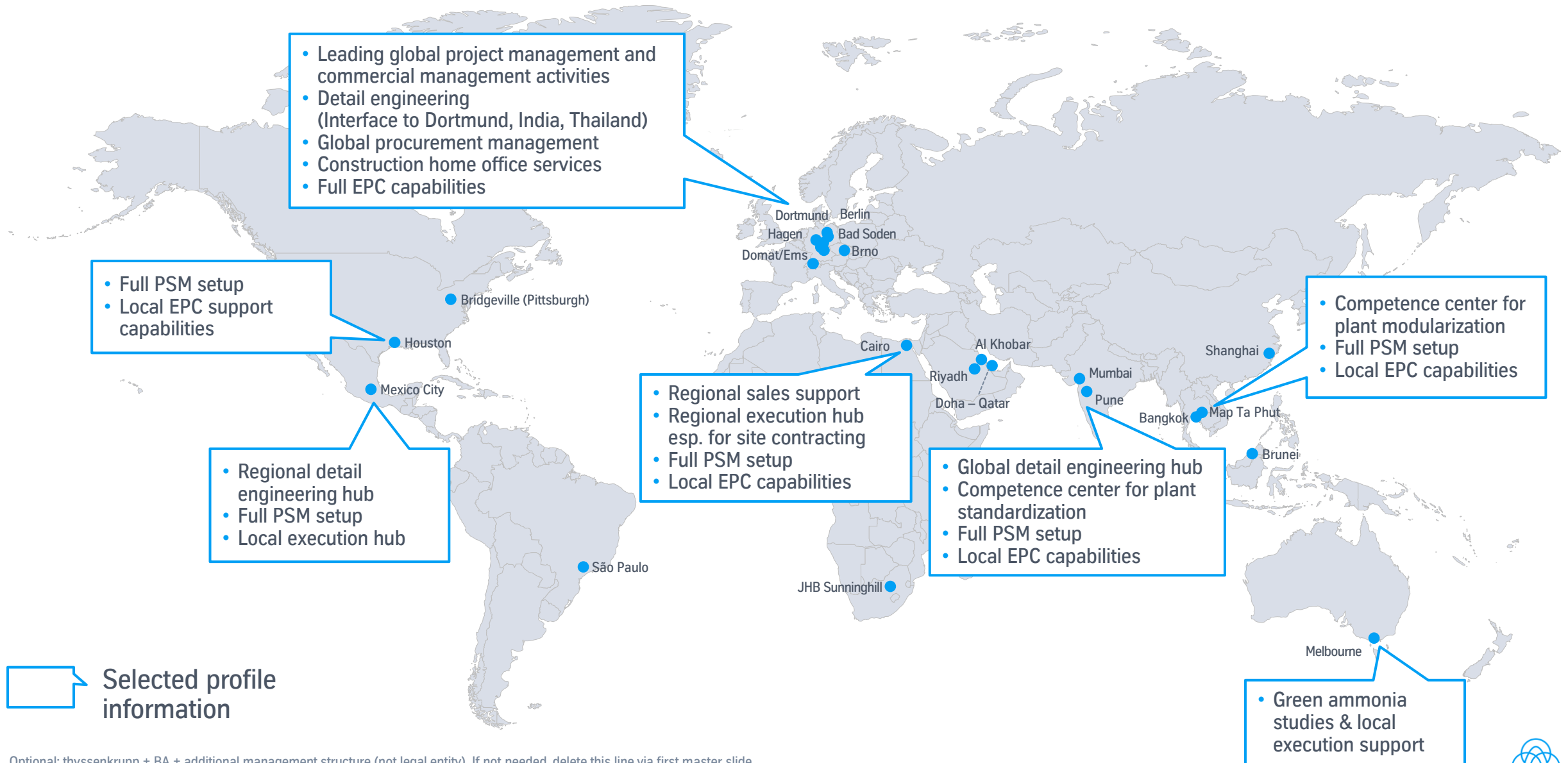


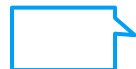
Technologies and Licenses



Improved safety and quality, reduced execution risk and decreased impact on local communities through modularization solutions

Uhde global footprint following an operational center approach



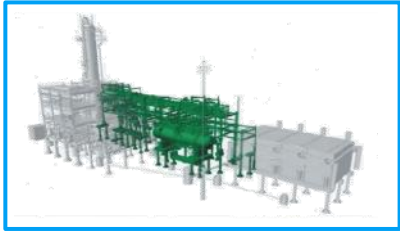
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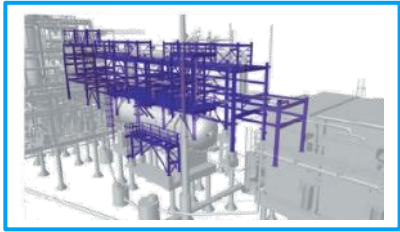
It is important to think from the construction requirements from the initial stage of the project



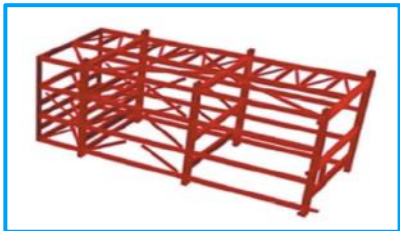
Level 1 – Construction Unit (CU)



Level 2 – Construction Work Area (CWA)



Level 3 – Construction Work Package (CWP)



Level 4 – Installation Work Package (IWP)



PPMOF* or modularization mitigates those risks and provides further benefits



Safety

- Work shifted from site to shop environment reducing total site hours
- Reduced work at height
- Potential reduction in crane usage



Quality

- Better labor availability
- Working in controlled environment (e.g. no weather effects)



Footprint

- Reduction of impacts on local communities and employed individuals (e.g. import skills and camps)
- Utilization of established yards

This is what drives our teams in Thailand in conjunction with technologies.

*PPMOF: Pre-fabrication, pre-assembly, modularization and offsite fabrication

Optional: thyssenkrupp + BA + additional management structure (not legal entity). If not needed, delete this line via first master slide

7 | time/date | presentation title | name of speaker (fill in as usual via first master slide)



Three examples of added value through modularization

1

Modular ammonia and methanol plants

Standard 300, 600 and 1,200 mtpd ammonia plants modularized
with 60 %+ degree of modularization

Standard 3,300 mtpd concept
completed soon

For a mid-sized project, this could
remove > 500,000 hrs from site

Considering the productivity increase moving work to a yard¹,
this could yield savings of ~30 %

2

Pre-dressing

Significant reduction of works at
height and scaffolding actually
achieved in current and recent projects

3

Modular substations

Schedule improvements
of 3 months in European reference
actually achieved in recent project

1. Productivity factor of 1.2 against USGC, Compass 2022 Global Construction Costs Yearbook



Significant cost improvements



- On-shore site
- Off-shore yard

Labor productivity³
Hourly all-in cost
Construction cost p.h.
Economic Productivity Ratio

Site	vs.	Yard
1.28		2.0
USD 176		USD 15
USD 224		USD 30
7.5		1

Significant savings on mid-sized ammonia plant

3. Productivity factors against USGC, Compass 2022 Global Construction Costs Yearbook



Critical factors to be taken into account



Decision for or against PPMOF to be done early in the project



Logistics study required to determine dimensional constraints and additional scope and costs



Project schedules are front loaded so that early procurement is possible



More material required, especially structural steel and higher logistic costs

PPMOF application individually evaluated as per international standards





Quick overview

20 years+ Modularization experience across technologies and countries with early focus on Australia

Recent references are deliveries of 50 modules to Europe in 2020 and 14 modules to the US in 2017

Many internationally experienced yards within only 1hr from our office and direct RoRo-port access

Yards follow high safety and quality standards and have excellent productivity

Thailand stable as a country

Thailand office

Module yard



We assist our customers to de-risk their projects and increase certainties



Improved
safety



Higher estimate
accuracy



Increased speed
to market



Better schedule
reliability



Less risk from industry
relations and labor access



Increased
quality



Thank you for your attention



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Pushing the Limits: Large Ammonia Plants

Uhde Ammonia Technology Users' Group Meeting

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



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Pushing the Limits: Large Ammonia Plants

Agenda



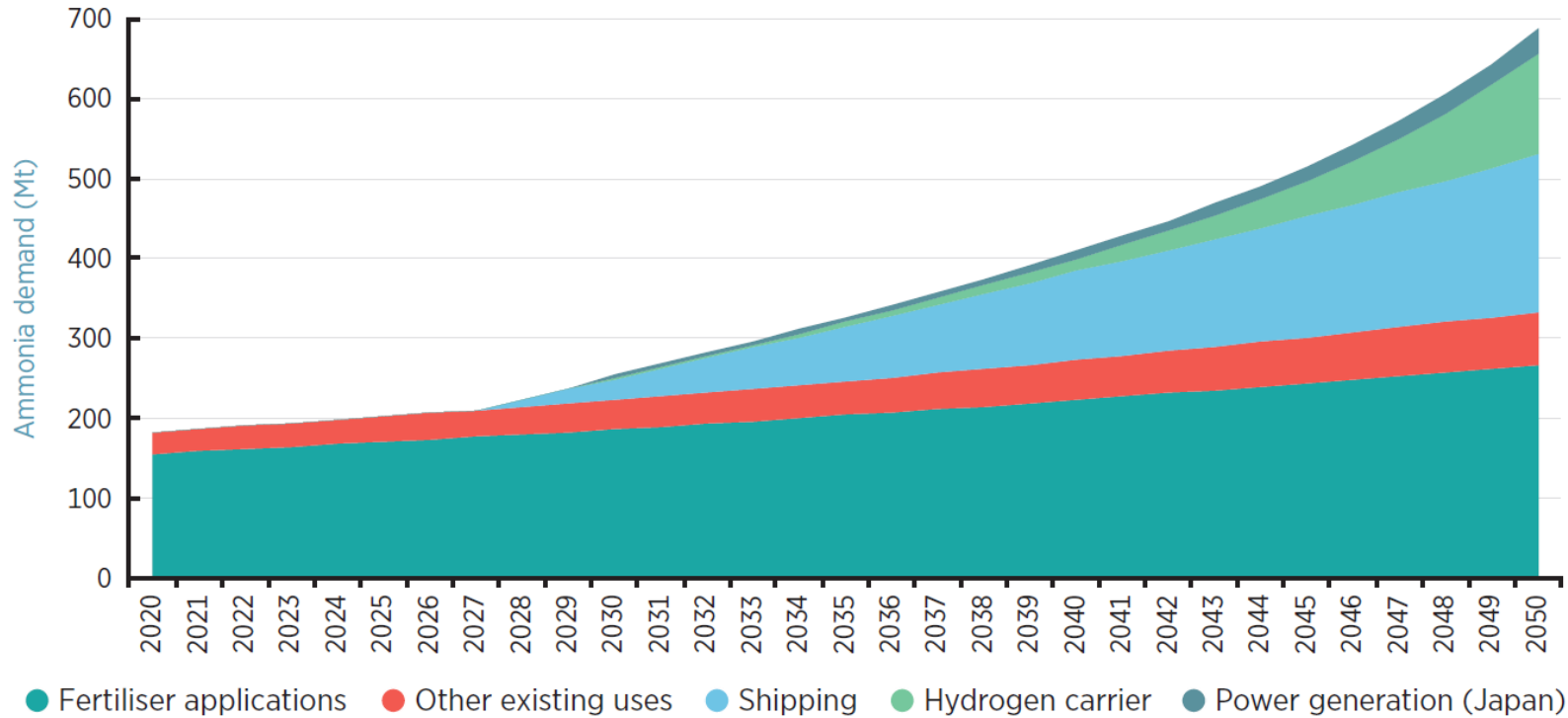
- 1 Motivation for large scale ammonia production
- 2 Uhde's large scale ammonia plant history
- 3 Safe scale-up: the Uhde way
- 4 ATR: The enabler for pushing the limits
- 5 Conclusion



