

Uhde innovate 2024

Innovative technologies for blue and green ammonia

05.06.2025 | Tobias Birwe & Karan Bagga
thyssenkrupp Uhde

engineering.tomorrow.together.



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Ammonia production pathway

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/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

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

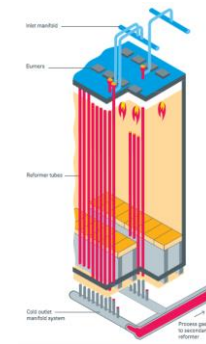


Technical Options for Large Scale Blue Ammonia Plants

Overview

Tubular steam reformer (SMR):

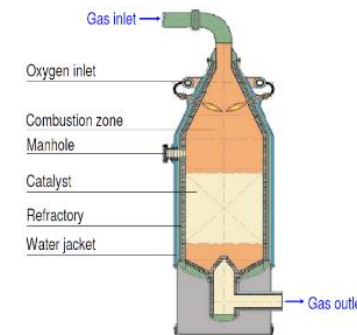
- State-of-the-art technology for ammonia plants: 5 largest running plants by Uhde, all with capacity of 3,300 mtpd or more
- 6th and 7th plant in execution
- With further size increases, maintaining equal temperature distribution can be challenging. However, up to 5,000 mtpd, our design ensures it is effectively manageable



... for blue plants, >75% CO₂ capture needs CO₂ removal from flue gas (PCCC)

Autothermal reformer (ATR):

- References for methanol plants exist, comparable in size to >5,000 mtpd ammonia
- Basic engineering incl. modularization completed for plant size of 3,500 mtpd
- Needs air separation for O₂ and N₂ supply
- In development for capacities up to 6,000 mtpd with high levels of confidence in scalability



... little CO₂ from fired heaters only, almost all CO₂ can be directed to process, easy to capture at ≥90%



Technical Options for Large Scale Blue Ammonia Plants

Comparison Steam Reformer vs. Autothermal reformer (ATR)

No additional CO ₂ recovery from flue gas required for CO ₂ reduction >70%	SMR	★	ATR ¹
Smaller front end due to later N ₂ addition	SMR	★	ATR
Smaller synthesis loop by fewer inerts in synthesis gas	SMR	★	ATR ¹
Lower capex for large plants	SMR	★	ATR
Lower construction effort, easier modularization and pre-fabrication	SMR	★	ATR
No air separation unit, no oxygen handling	SMR	★	ATR ²
Smaller syngas compressor (in case of higher front-end pressure)	SMR	★	ATR
Higher number of references, leading to lower project risk	SMR	★	ATR
Easier turndown operation	SMR	★	ATR
Lower operating cost	SMR	★	ATR
Blue hydrogen as additional (by-)product possible	SMR	★	ATR

1. for ATR in combination with Uhde’s selection of downstream gas cleaning steps | 2. ASU can be outsourced to operating company and supply over the fence



Uhde Ammonia Process with ATR-based Synthesis Gas Generation

Advantages



Technology integration and flexibility

- Supply of O₂ and N₂ over the fence by service provider possible
- Flexibility on ATR setup (ATR or ATR/GHR)
- Flexibility on steam setup
- CO₂ removal unit based on BASF OASE white® technology or physical CO₂ wash system



Commercial feasibility

- Small and compact NH₃ frontend
- Supply of O₂ and N₂ over the fence by service provider possible
- Plant easier to modularize resulting in less construction cost
- No inert gases resulting in reduction of size and cost of ammonia synthesis



Experience / reference

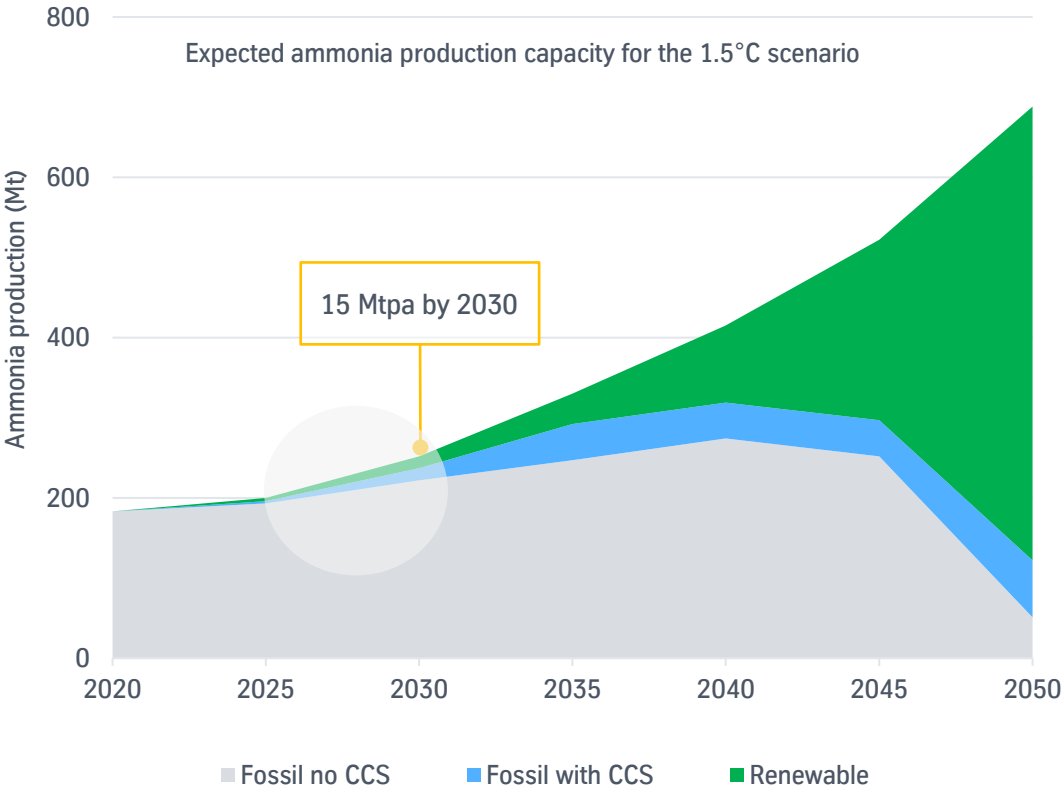
- The ATR is proven in many methanol plants in equal size
- Uhde is experienced in ATR processes and integrating the same
- All plant components are well proven at larger scale plants

