From Micro to Mega

How the green ammonia concept adapts

Ammonia = Hydrogen 2.0 Conference | Aug 2019 | Rhys Tucker and Karan Bagga
thyssenkrupp Industrial Solutions

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Recent / Large Scale Ammonia Projects by tkIS

CFI, Port Neal, USA
2,200 mtpd

SAFCO 4, Saudi Arabia
Initially 3,300 revamped to 3,670 mtpd

Brunei Fertiliser Industries
2,200 mtpd

CFI, Donaldsonville, USA
3,300 mtpd

Ma'aden 1,2&3, Saudi Arabia
3 x 3,300 mtpd

Cutting-edge ammonia technology since 1928

uhde® ammonia process

- One of the leading technology providers in ammonia field
- Improved energy efficiency and higher capacities
- Reassuring reliability
- Pioneers in critical plant equipment

Experience cannot be copied.

#1
supplier in EPC business for ammonia plants

≈ 130
ammonia plants realized worldwide

> 90
years of turnkey EPC solutions




thyssenkrupp

Hydrogen at scale – large water electrolysis plants

Experience cannot be copied.

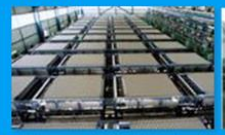
#1 in electrolysis worldwide

over **600** electrochemical plants realized

over **200,000** electrolytic cell elements produced

Chlor-Alkali Electrolysis:

Uhde BM2.7



Chlorine Engineers BiTAC

NaCl ODC[1]

Hydrochloric Acid Electrolysis:

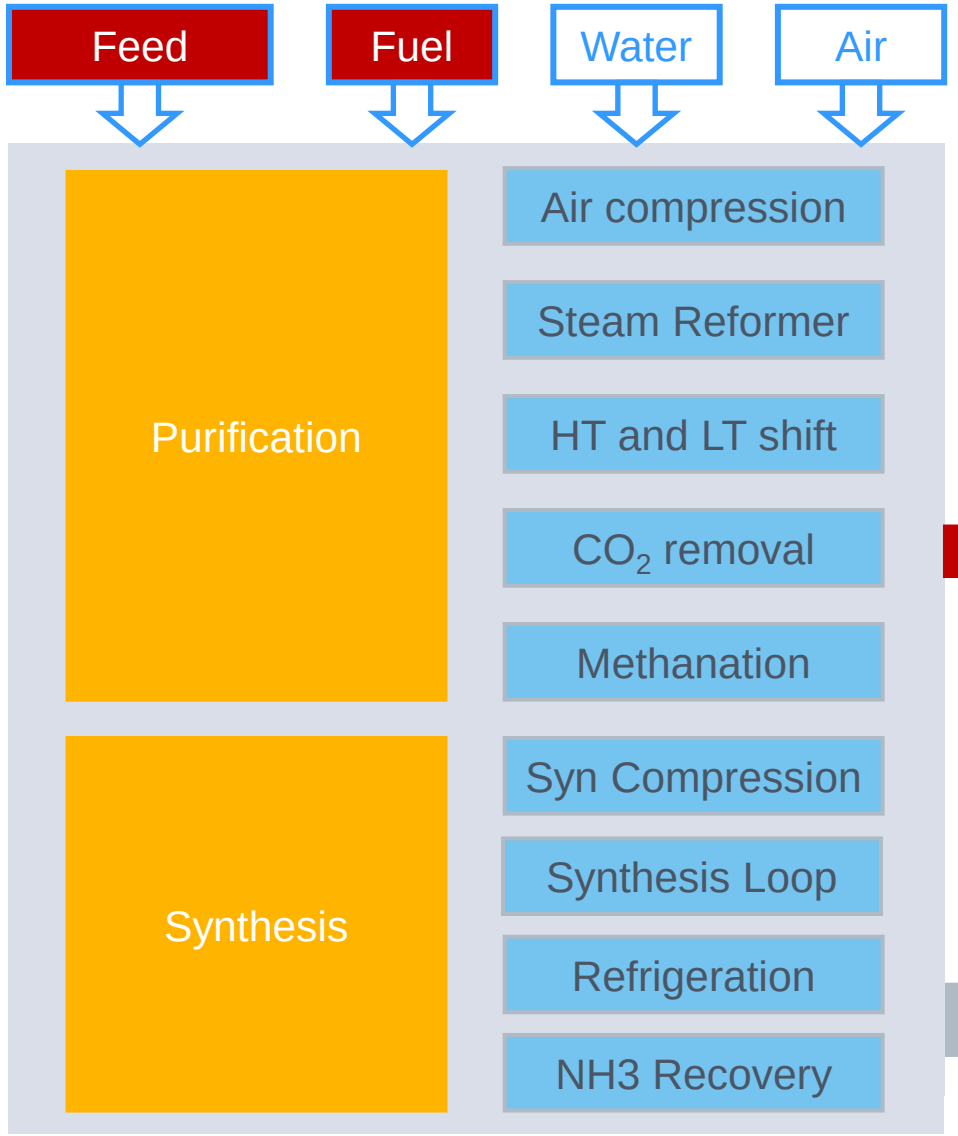
HCl Diaphragm el.