Market forecast for ammonia demand

Bright future for ammonia producers

Expected ammonia demand up to 2050 for the 1.5°C scenario ¹⁾



- Increasing demand by 33% from 188 MMt/a (2020) to 250 MMt/a (2030) ¹⁾
- Completely new ways of ammonia usage
- Maritime applications alone will grow to 180 MMt/a in 2050
- Substantial requirement for installation of additional production capacity
- Can only be achieved with large scale plants
- Driver: Government and company commitments to GHG neutrality until 2050

Expected substantial growth in ammonia demand for the energy sector – but it has to be CO₂-neutral

1. IRENA and AEA (2022), Innovation Outlook: Renewable Ammonia



Ammonia production pathways

From gray 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/year¹
- Use of ammonia as chemical feedstock, but mostly for fertilizer production (85%)

Expectation:

- Requirement to reduce CO₂ emissions in all industry sectors
- 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

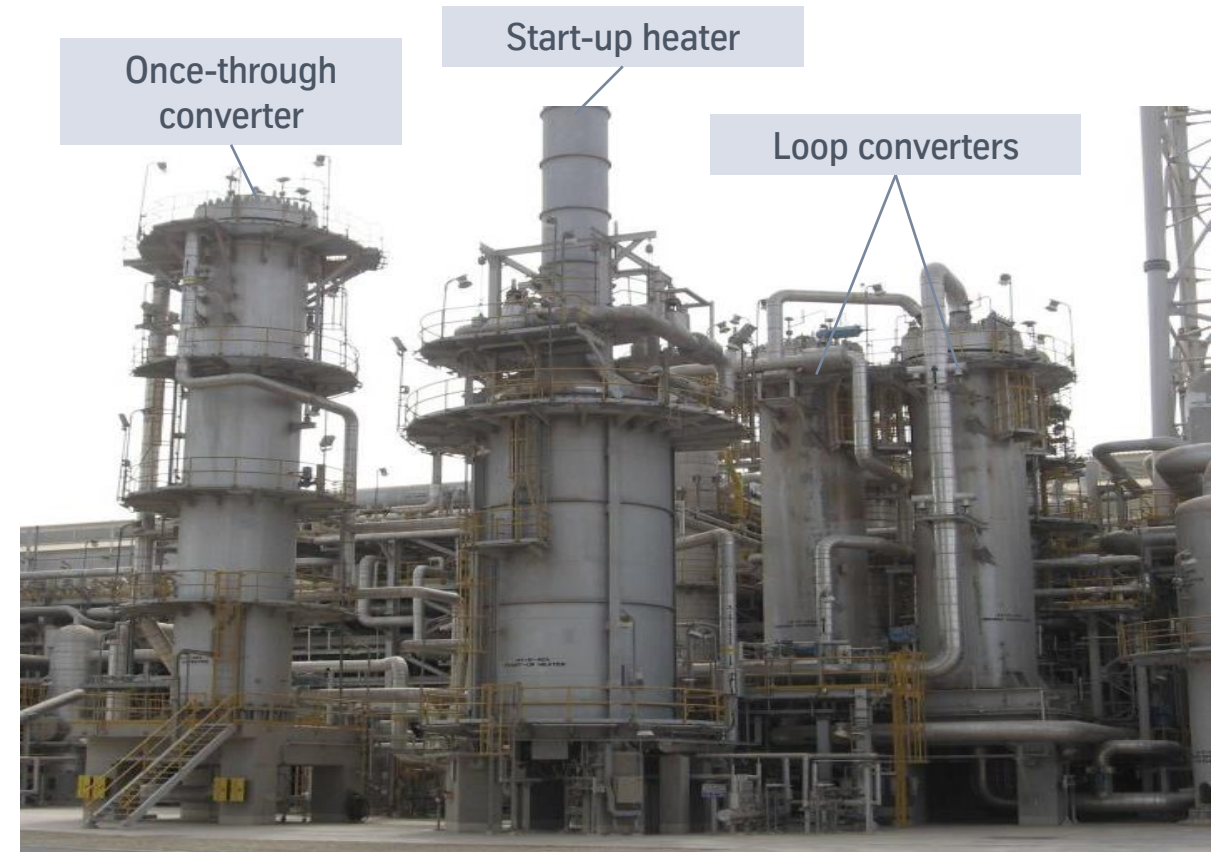
1. The Royal Society: Ammonia: Zero-carbon fertiliser, fuel and energy store, February 2020



2006: First newly built Dual-Pressure ammonia plant

A look back in history

- First installation of Uhde's Dual-Pressure ammonia process in newly built plant: SAFCO 4 back in 2006



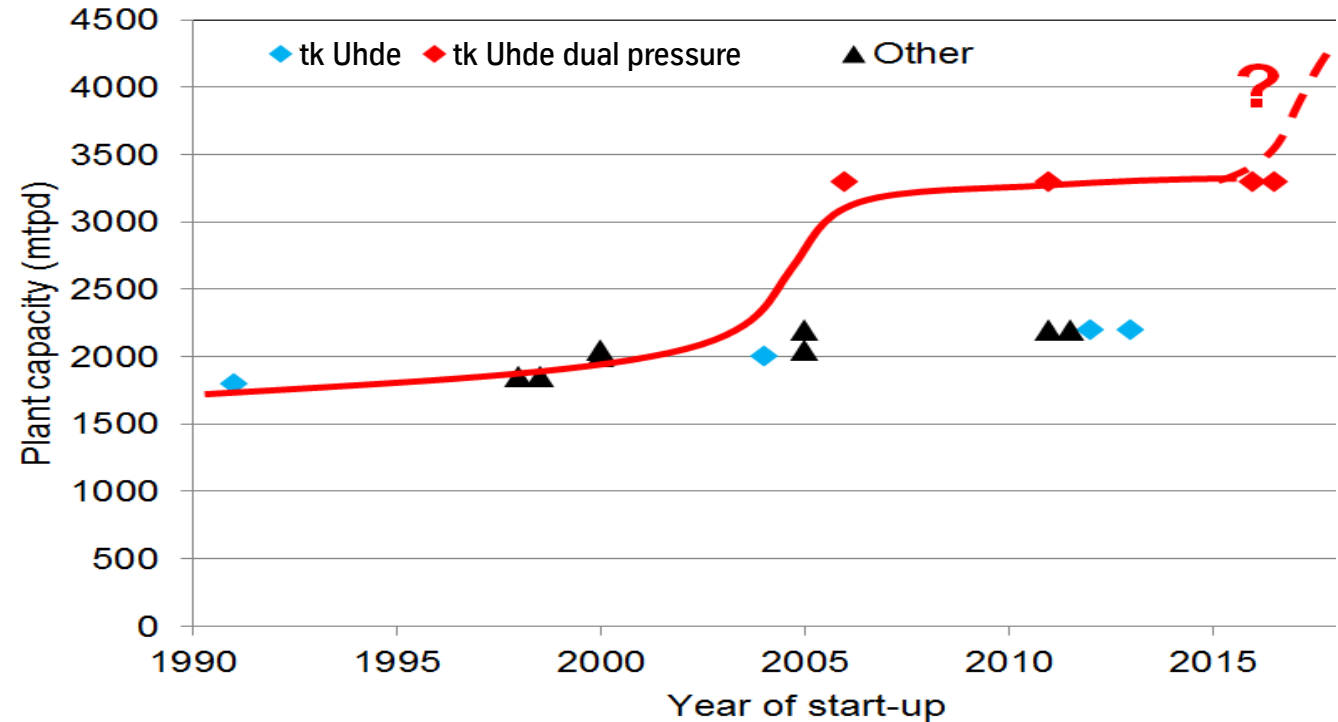
SAFCO 4: Largest NH_3 plant of the world (currently at 3,670 mtpd), a major milestone in NH_3 history

Uhde Dual-Pressure ammonia plant achievements

A story of success

- Dual-Pressure process is first to allow for capacities of 1 million tons ammonia per year
- 5 new plants from tk Uhde within 15 years:
 - 16,500 mtpd = 5.8 million tons per year production
 - 3.2% of the world's ammonia production
- 6th plant is under construction (QAFCO 7)