Uhde recommends ATR technology for capacities over 4000 mtpd and with high CO₂ emission reduction targets



Green ammonia is set to be a megatrend, however the market development has been slow

Expected ammonia production capacity for the 1.5°C scenario



Expected market correction



Source: IRENA Innovation Outlook Ammonia, 2022 and Uhde estimates



What is driving the slow market development ...



Technology integration and execution risks

Financing institutes seek project bankability (end-to-end performance, cost, schedule..) → execution-ready solutions required to lower the cost of capital



High cost of production

2-3x more expensive (pre-subsidy) than grey ammonia, mainly driven by renewable power cost and plant utilization (renewables intermittency)



Variability in definition of clean hydrogen

Carbon intensity e.g. 3.38 - 4 kg CO₂/kg H₂ (EU - Korea)
Scope of emissions LCA e.g. Well to Gate, Shipping (in/out?)
Special conditions: Time matching of renewables e.g. RED III



Early influence on technical concept



Slow roll-out of policy seeding incentives

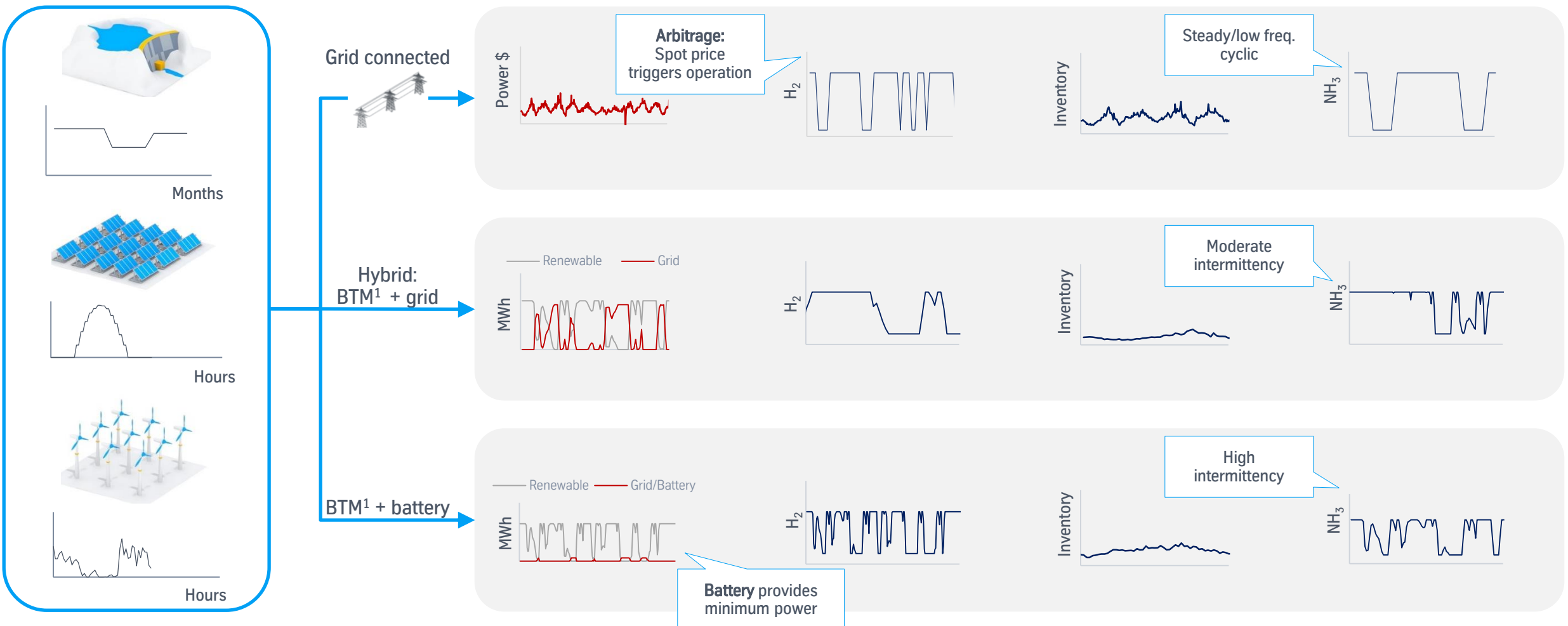
Policy support is limited to a few regions and trading chains e.g. US, EU, Australia, Japan and Sth. Korea



Focus



What do the integrated Power-to-ammonia concepts look like?