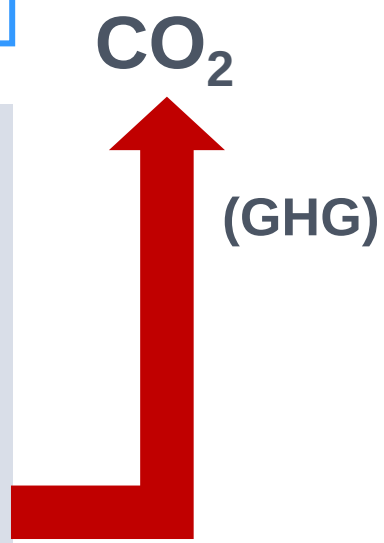
HCl ODC[1] electrolysis

Alkaline water electrolysis

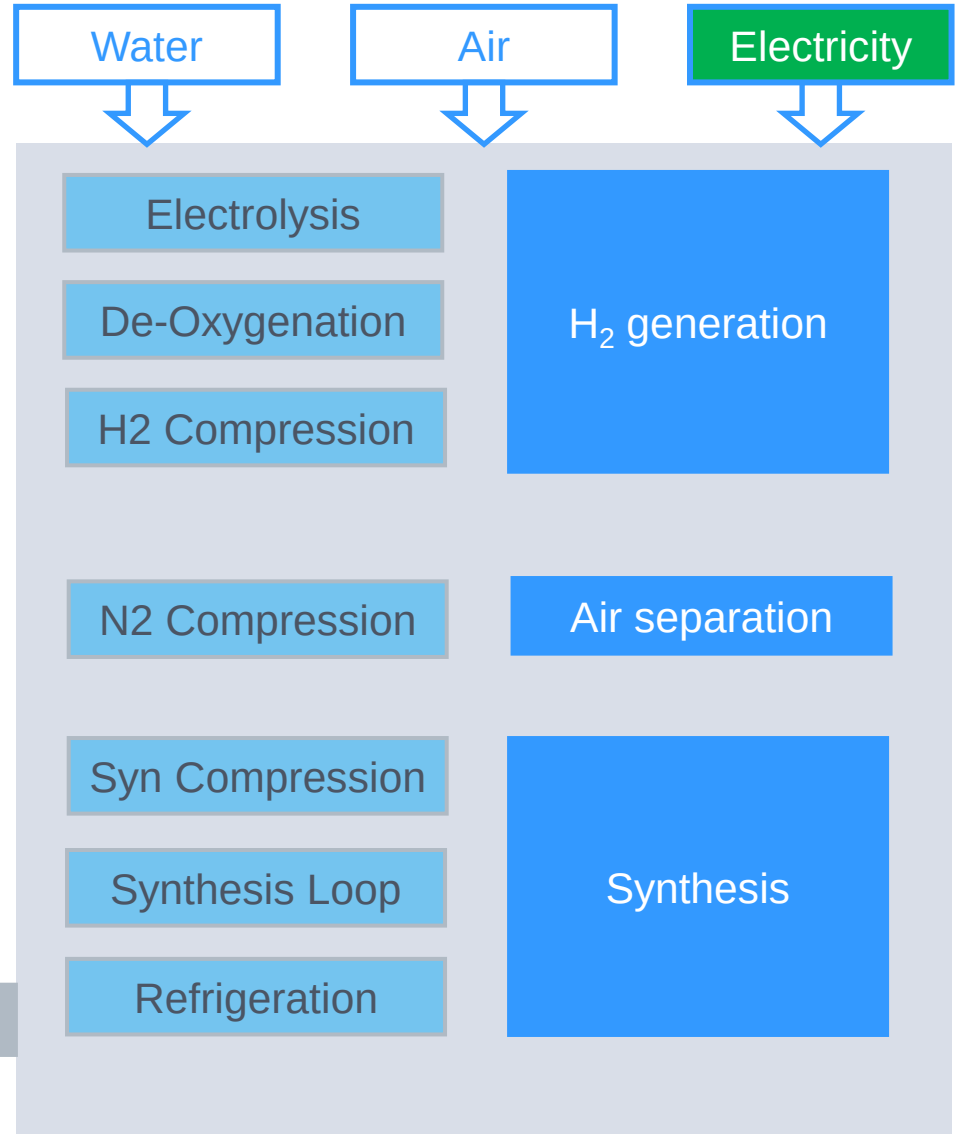
[1]Oxgen Depolarized Cathode

Conventional ammonia production





Electricity-based ammonia production



Introducing renewable ammonia by thyssenkrupp

2 worldwide leading processes

1 holistic solution

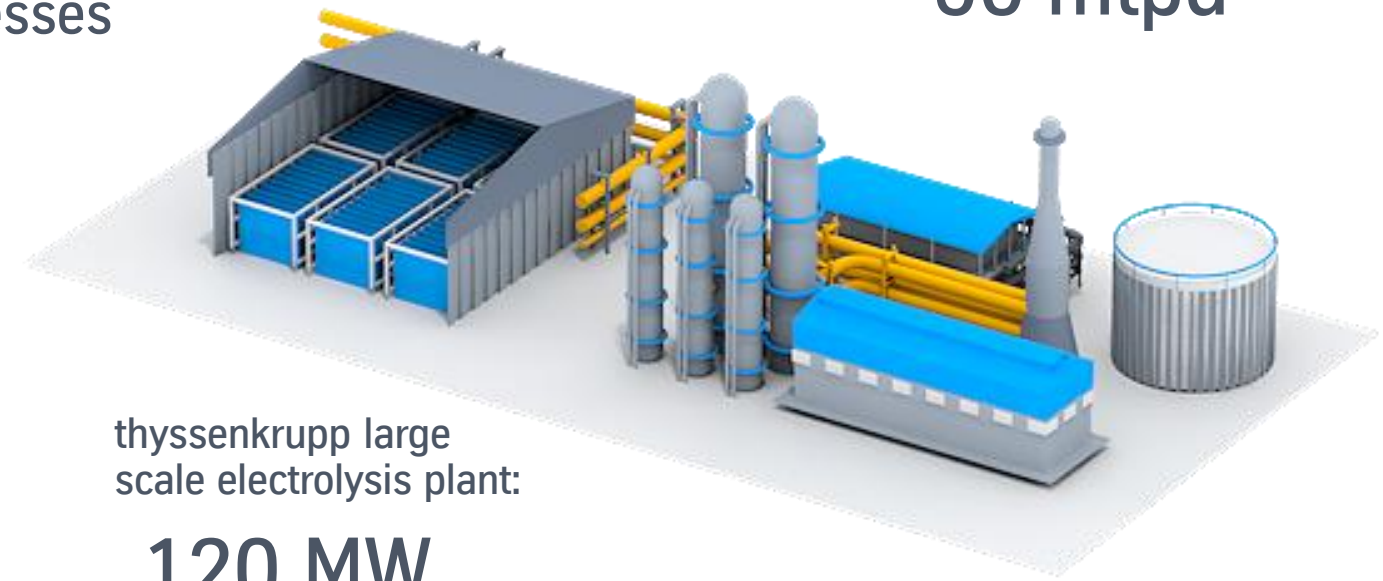
0 CO_2 emissions*

thyssenkrupp electrolysis plant:

20 MW

thyssenkrupp (A01)
micro scale ammonia plant:

50 mtpd



thyssenkrupp large
scale electrolysis plant:

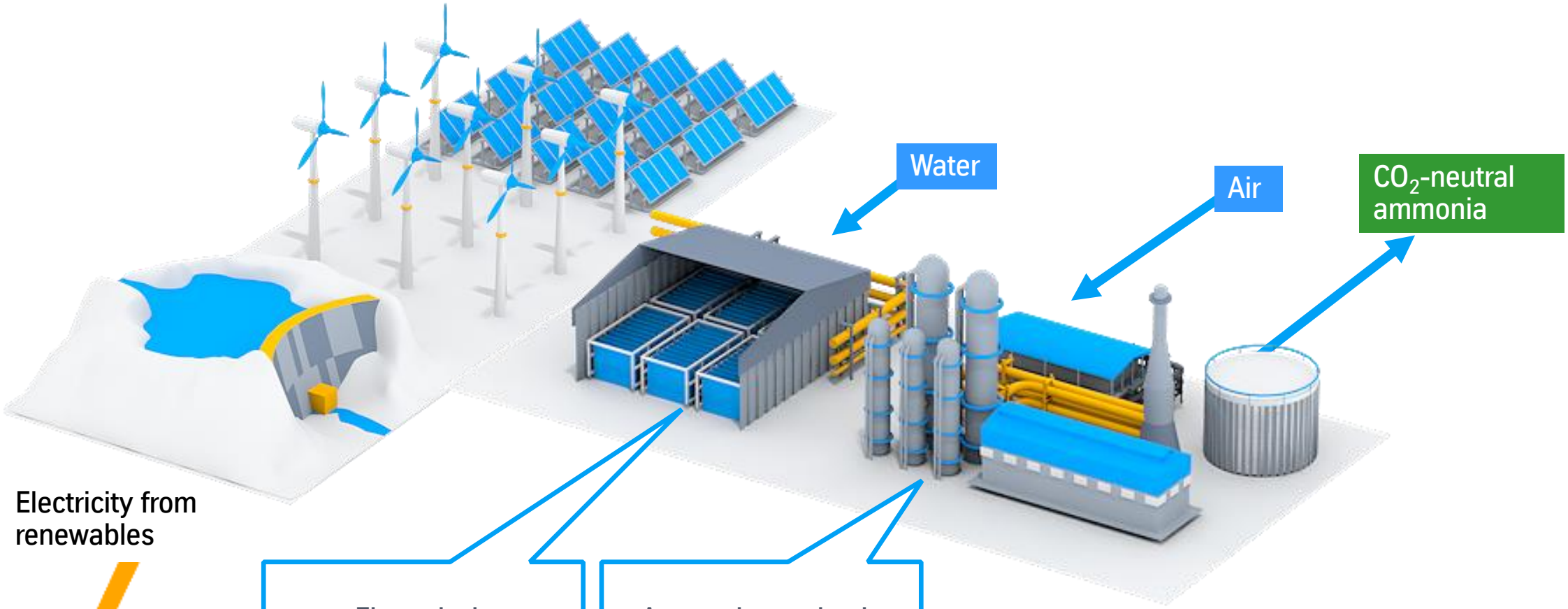
120 MW

thyssenkrupp (A04)
small scale ammonia plant: 300 mtpd

thyssenkrupp (A30)
mega scale ammonia plant: 5000+ mtpd

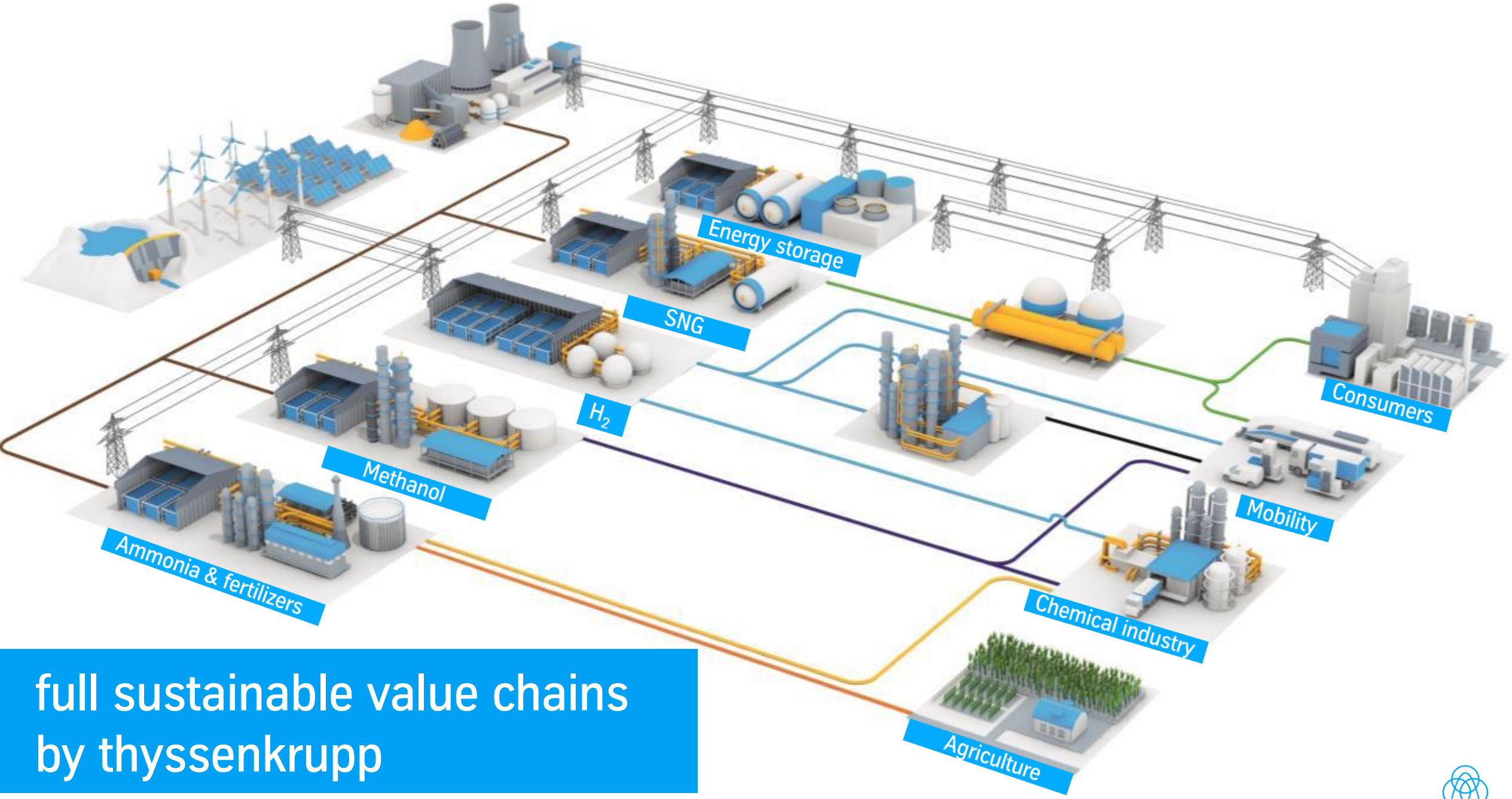
*depending on E-power source

Introducing renewable ammonia by thyssenkrupp



* For specific consumption figures please contact tkIS-AU directly