Selection of large-scale ammonia plants

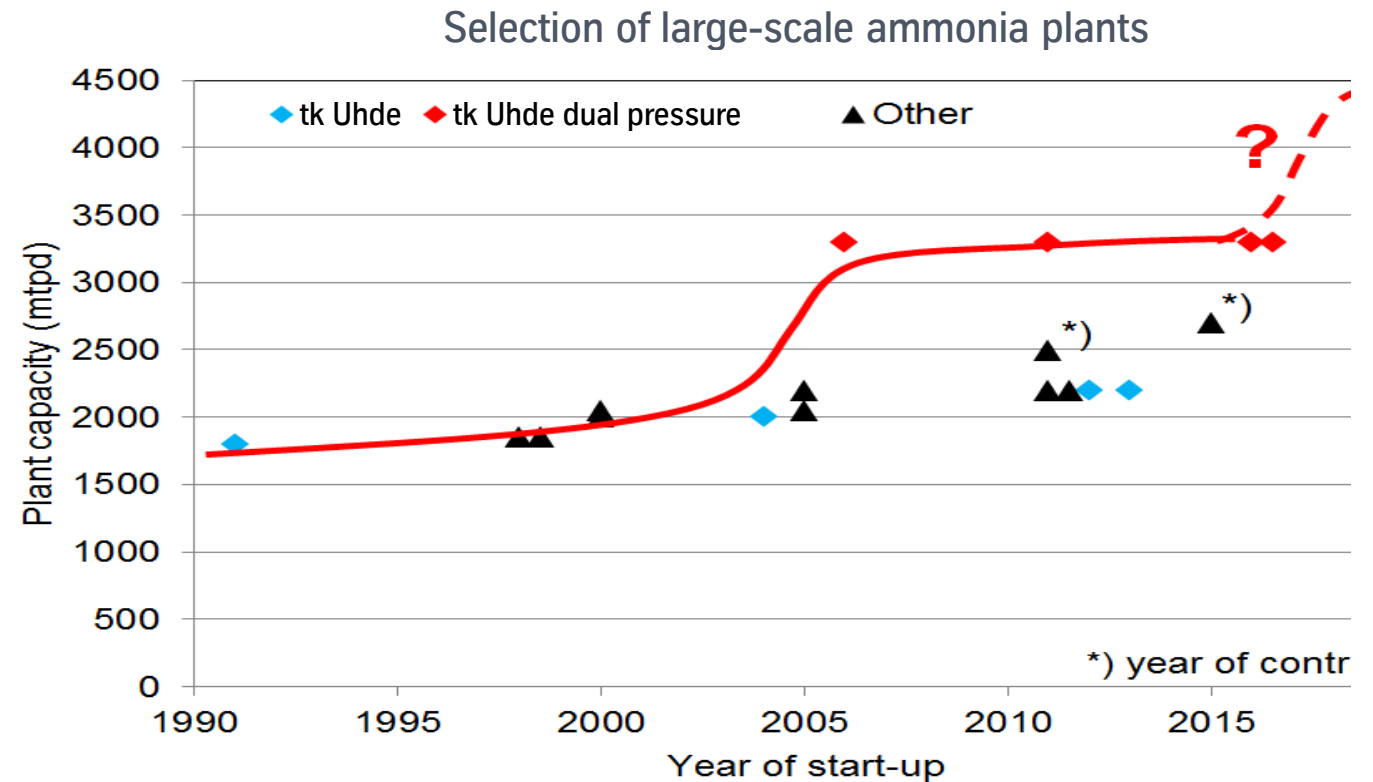


Is this the end of new developments?



Response of market and competitors

- Other projects with capacities of 2,500 and 2,700 mtpd appeared:
 - competitors offered conventional processes
- Expect more projects around 3,000 to 3,500 mtpd for the next years, or even larger



Task for Uhde: check process for further improvements!



Critical equipment and scale-up

- Overview on risks associated with scale-up (seen as before in former scale-ups):

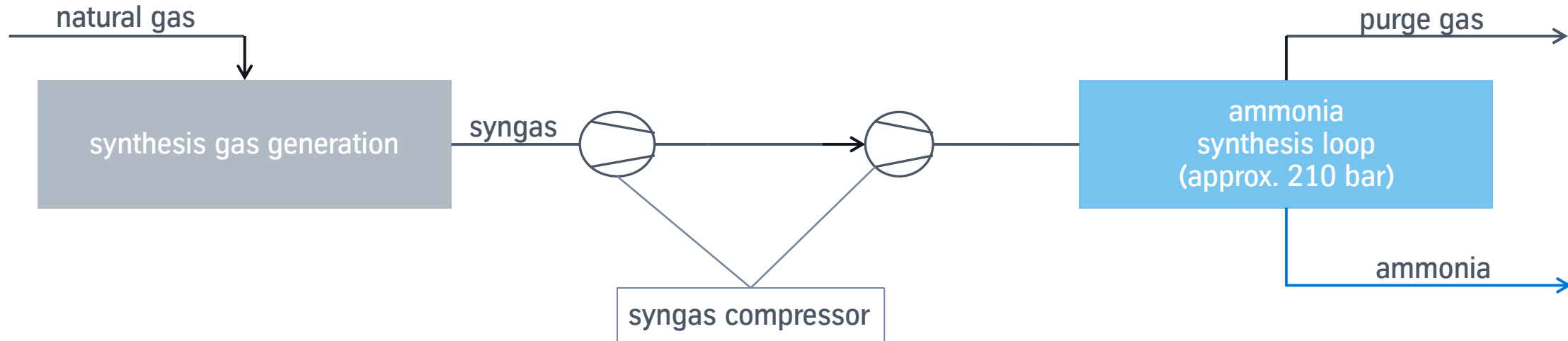
	Plant area	Scale-up risk
Front End	Reforming section	↓
	Process gas cooler	↗
	Process air compressor	→
	CO shift reactors	→
	Front end piping	↓
	CO ₂ removal	↗
Back End	Syngas compression	↑
	Synthesis equipment	↗
	Synthesis piping	↑
	Refrigeration compressor	→

Problematic area.
How to overcome this ?



Principle of Uhde Dual Pressure Process

- Conventional process

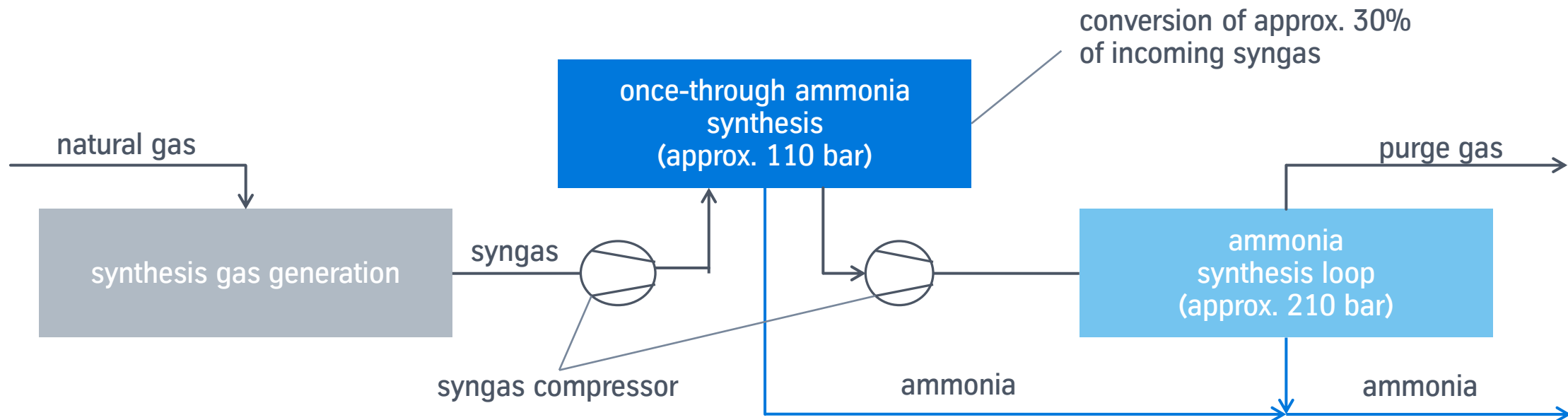


Principle of Uhde Dual Pressure Process

Increased production by Once-Through synthesis

exclusively from
thyssenkrupp Uhde

- Conventional process + once-through ammonia synthesis = dual pressure process



also applicable as
retrofit for existing
plants



Critical equipment and scale-up using Dual-Pressure Process

- Overview on risks associated with scale-up:

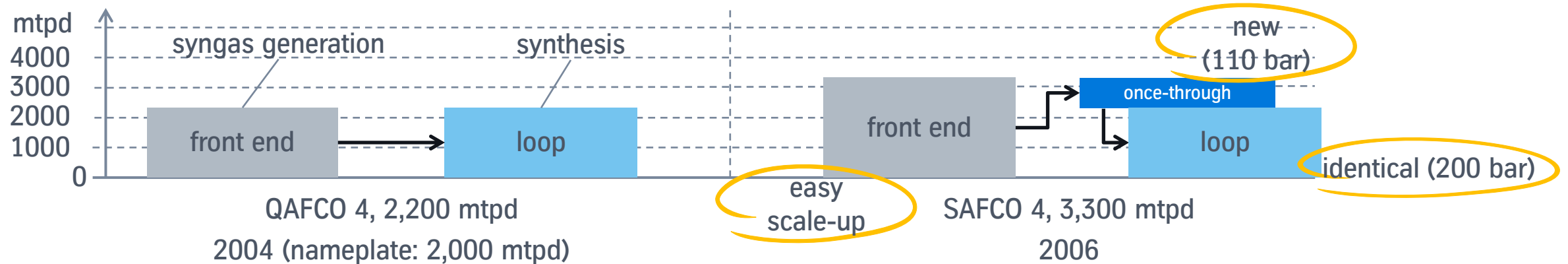
	Plant area	Scale-up risk	Scale-up risk with dual pressure process
Front End	Reforming section	↓	↓
	Process gas cooler	↗	↗
	Process air compressor	→	→
	CO shift reactors	→	→
	Front end piping	↓	↓
	CO ₂ removal	↗	↗
Back End	Syngas compression	↑	→
	Synthesis equipment	↗	↓
	Synthesis piping	↑	↓
	Refrigeration compressor	→	→

Improvement by dual-pressure process. Scale-up risks mitigated.