1. BTM: Behind the Meter or Island Mode



Credible techno-economic concept development is critical for the ultimate success of the project

Considerations



- Concurrent variables affect project viability
- Energy intermittency (deliberate or natural)
- Uncertainty (energy pattern, price..)
- Energy storage (size, form, cost, TRL..)
- Offtake pattern (constant, diurnal, seasonal..)
- Carbon intensity (CI) restrictions

Topics to solve

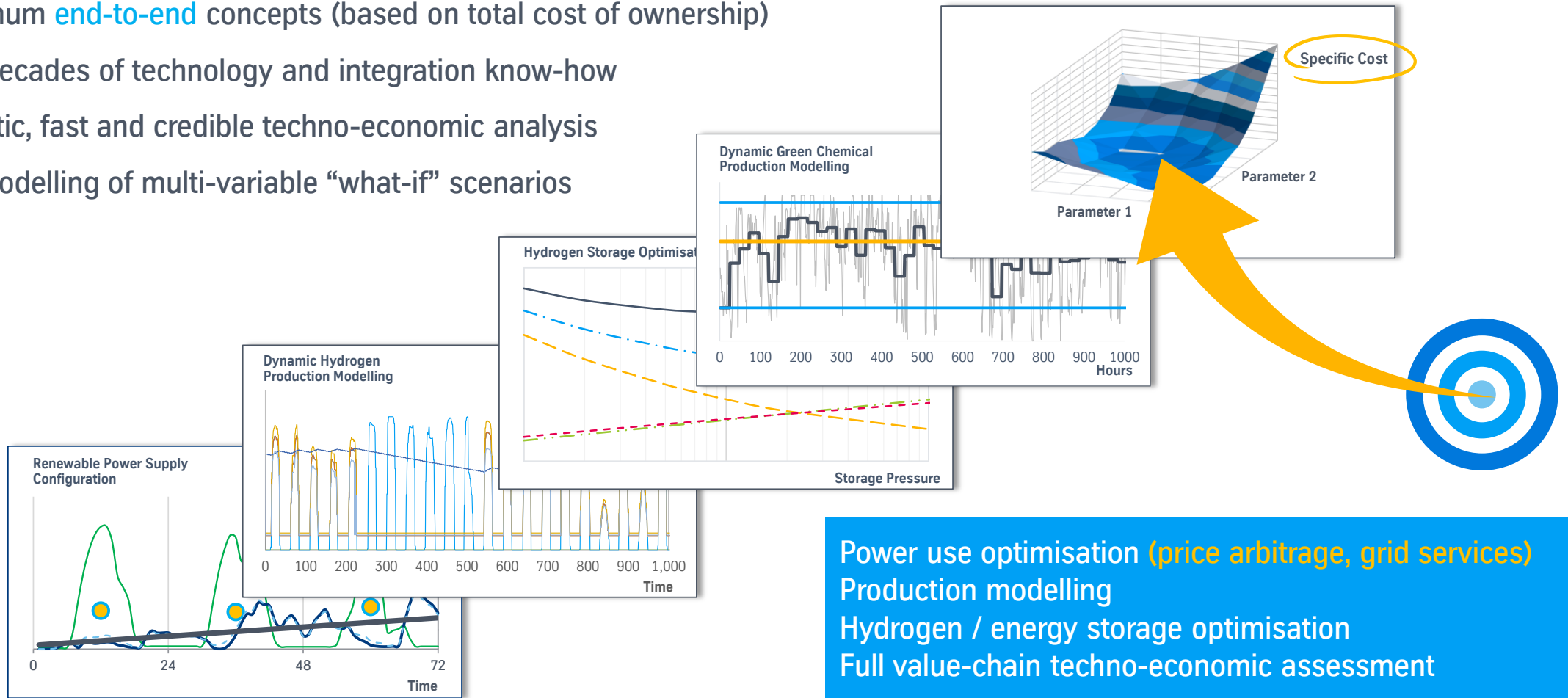


- What does the optimal flowsheet look like?
- How to reduce the production cost?
- How does the offtake pattern influence cost?
- What is the best geo-spatial site setting?
- How to handle future expansion scenarios?
- How to comply with the CI limits?