Best in class energy efficiency and utility demands *



full sustainable value chains by thyssenkrupp

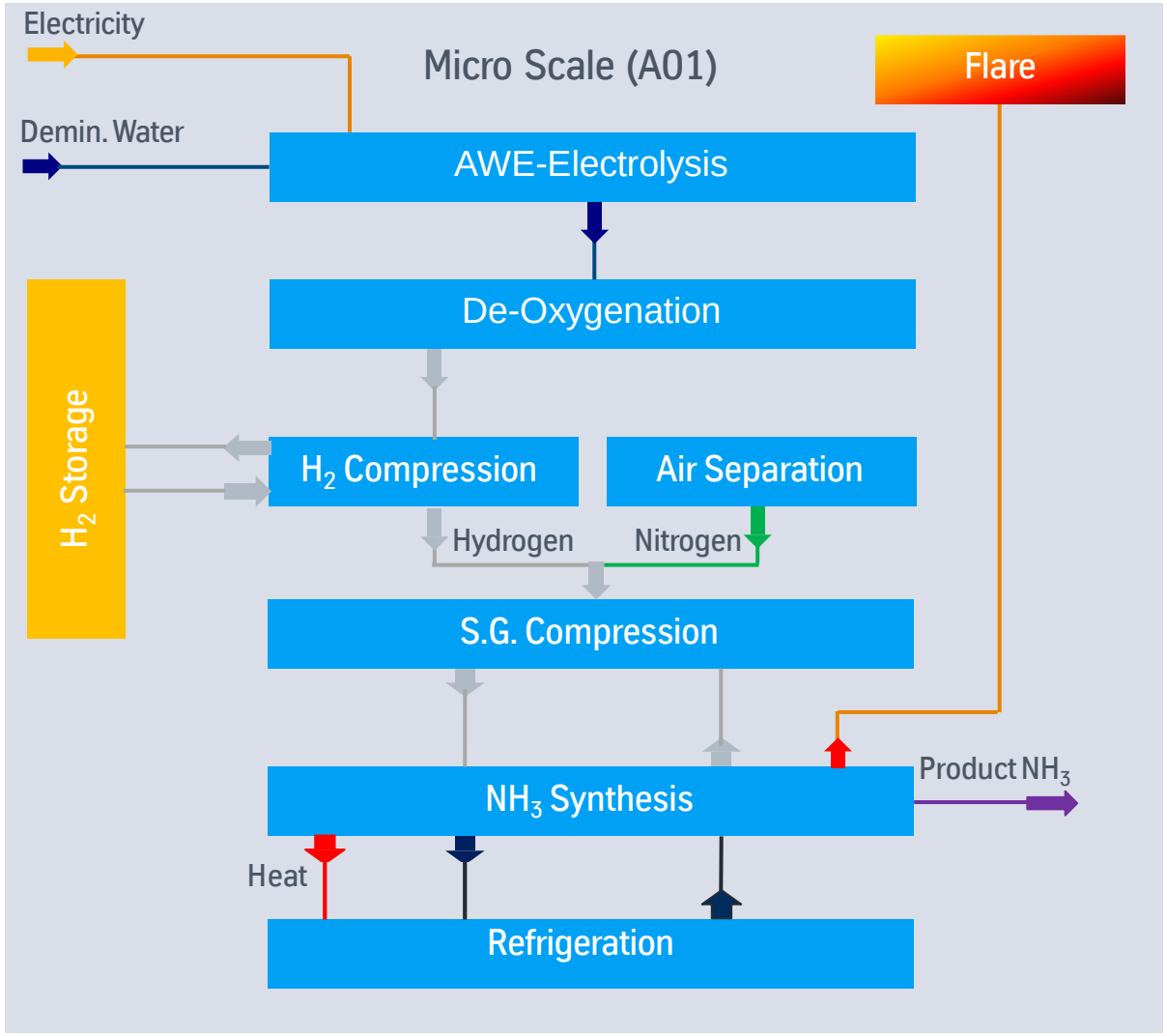
thyssenkrupp engineering. tomorrow. together.

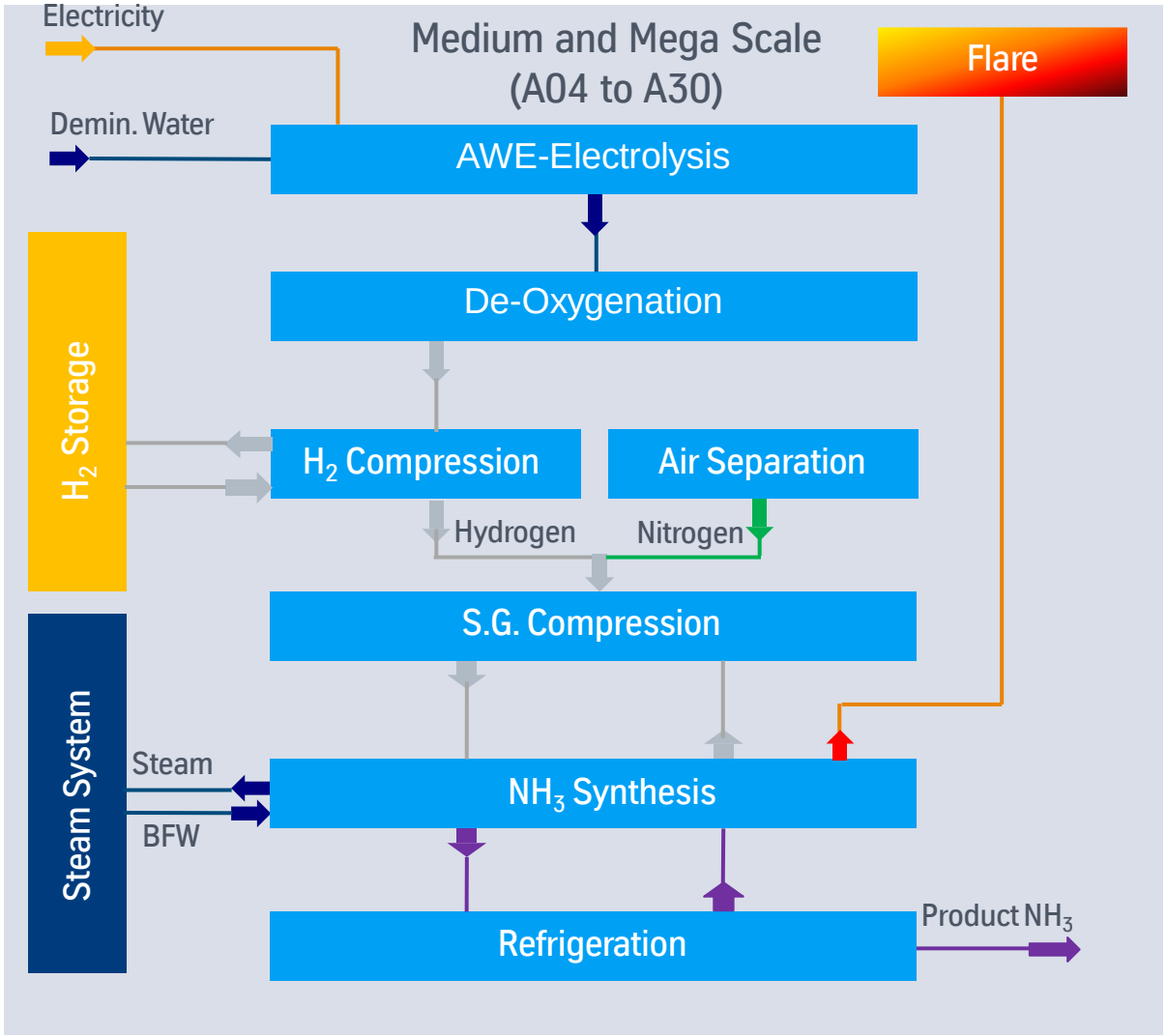
Renewable Ammonia Case Studies

How the green ammonia concept adapts

Green Ammonia Micro and Mega Scale Concept (Haber Bosch)