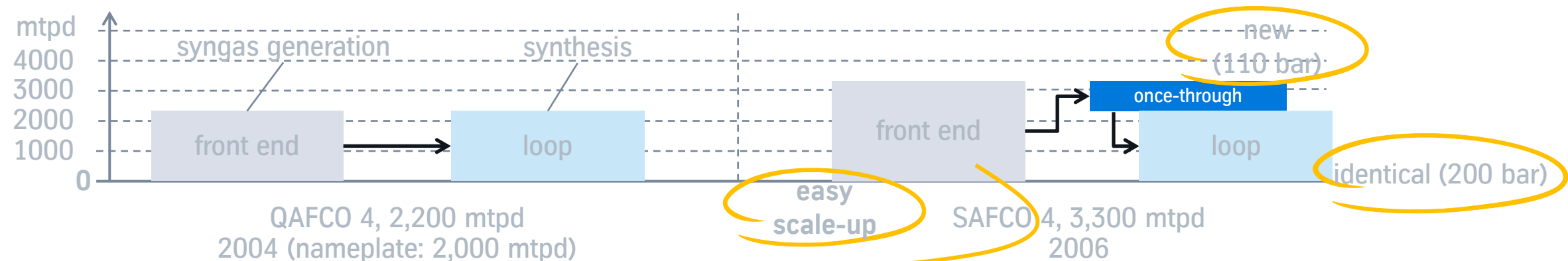
More than a decade of safe scale-up

- Previous development of large capacity ammonia plants at thyssenkrupp Uhde:

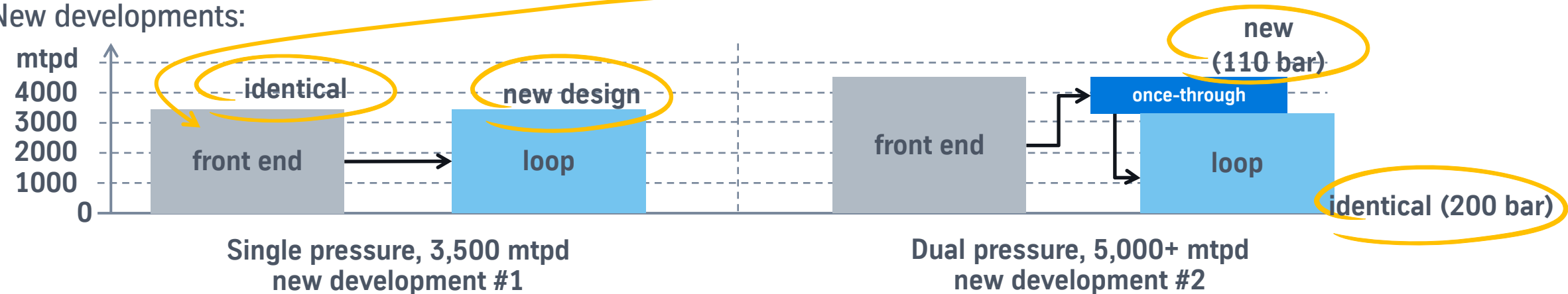


More than a decade of safe scale-up

- Previous development of large capacity ammonia plants at thyssenkrupp Uhde:



- New developments:



thyssenkrupp Uhde's strategy to minimize the scale-up risk – continuing until today



Pushing the limits: Syngas generation

- Uhde has concepts for the synthesis (back end) of 5,000+ mtpd, based on the proven Dual Pressure technology
- But what about the syngas generation (front end)?
- Scale up of an SMR has its limitations:
 - Flue gas and temperature distribution becomes critical
 - More structural steel required for reinforcement
 - Increasing construction effort
 - Startup time becomes longer and needs more attention
 - Operational issues increase due to plurality of burners, valves, tubes, instruments etc.



→ We need a new approach for large scale syngas generation



Syngas generation with ATR

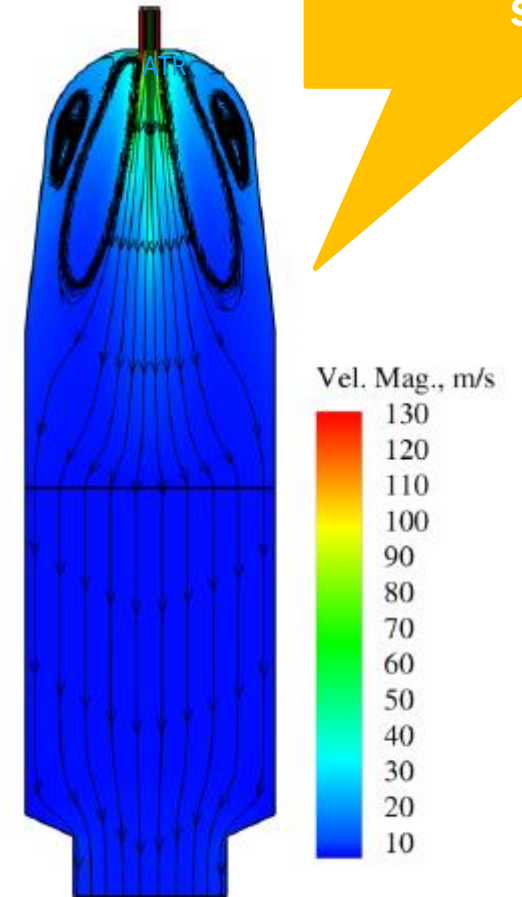
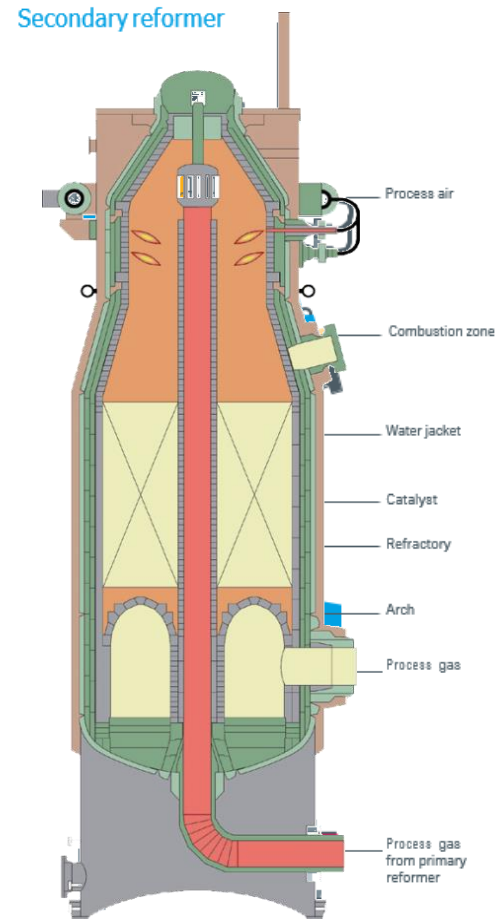
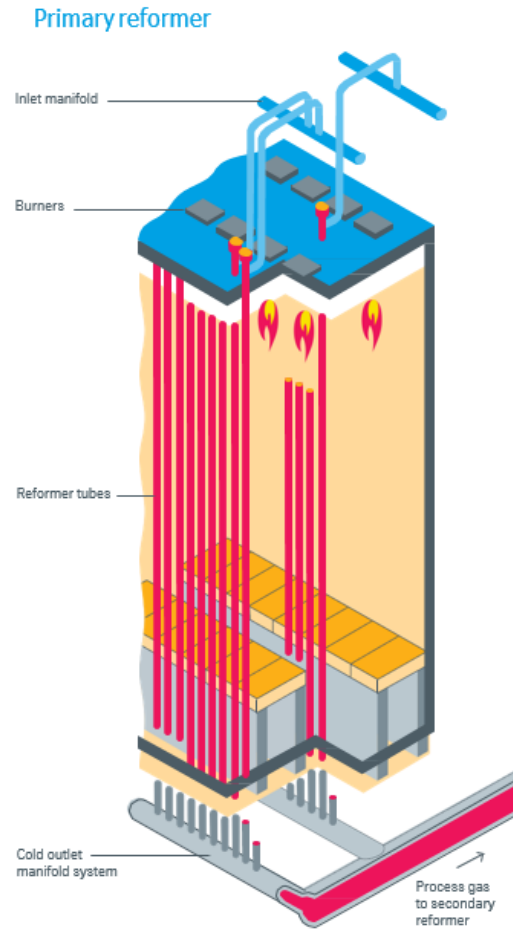
Basics

- ATR technology: Autothermal reforming
- Hydrocarbons + steam are reacting at very high temperature to form H_2 , CO and CO_2
- Technically it is a combination of steam reforming and partial oxidation
- Heat for reforming is provided “on the inside of the process” by burning parts of the feedstock with pure oxygen
 - Exothermal combustion zone:
$$\begin{array}{l} O_2 + 2 CH_4 \rightleftharpoons 2 CO + 4 H_2 \\ O_2 + 2 H_2 \rightleftharpoons 2 H_2O \end{array}$$
 - Endothermal reforming zone:
$$\begin{array}{l} CH_4 + H_2O \rightleftharpoons CO + 3 H_2 \\ CO + H_2O \rightleftharpoons CO_2 + H_2 \end{array}$$
- ATR technology is applied for many years in large scale methanol plants
- ATR is fired with oxygen instead of air → no inert N_2 in the front end !
- ATR can be operated at significantly higher pressure



Comparison of reformers

SMR vs. ATR



The ATR is comparatively simple

2 Steam Reformers are required for the SMR Technology while for the ATR Technology only 1 Autothermal Reactor is necessary