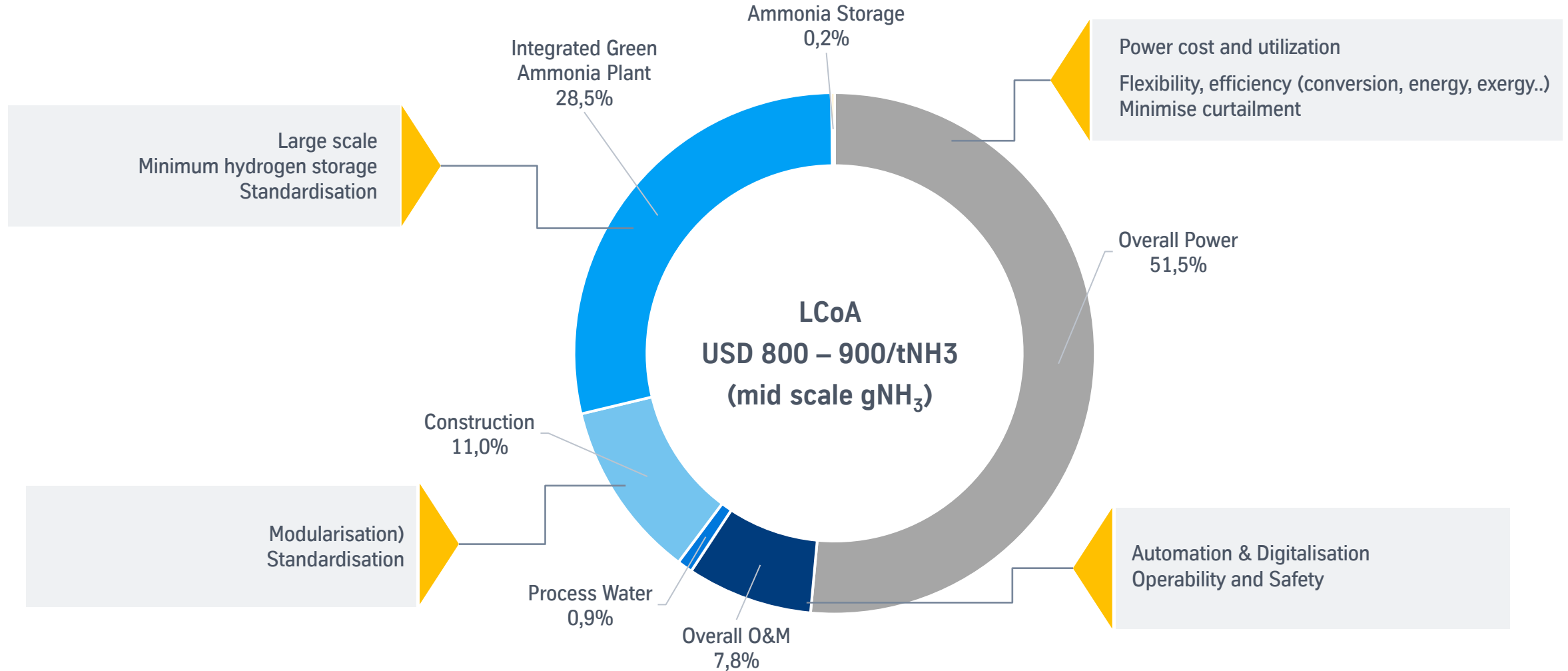


RHAMFS® - finding the sweet spot for your PtX business case

- Identify optimum **end-to-end** concepts (based on total cost of ownership)
- founded on decades of technology and integration know-how
- built for holistic, fast and credible techno-economic analysis
- concurrent modelling of multi-variable “what-if” scenarios



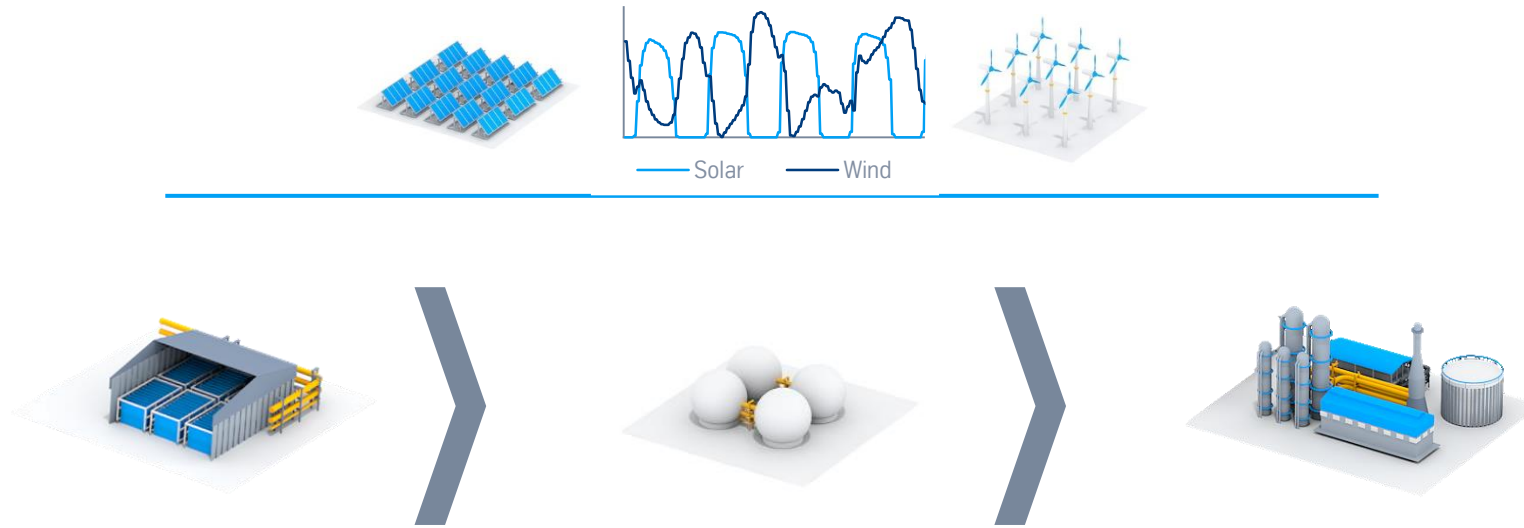
Green ammonia production economics drive our technology and execution solution focus



Analysis based on modularised plant concept, power cost 30-40 USD/MWh, Alkaline Water Electrolysis, small ammonia storage. LCoA: Levelised Cost of Ammonia