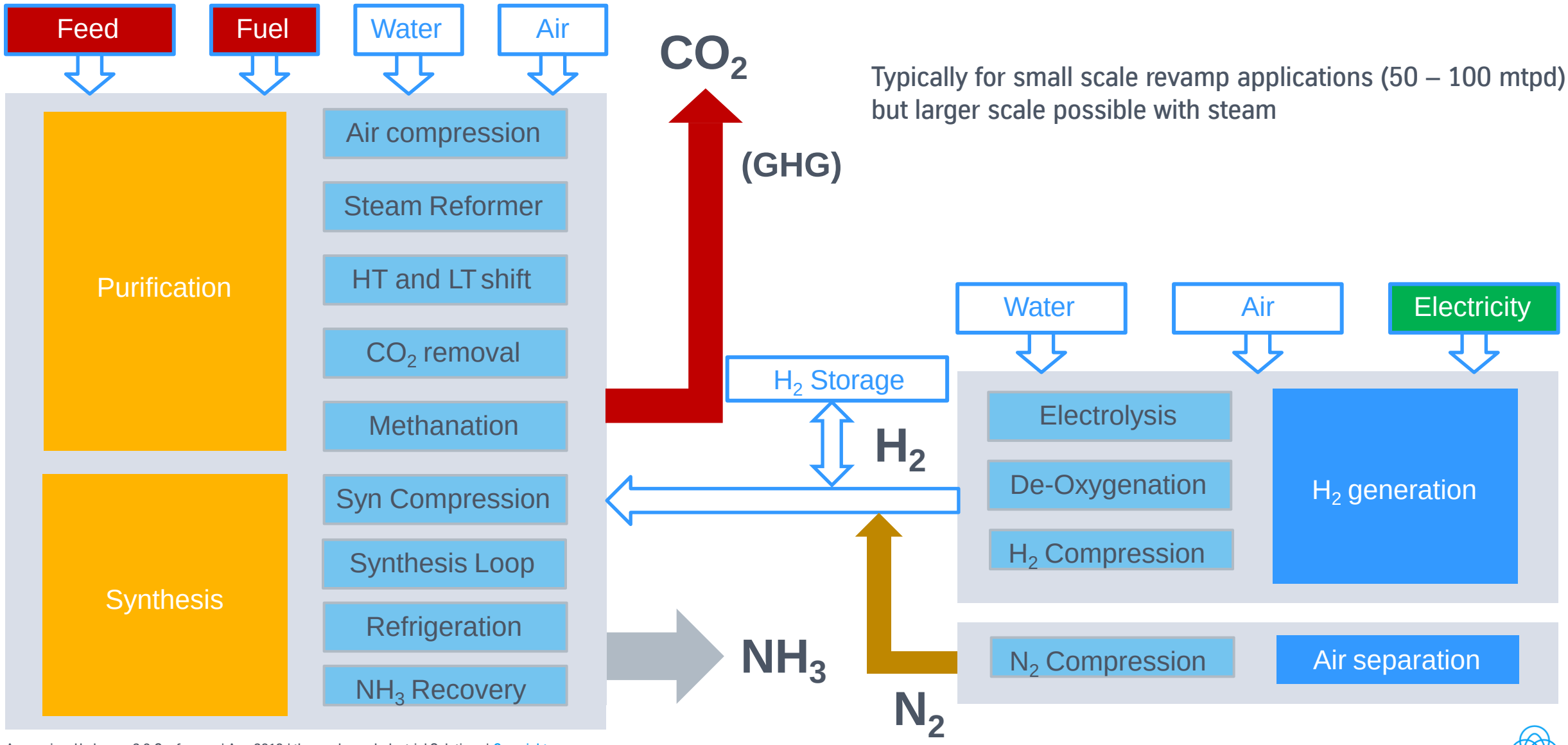
Overview with AWE Process





Green Ammonia Micro and Mega Scale Concept (Haber Bosch)

Revamp Concept



Typically for small scale revamp applications (50 – 100 mtpd) but larger scale possible with steam

Green Ammonia Synthesis

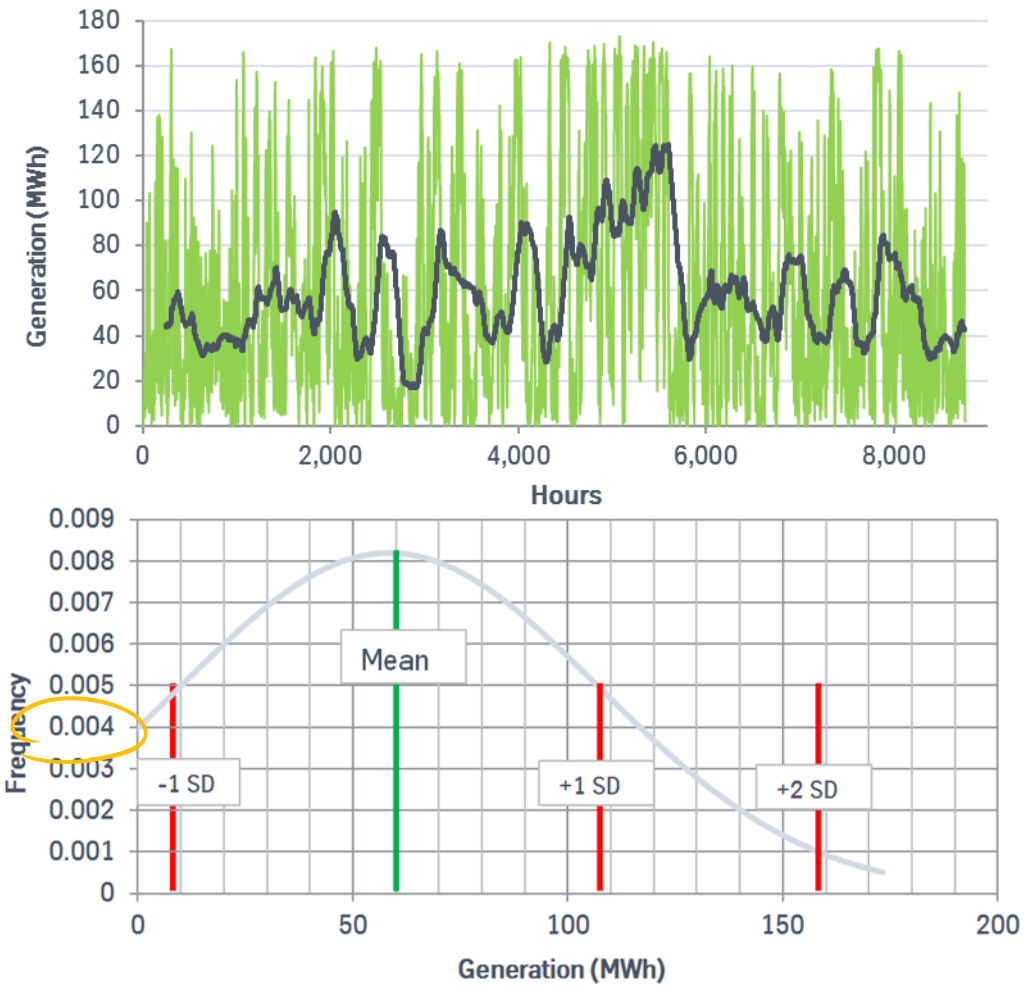
Unique Challenges

Major concerns for ammonia synthesis loop

- High fluctuation of hydrogen input due to high variability of power generation
- High frequency of shut-down and start-up scenarios - no generation
- High Synthesis loop turndown required to avoid shutdown (conventionally limited to 40%)
- Converter controllability due to frequent ramp-up/down (composition fluctuation, pressure, temperature)

Power Generation Profile (e.g. based on Micro Scale)