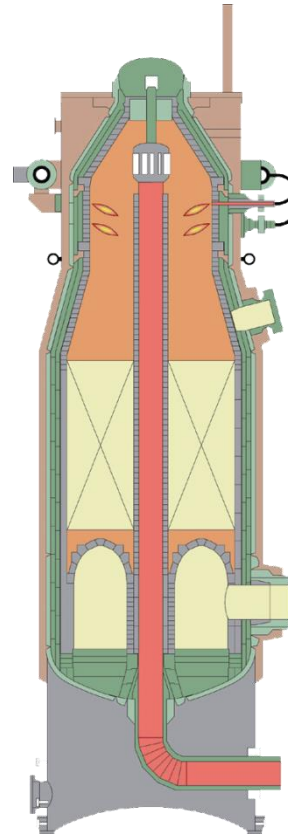


Comparison of reformers

Syngas production (Example for 3,500 mtpd Ammonia)

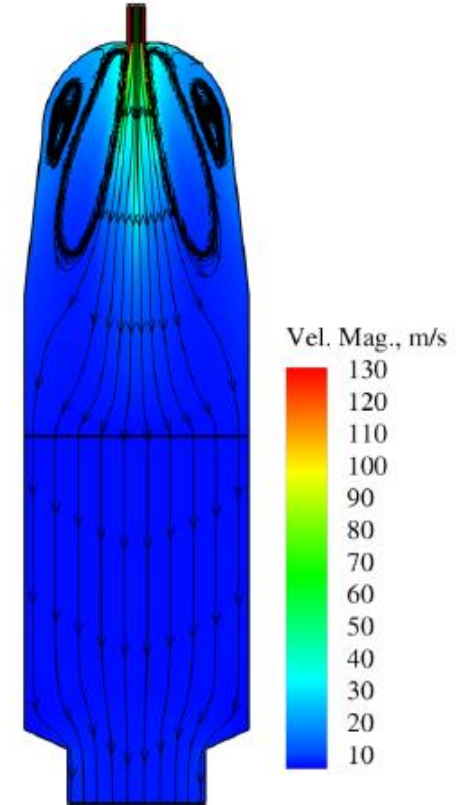
Secondary reformer

Reformed Gas	460 t/h
T _{out}	approx. 1,000 °C
p	approx. 45 bar
ID (refractory)	4,150 mm
Height	approx. 20 m
Weight	approx. 220 t



Autothermal reformer

Reformed Gas	460 t/h
T _{out}	approx. 1,000 °C
p	> 60 bar
ID (refractory)	4,150 mm
Height	approx. 24 m
Weight	approx. 280 t



The dimensions and weight of an ATR is well known from todays secondary reformers



ATR front end scale up

Advantages

- The ATR is a single and simple reactor
- The basic construction of the pressure shell is comparable to well known secondary reformers
- Through its simplicity it gains high reliability
- Construction cost at site are significantly lower
- High pressure and absence of nitrogen enable small equipment and piping sizes
- Decades of industrial experience are available, especially from employees of our partner GasConTec
- ATR scale-up studies conducted up to 5,650 mtpd ammonia
- Other process units like fired heaters or ASU have been referenced even at larger scale

→ ATR is the right technology to scale-up for trouble-free large scale syngas production



ATR process options for CO₂ emission reduction

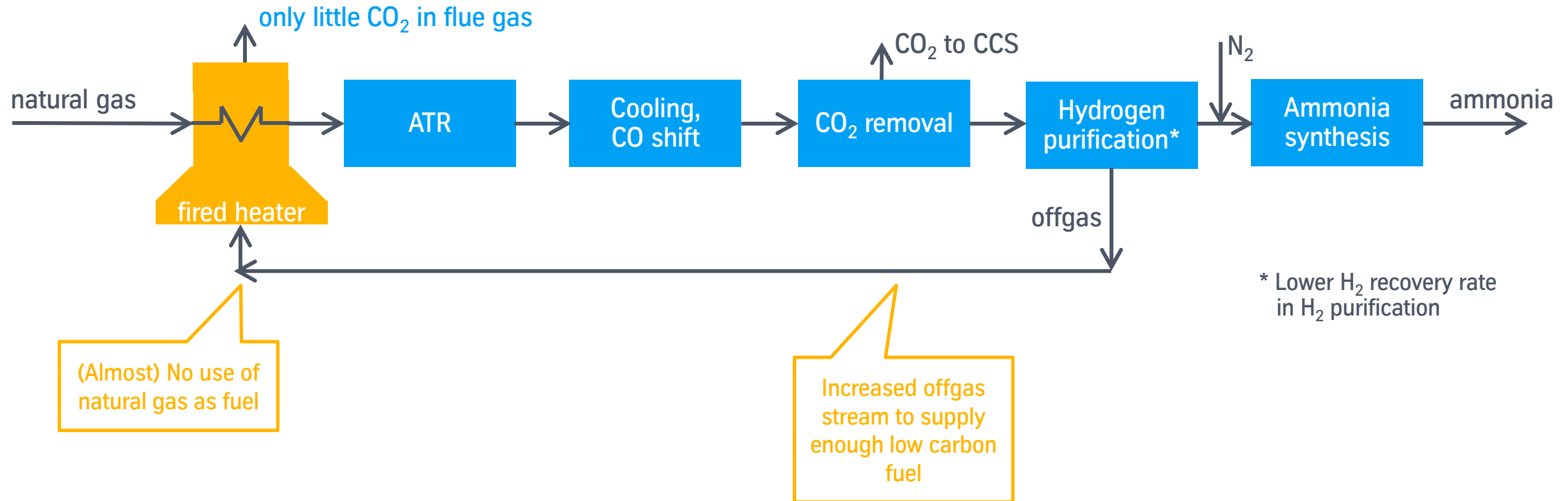
High CO₂ reduction and high flexibility

- The fired heater in the ATR process has less firing duty and hence has 43% less CO₂ emissions in its flue gases
- For further reduction of CO₂ from fired heater flue gas, firing with carbon-reduced fuel can be applied
- Carbon-reduced fuel is achieved by:
 - natural gas fuel substitution with increased amount of process offgas stream
 - and for further increase of CO₂ capture rate up to 99% :
 - additional treatment of process offgas stream before combustion to reduce carbon content of fuel
 - separated carbonaceous components will be recycled to the process side
- No need for flue gas washing unit
- Carbon capture rate in ATR process can be adopted to project requirements, but front-end will be artificially blown up



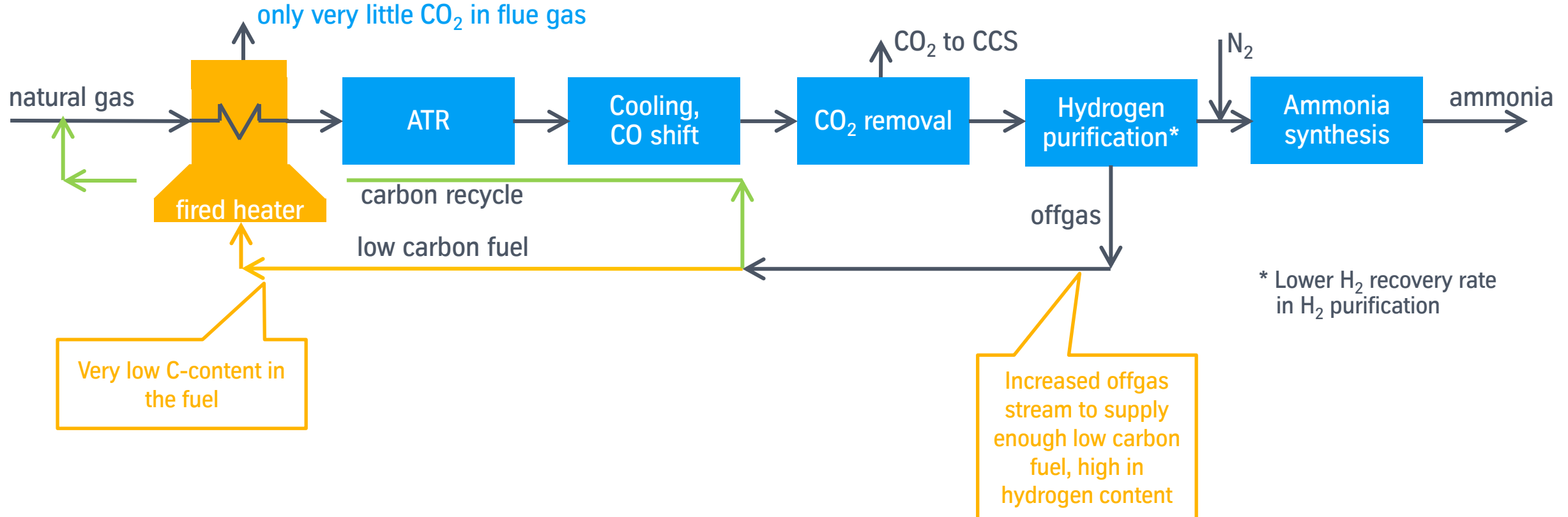
Optimized ATR process (1)

ATR process, optimized for **blue ammonia**: only 1 point of CO₂ emission to be tackled in case CO₂ emission shall be reduced by 90%