Intermittency of renewable energy poses technical challenges for green ammonia synthesis, which are not fully addressed via the conventional plant design approach



- Oversized to time shift hydrogen availability

- Large buffer storage

- Possibility of reaction snuff-out
- Catalyst damage (thermal cycling)
- Potential loss of containment due to pressure cycling fatigue



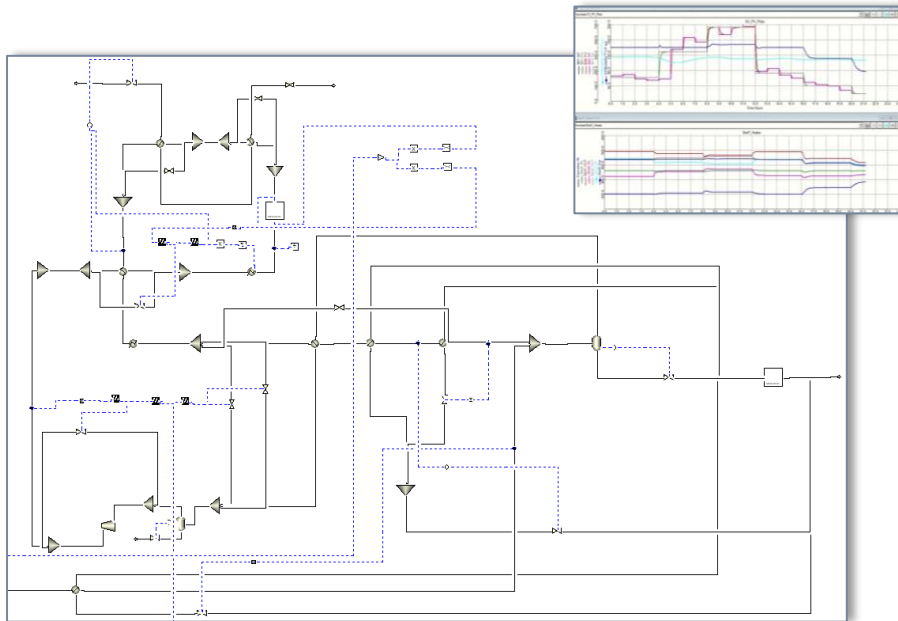
LCoA (\$/tonne)



Dynamic green ammonia process technology underpins our plant design

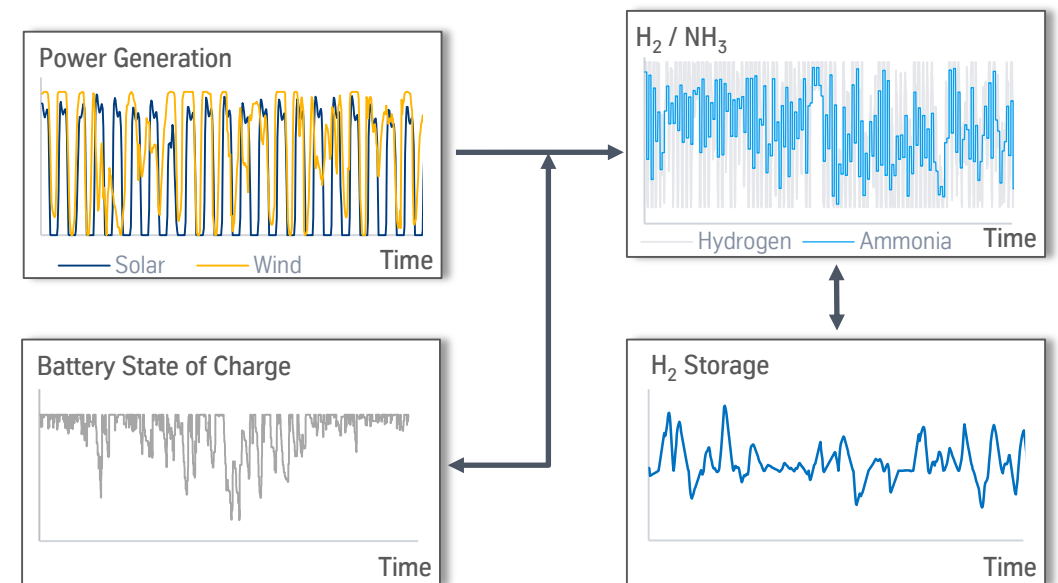
Green NH₃ dynamic load management

- Dynamic simulations and plant tests performed to develop new design features
- Encompassing power supply to ammonia production
- ✓ Confirmed high ramp capability (2%/min) i.e. min. H₂ storage
- ✓ Confirmed dynamic turndown to 10% of nameplate