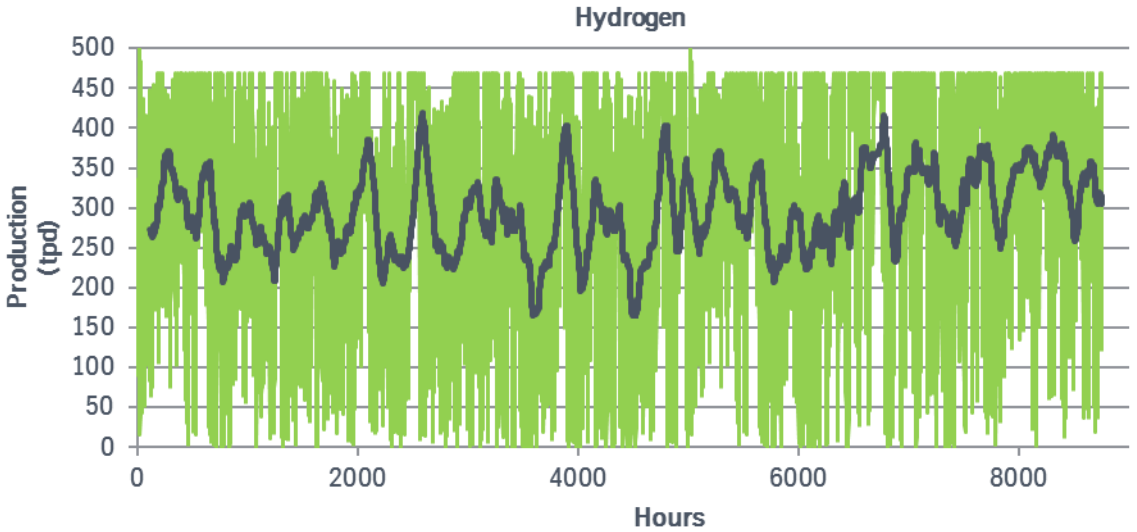
Courtesy AEMO: Gullen Range Wind & Solar Farm, NSW (166 + 10 MW), 2018 Production Data

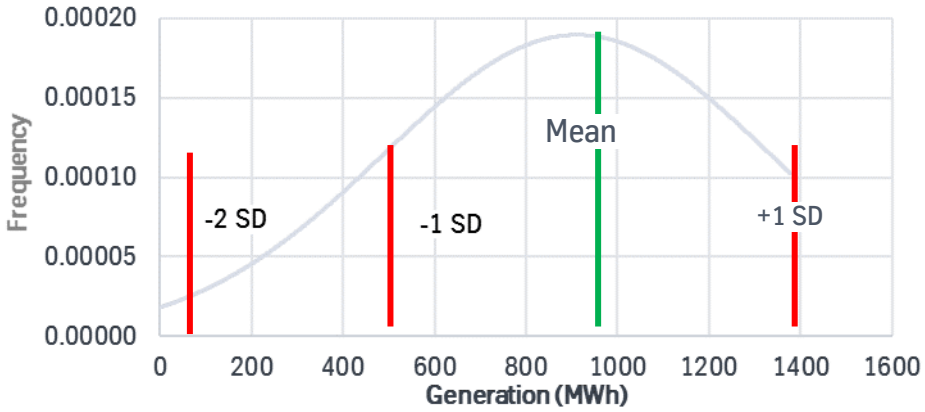


Green Ammonia Synthesis

Unique Challenges – Case Studies

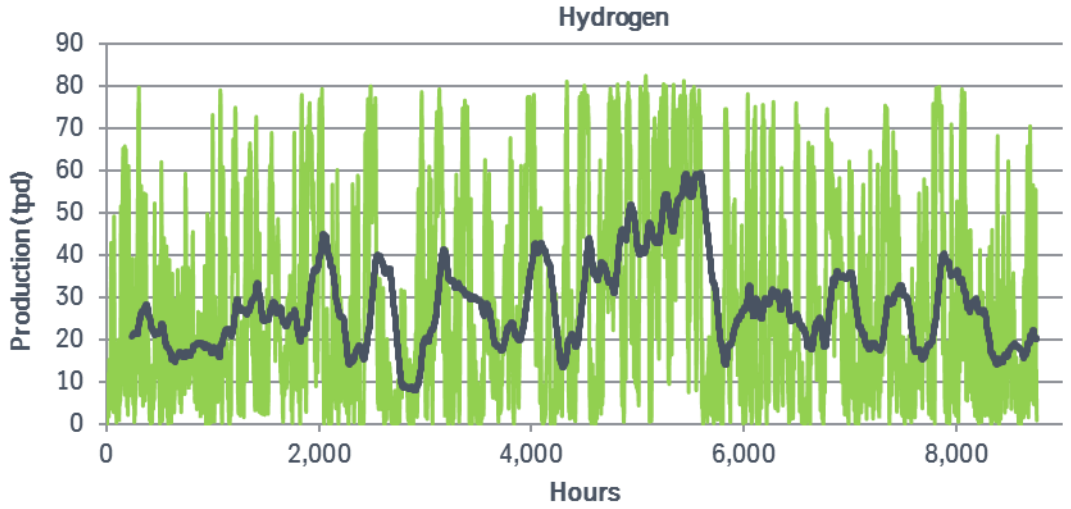
Mega Scale – Case Study 1
Hypothetical Wind & Solar Farm (1400 MW)

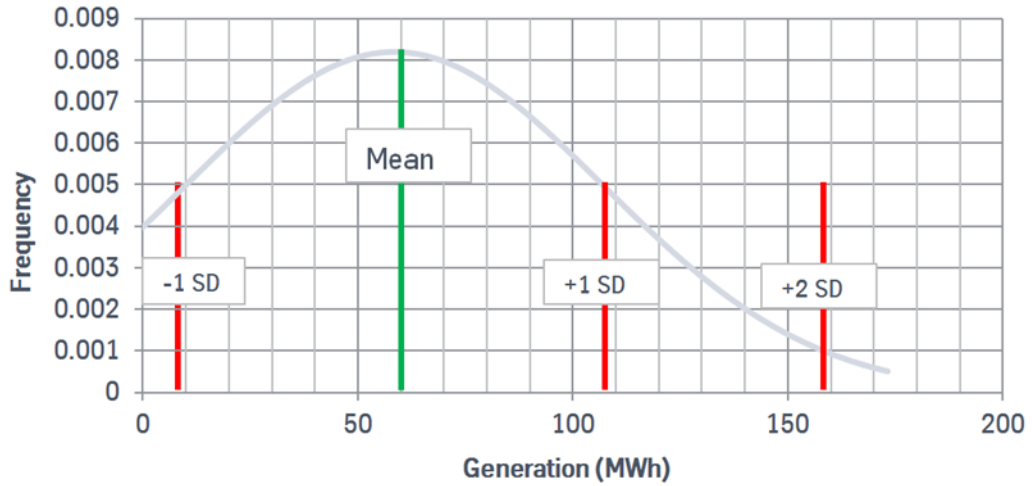




Micro Scale – Case Study 2
Gullen Range, NSW Data (2018)

Courtesy AEMO: Gullen Range Wind & Solar Farm, NSW (166 + 10 MW), 2018 Production Data