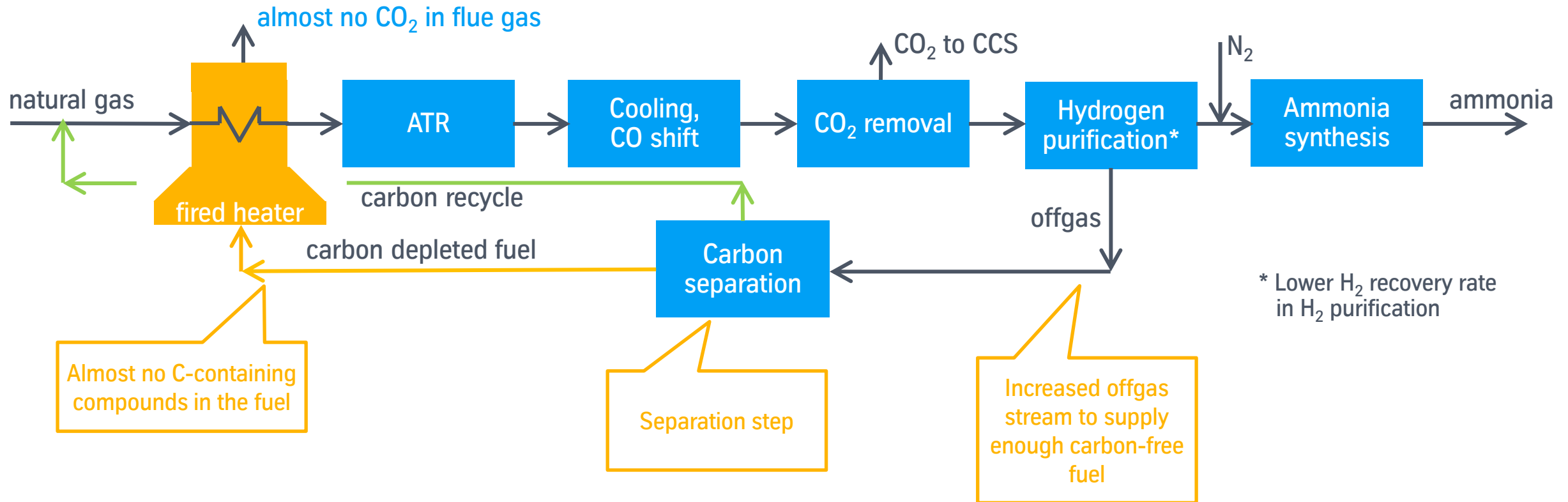
Optimized ATR process (2)

ATR process, optimized for **blue ammonia**: only 1 point of CO₂ emission to be tackled. Carbon recycle together with low-carbon fuel enables CO₂ emission reduction by 95%



Optimized ATR process (3)

ATR process, optimized for **blue ammonia**: only 1 point of CO₂ emission to be tackled. Offgas decarbonization paves the way for carbon-free fuel, which enables CO₂ emission reduction by 99%



The ATR technology offers high capture rates and can be customized to your needs



Pushing the Limits: Large Ammonia Plants

Conclusions

- Ammonia as a carbon-free energy carrier creates new markets for ammonia producers
- Expectations in future ammonia demand are huge
- thyssenkrupp Uhde is a pioneer in large scale ammonia technology
- Ammonia synthesis scale-up is mitigated by the successfully applied Uhde approach
- SMR technology has some pitfalls when it comes to very large capacities
- ATR technology due to its simplicity can be scaled-up easily
- The ATR process offers high and adjustable CO₂ capture rates with comparatively low effort
- Ammonia production capacities of up to 6000 mtpd can be realized as single train
- CO₂ emission reduction up to 99% can be achieved

thyssenkrupp Uhde is ready to push the ammonia plants together with you to new limits



Thank you for your attention



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Hydrogen from ammonia - Ammonia cracking

Uhde Ammonia Technology Users' Group Meeting

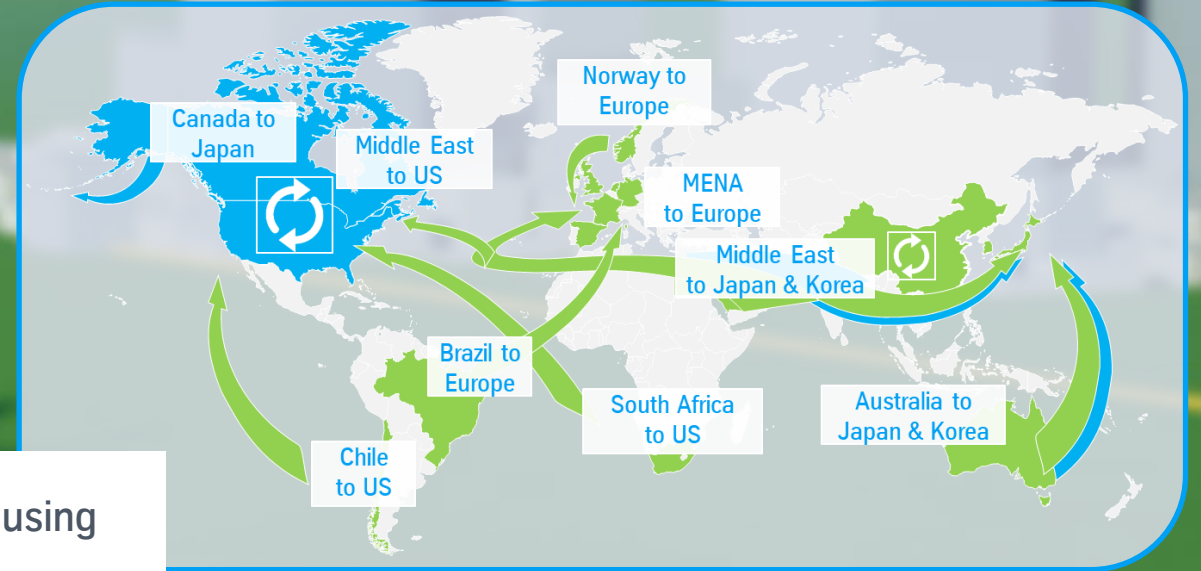
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Green hydrogen – an ideal energy carrier ...so is green ammonia

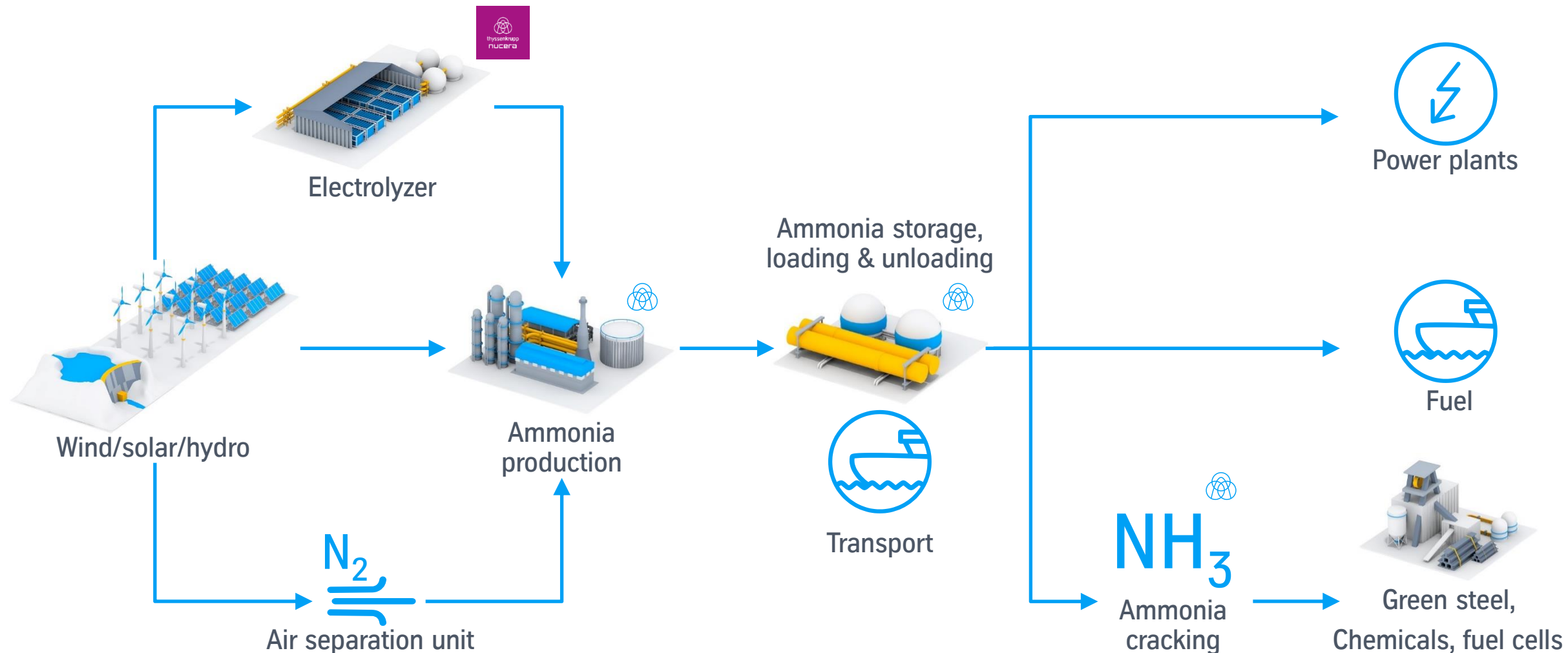


- CO₂ emissions-free production by water electrolysis using water and renewable energy
- Various options for utilization: fuel cells, combustion, mixing with other fuels, chemical feedstock
- Competitive price with production at locations with abundant resources of renewables



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



Ammonia as hydrogen carrier

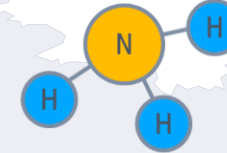
Why ammonia?