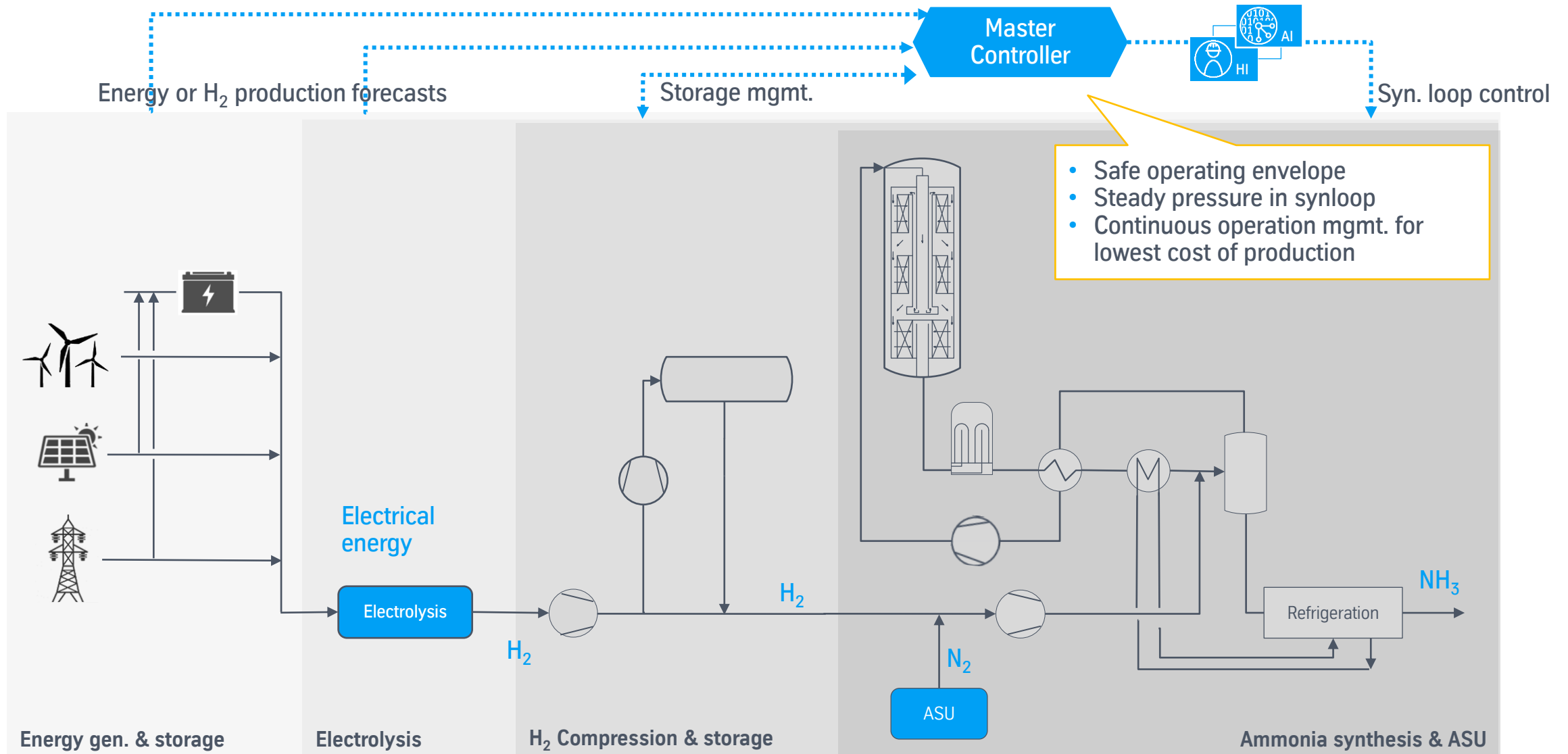


RHAMFS® - System sizing tool

- Optimal sizing of key technology blocks
- Used in early in the project development phase to optimise the concepts for the lowest LCoA



Digital Solutions | Flexible ammonia synthesis enabled via proprietary Master Controller