Green Ammonia Synthesis

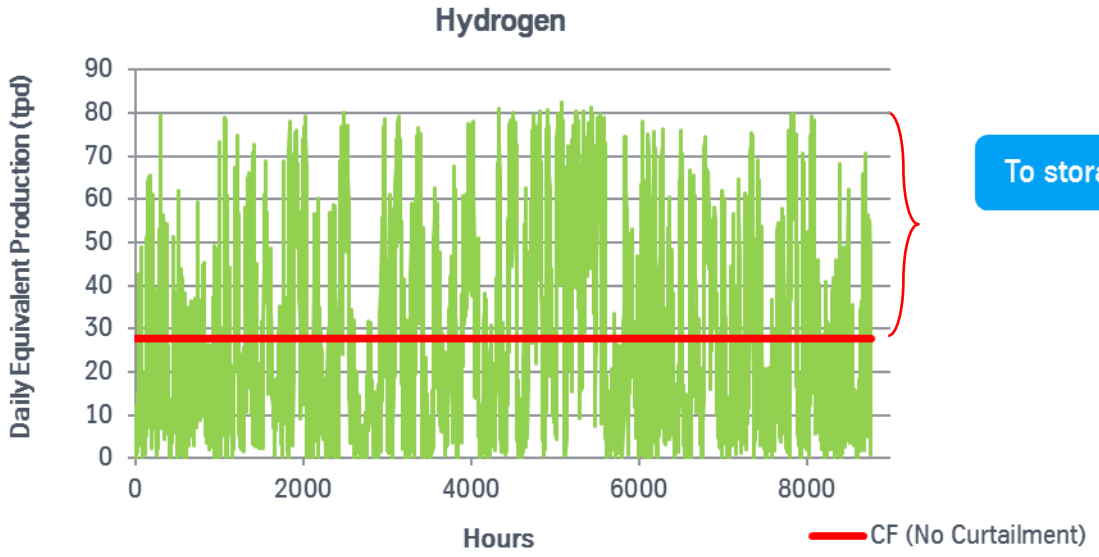
Unique Challenges - High Variability of power generation

Major concerns

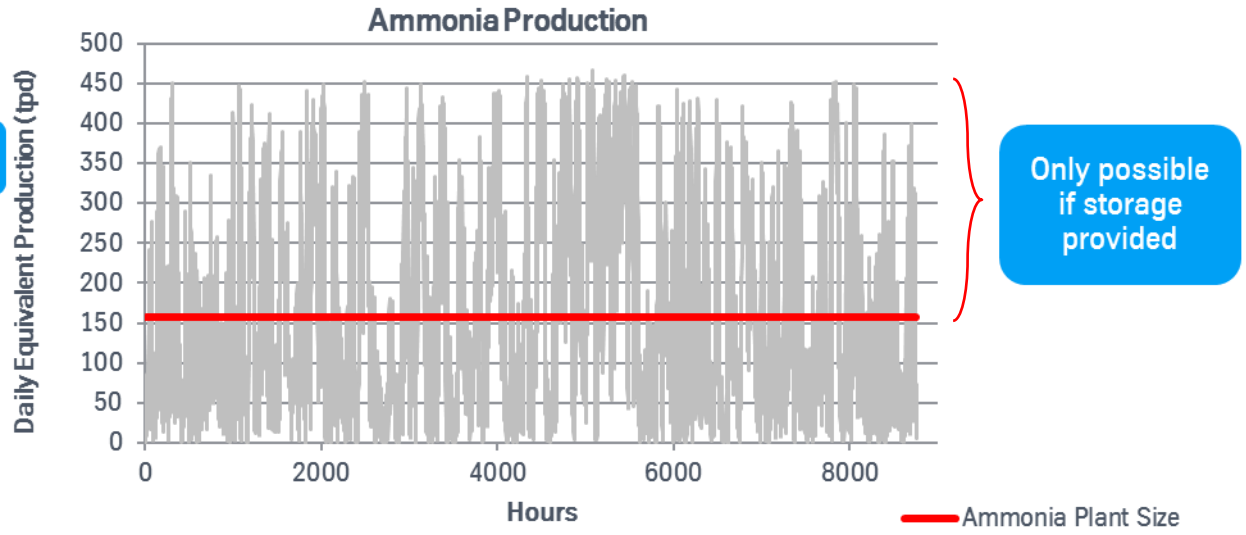
- High fluctuation of hydrogen input due to high variability of power generation

Consequence

- High underutilisation of hydrogen and ammonia generation plants if facility sized for peak production - cost penalty
- Large hydrogen storage required if facility sized based on yearly average production (reflected by CF) – cost penalty



To storage



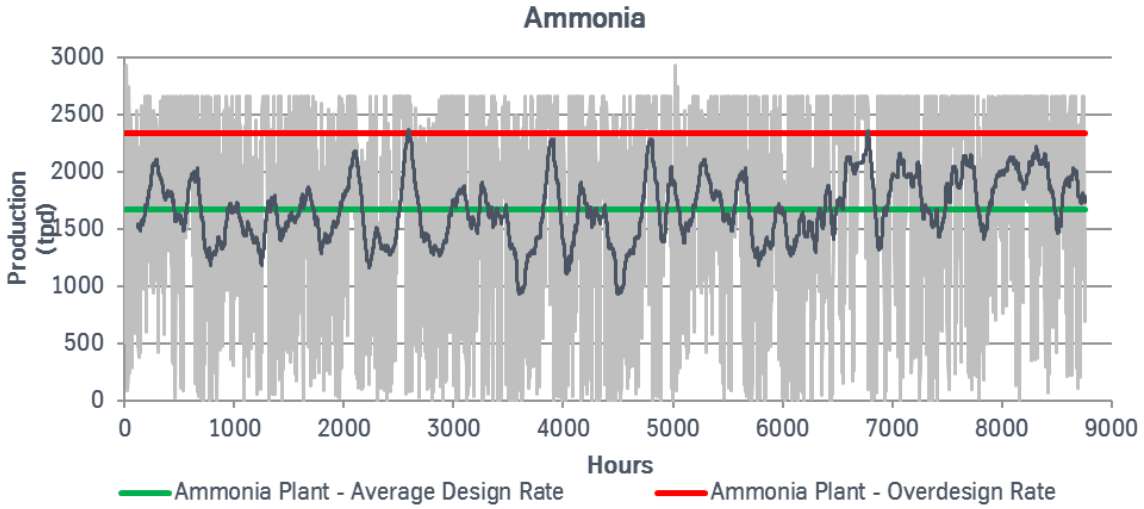
Only possible if storage provided

Green Ammonia Synthesis

Solution – Hydrogen storage or oversized facility

Mega Scale Ammonia

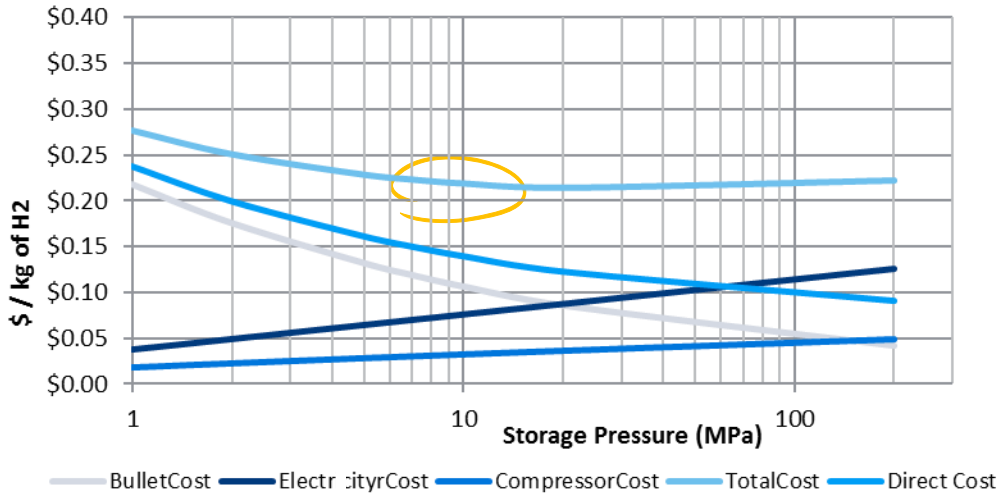
- Large hydrogen storage required if facility sized for average capacity factor, which is uneconomical
- In comparison, oversizing of ammonia plant found to be more cost favourable due to economies of scale and higher capacity factor delivered by large scale generation