Transport of hydrogen



- Low volumetric energy density
- High pressure to transport as a gas or extremely low temperature of -253 °C for transport as a liquid
- High effort/energy input
- Infrastructure needs to be developed

Transport of ammonia



- High hydrogen density (17.8 wt.-%)
- -33 °C for transport as a liquid
- High, but known effort
- Transport by ship is proven technology
- Large-scale infrastructure available

Transport of NH_3 over long distances is state of the art



Location of ammonia cracking

Centralized vs. local NH₃ cracking

Location of ammonia cracking

1

Local small-scale cracking



- No hydrogen infrastructure required
- Advantages of ammonia transport up to consumer
- Electrically heated process suitable



- Additional ammonia infrastructure needs to be developed in parallel to hydrogen if available
- Risks/restrictions for ammonia transport by train or truck
- Higher specific investment/operation costs
- Increased CO₂ footprint if electric power is not generated totally from renewables

2

Centralized large-scale cracking



- Economy of scale
- Integration into an existing regional hydrogen economy
- Fired reactor technology suitable



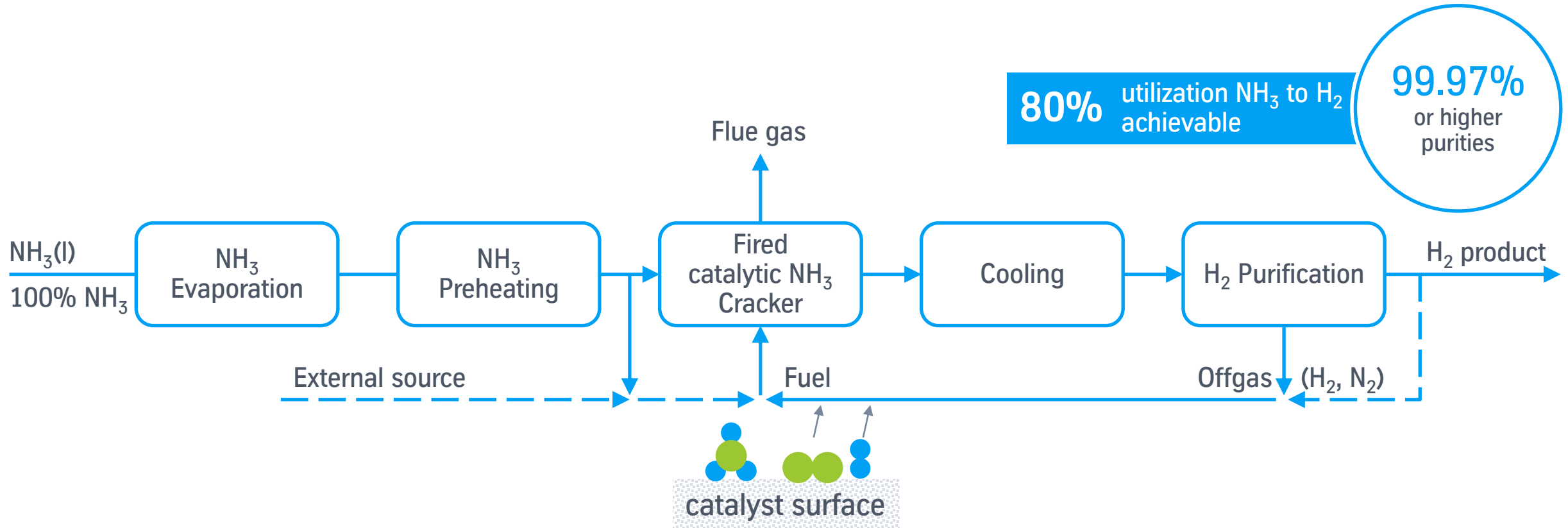
- Hydrogen infrastructure needs to be developed if not available
- High effort for authorities' approval

Centralized large-scale units can achieve higher energy efficiency and lower CO₂ emissions



Hydrogen from ammonia - ammonia cracking

thyssenkrupp Uhde developments



- Based on Uhde's well proven SMR prop. equipment
- High catalytic NH₃ conversion to H₂ (above 98%)
- Purities adaptable to requirements of user

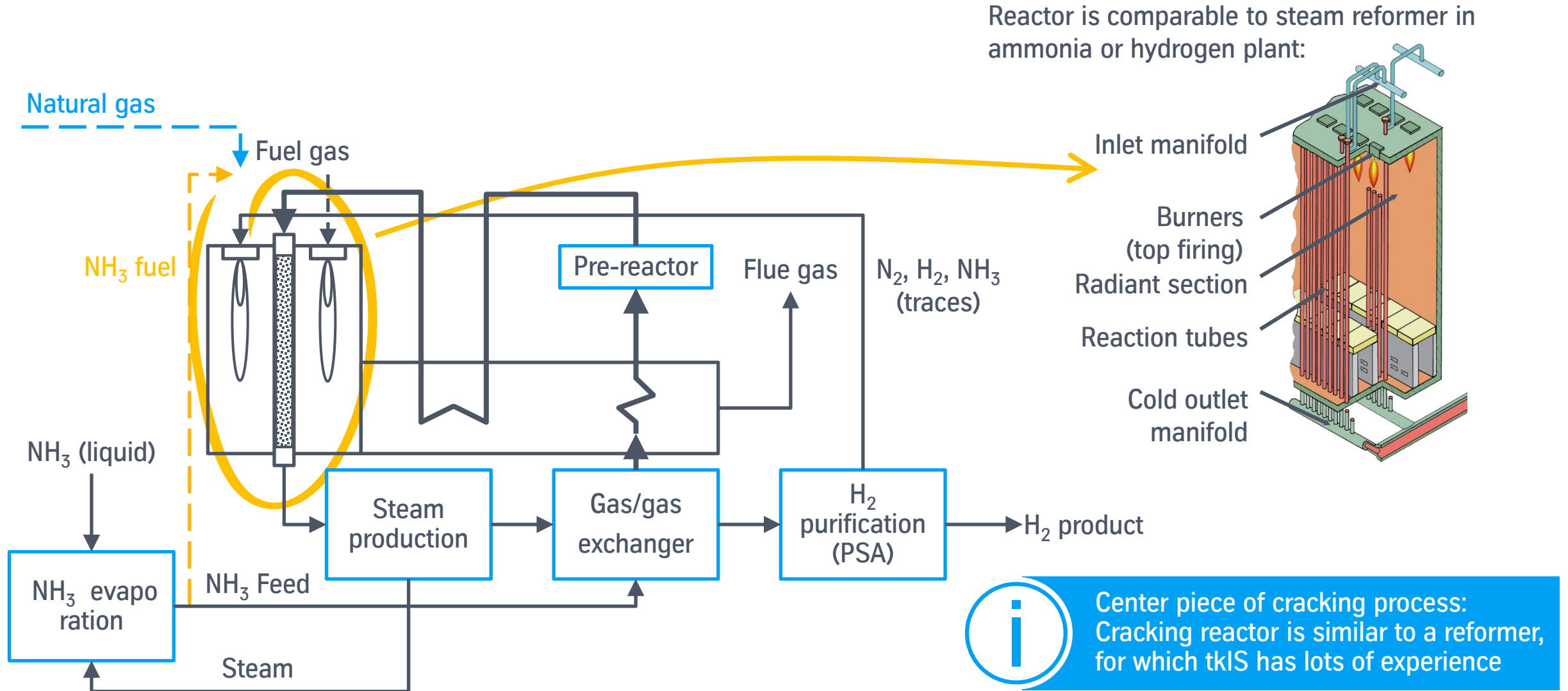


- Already proven in 1970's in small-scale units
- Designed for large scale solutions up to 3,000mtpd
- State-of-the art catalysts