Alexandria, Egypt

4/6/2024 11:12:00 AM

Egypt Standard Time

 **21°C**

 **7.4 m/s**

Forecast+1

 **21°C**

 **7.5m/s**

Forecast+2

 **21°C**

 **7.7m/s**

Forecast+4

 **21°C**

 **8.1m/s**



Actual:
59.94 MW/h

Forecast +1:
60.42 MW/h

Forecast +2:
54.62 MW/h

Forecast +4:
41.27 MW/h



Actual:
138.61 MW/h

Forecast +1:
140.48 MW/h

Forecast +2:
144.23 MW/h

Forecast +4:
151.72 MW/h



Pressure:
108.46 bar

Mass:
21497.09 kg



Actual PV:
508 tpd

Actual SP:
553.33 tpd

SetPoint +1:
545 tpd

SetPoint +2:
555 tpd

SetPoint +4:
529 tpd



Supplementary Power:
0 MW/h

Forecast +1:
0 MW/h

Forecast +2:
0 MW/h

Forecast +4:
0 MW/h



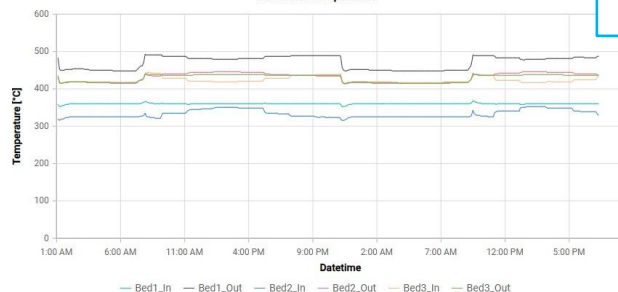
Actual:
96.28 tpd

Forecast +1:
96.78 tpd

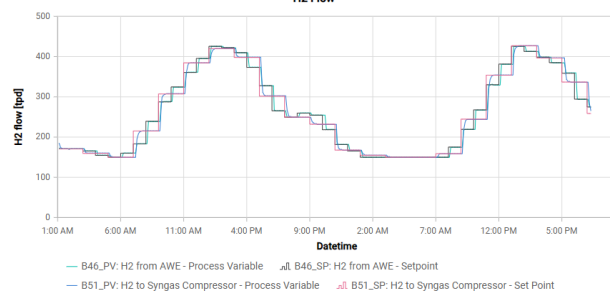
Forecast +2:
98.55 tpd

Forecast +4:
94.03 tpd

Converter Temperature

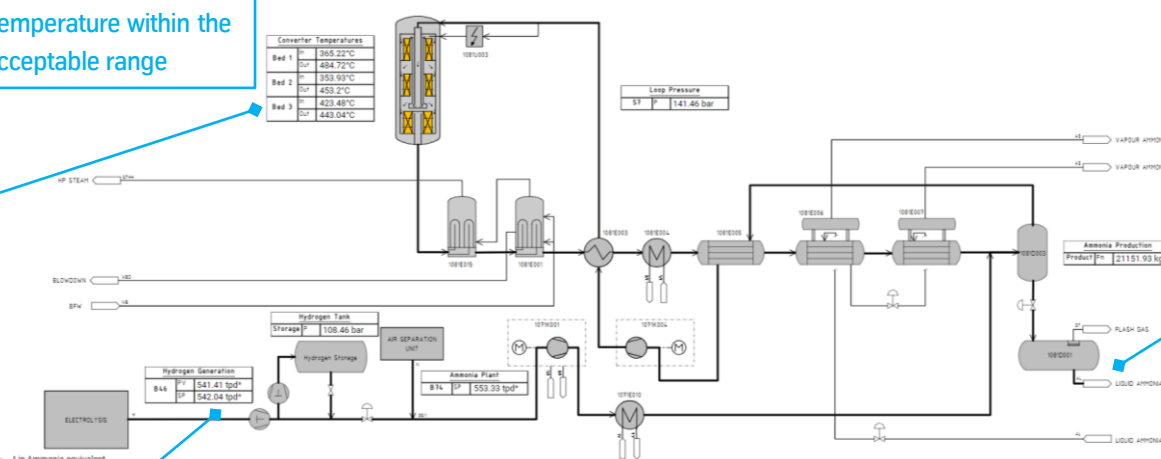


H2 Flow

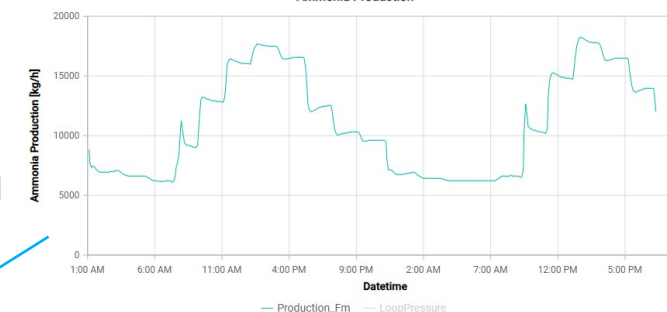


Temperature within the acceptable range

Cyclic hydrogen feed (PV+wind)



Ammonia Production



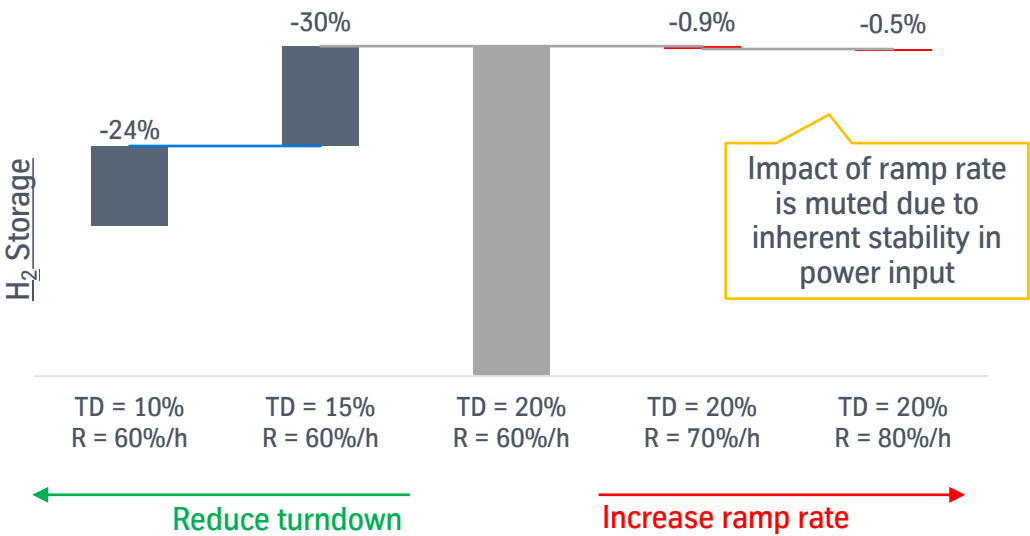
Case Study – Impact of turndown and ramp rates

A project specific approach to focus on the right technology solution for the project