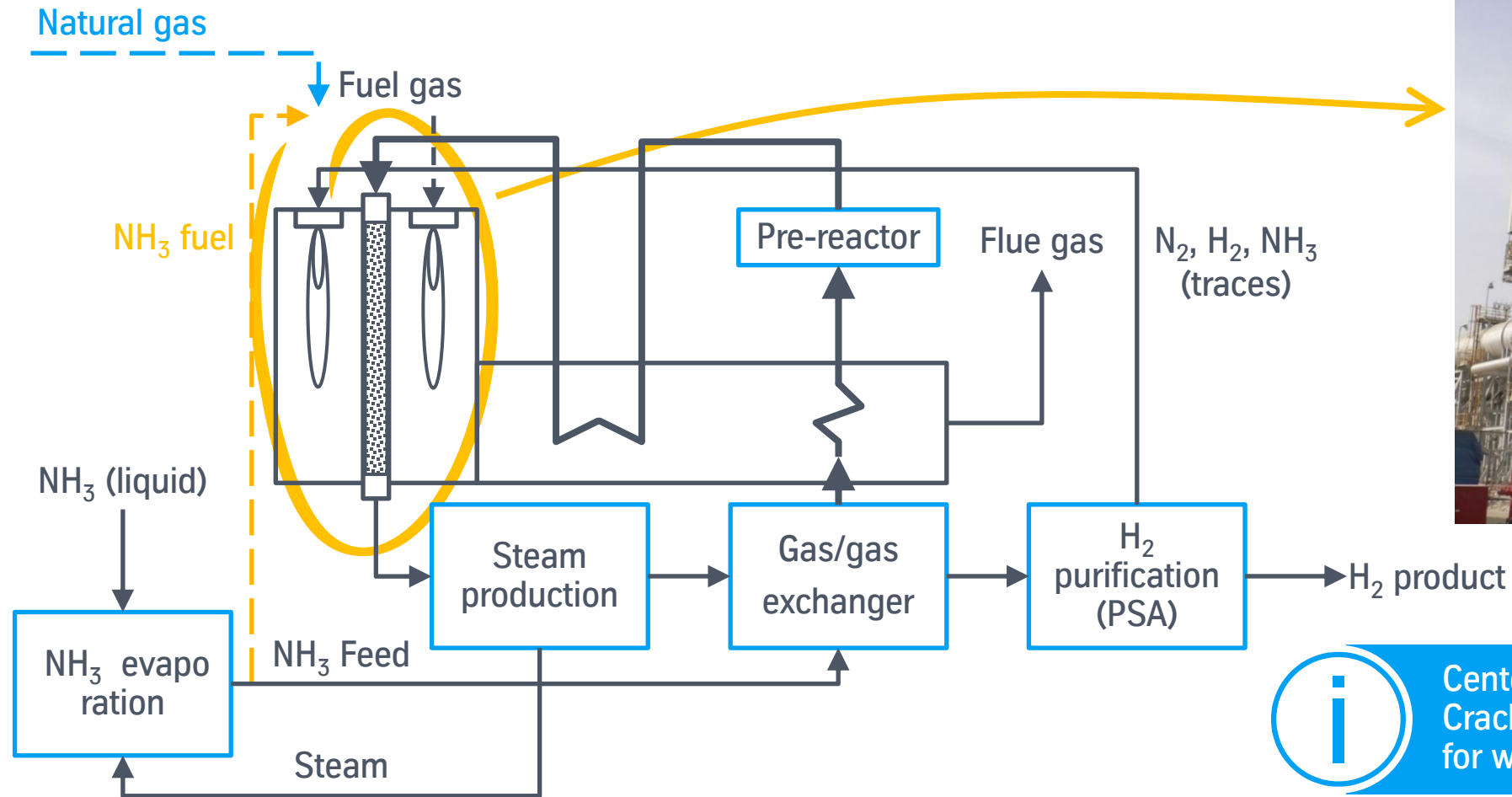
Ammonia cracking technology

SMR – the DNA of Uhde



Ammonia cracking technology

SMR – the DNA of Uhde

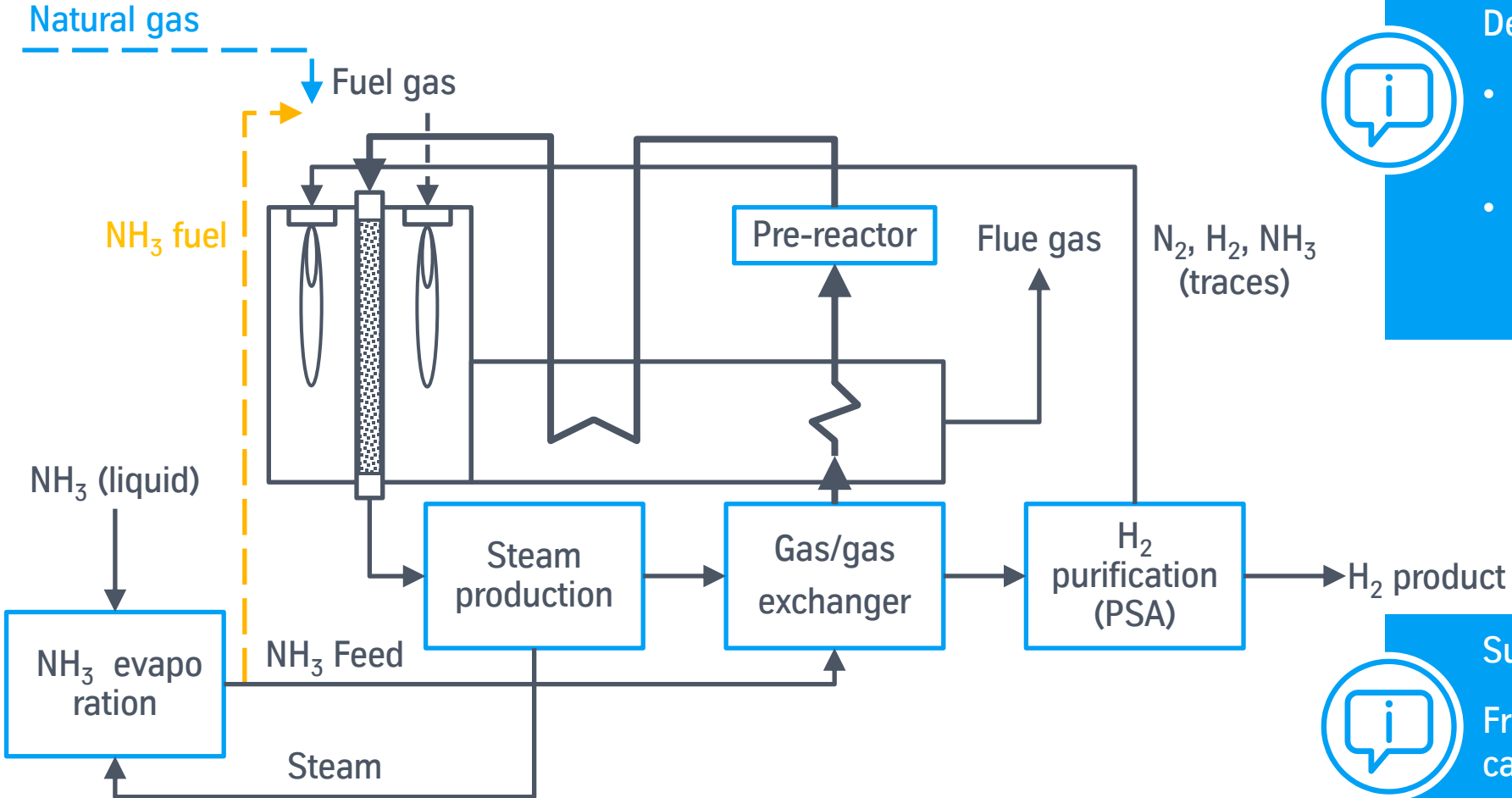


Center piece of cracking process:
Cracking reactor is similar to a reformer,
for which tkIS has lots of experience



Ammonia cracking technology

SMR – the DNA of Uhde



Decision on:

- Heat source (should be “green”), also electrical energy possible
- Energy integration of heating and cooling step (internal heat exchange)

Suitable for large scale applications

From 1 kg NH_3 0.14 kg H_2 can be produced

Purities of 99.97% or higher are possible

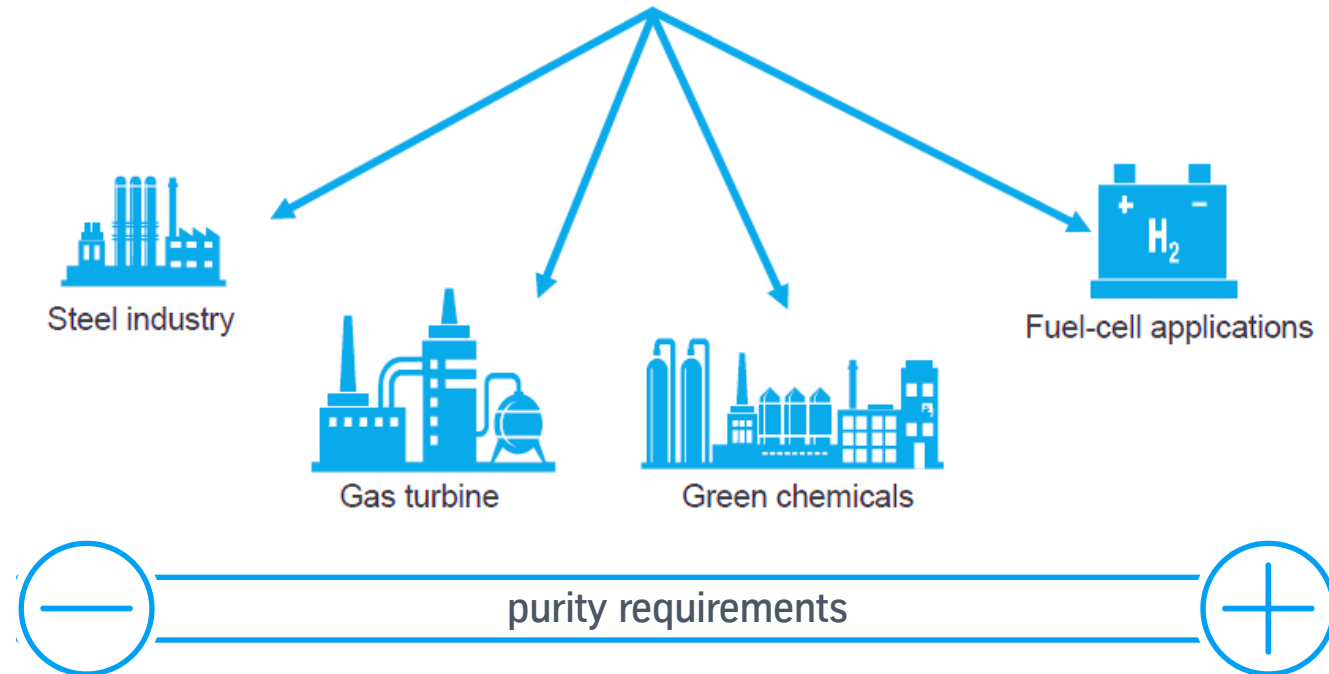
Green ammonia to green hydrogen

Our technology, your market



Decision on:

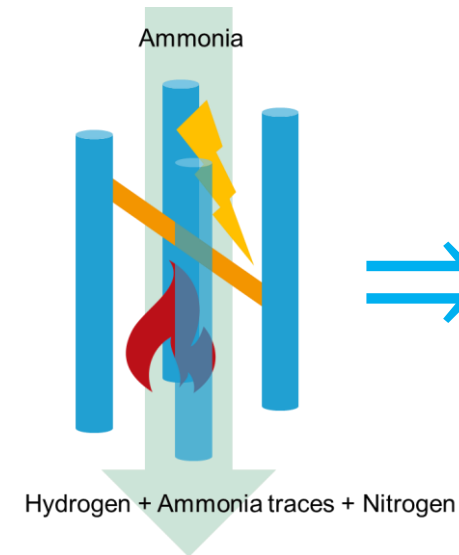
- Product purity with respect to residual NH_3 and N_2 content
- Technology for last purification step (e.g. PSA, membrane)



Ammonia cracking

Ongoing development for large-scale process

- Burner / combustion behavior research:
 - Flame pattern research with H_2/NH_3 mixtures. Burning too fast (H_2) or too slow (NH_3); temperature profile on flue gas side?
⇒ Uhde has carried out tests with research centers and burner manufacturers: Stable flame can be obtained
 - Flue gas contains NO_x and N_2O
⇒ Uhde has vast experience in its EnviNOx[®] technology for N_2O abatement of offgas of nitric acid plants
- Reaction behavior inside the reaction tube:
 - Temperature profile and influence on kinetics; equilibrium tests
⇒ Tests will be made in heated pipe section (only fixed bed and / or single electrically heated reformer tube necessary)
- Demonstration plant to enable scale-up:
 - Set-up of heated reactor with reduced number of reaction tubes (~30 mtpd NH_3 / 5 mtpd H_2)
⇒ Demonstratoin plant under engineering



Ammonia cracking

Summary

- Green hydrogen (from electrolysis, using electricity from renewable sources) and blue hydrogen:
High potential for CO₂-free energy
- Transport of hydrogen to consumers over long distances is difficult:
Here ammonia comes into play
 - Ammonia production is a mature technology
 - Ammonia transport is an established business
 - Use as energy carrier or re-conversion to hydrogen:
both possible without CO₂ emission
- Ongoing developments:
 - Green ammonia: making ammonia process flexible
to match the fluctuating availability of electric power
 - Ammonia decomposition to hydrogen: Optimization of the large-scale process with respect to capex and opex
- Expected penalties on CO₂ emission make investment in green and blue ammonia feasible



Thank you for your attention



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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!