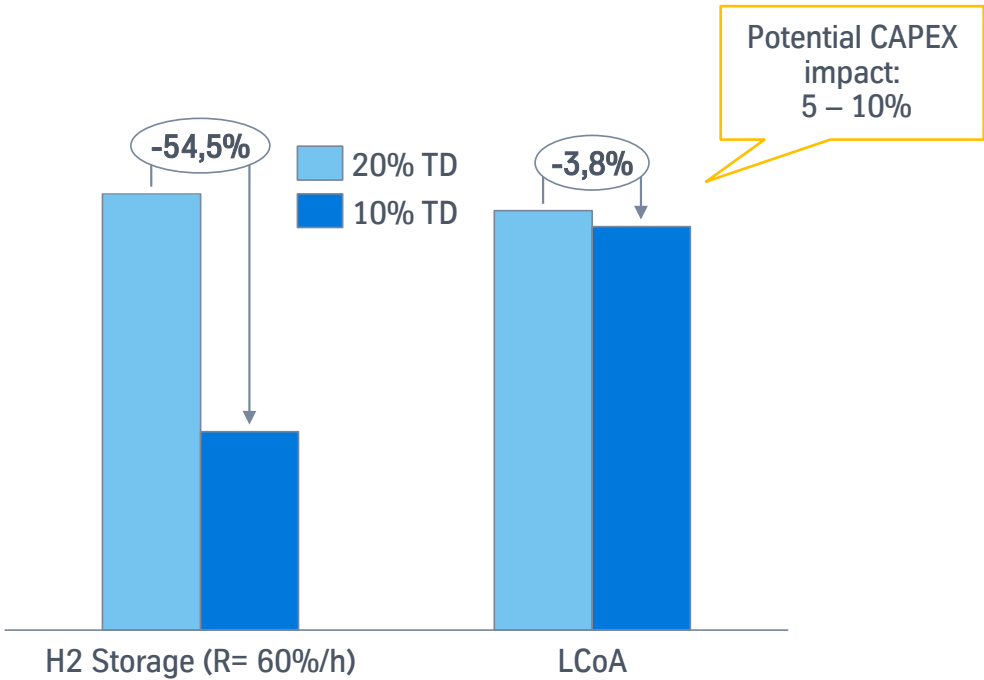


Facility turndown and ramp sensitivity

- 2.7 GW /6,500 tpd, island mode + battery
- Wind + PV : Complementary mix for high stability)



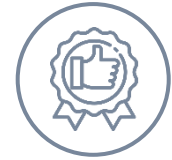
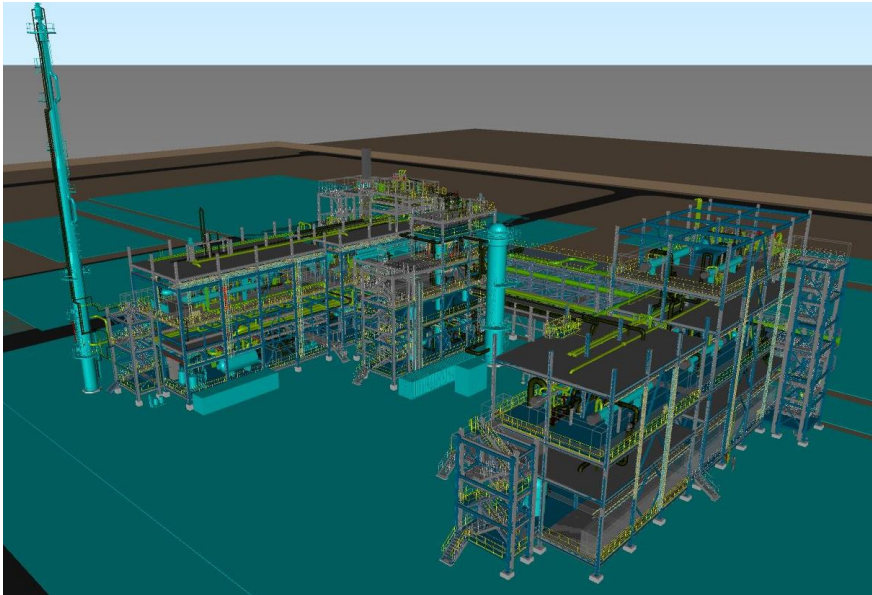
Impact on plant and cost



Turndown has the highest impact on the storage size of all the key parameters of the synthesis loop



In Summary - Innovative technology, embodied in standardised, pre-integrated, modularised plant delivers low TCO and de-risks execution



	Performance		Project Benefits
Technology	Turndown	up to 10%	- Low TCO - Safe, reliable & high operability - High flexibility via digitalisation - Minimal H₂ storage - Environmental approvals ready
	Ramp	2%/min	
	Energy cons. ¹⁾	~ 0.15 MWh/kg NH ₃	
	Conversion	>98% H ₂ to NH ₃ product	
	Availability	> 96%	
Standardisation	- Pre-integrated standard concepts - Core synthesis + critical support units - Available - 300/600/1200 tpd - in progress - 2400/3400 tpd		- Minimise performance guarantee interface - Procurement de-risk - FEED schedule reduced by 3 mth
Execution	- Modularised delivery (where justified) - Construction mgmt. Services		- Construction cost de-risk - Construction schedule assurance
Contract models	- Std. License + prop Eq - Extended license – integration engg. - EP/EPF - EPF + site services (Cm)		Flexibility for project needs (JVs, grant requirements etc.)

1 – H₂ and N₂ supply at 30 barg, with power generation, ex utilities, CW supply at 30°C

TCO Total cost of Ownership



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