Micro Scale Ammonia

- Provision of compressed hydrogen storage is more economical at smaller scale, lower capacity factor facilities
- However analysis required to select optimal storage pressure. High pressure small scale storage also possible (40 – 70 MPa) – especially beneficial if cheap power available

Case Study 2: Half day storage , Power price 40 cents/ kwh Gullen Range Wind & Solar Farm, NSW (166 + 10 MW)



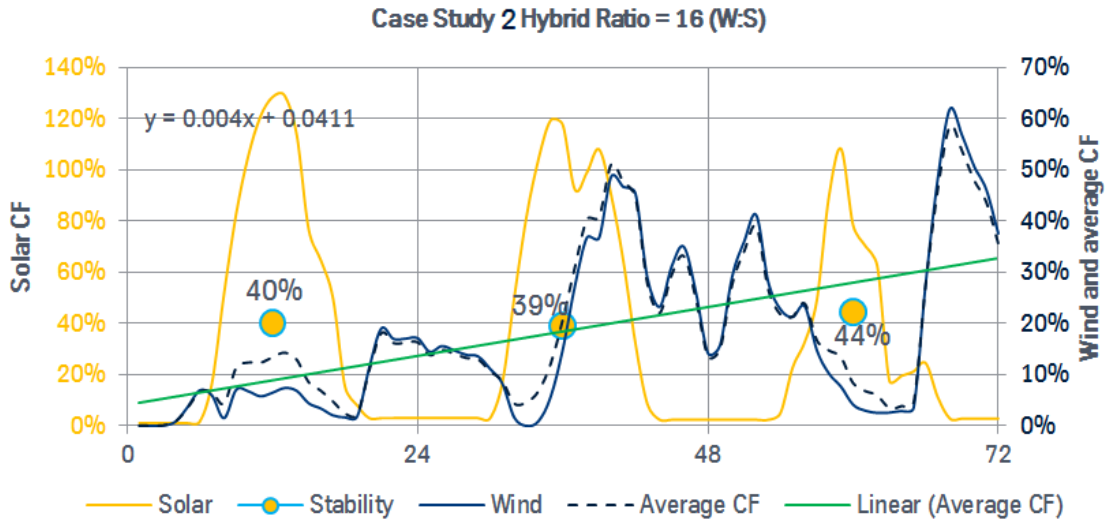
No single solution – Economic analysis required to determine optimum approach to hydrogen generation variability

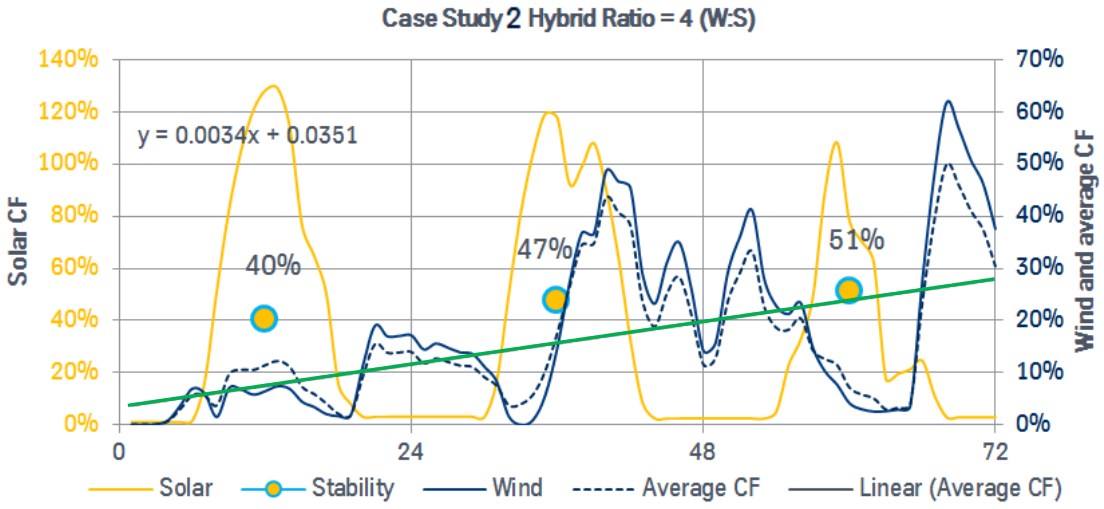
Green Ammonia Synthesis

Solution – Optimal Wind & Solar mix

Optimal Wind and Solar ratio to improve stability

- Stability of power generation is desirable to minimise storage requirements and synthesis loop perturbations
- Stability will be high where wind and solar compliment each other through i.e. Solar sinusoidal shape is complimentary to wind
- Can be quantified mathematically to reflect the “shape” of the generation profile and perform sensitivity





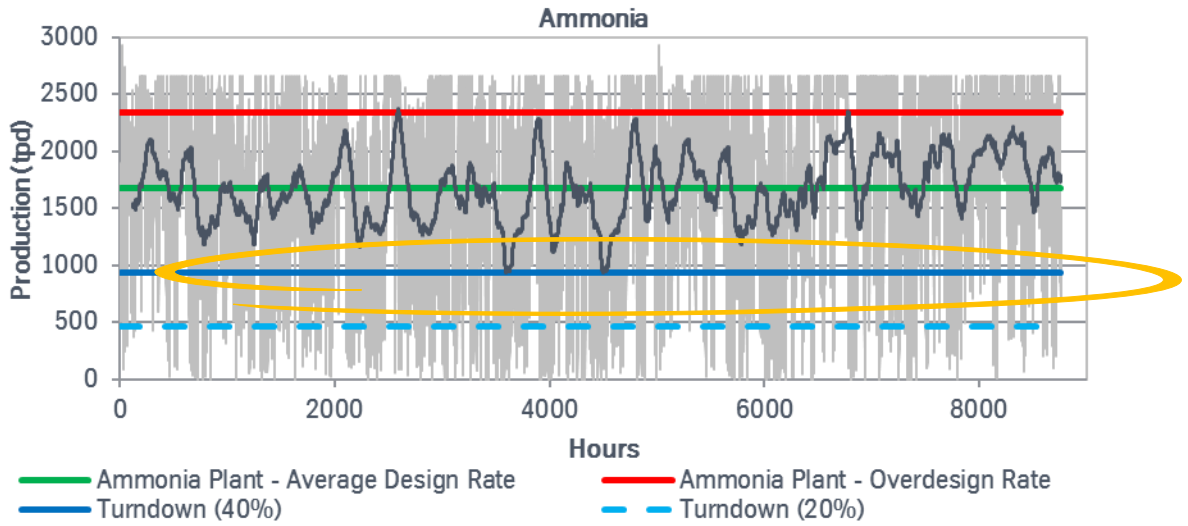
Based on Case Study 2: No Curtailment Considered

Green Ammonia Synthesis

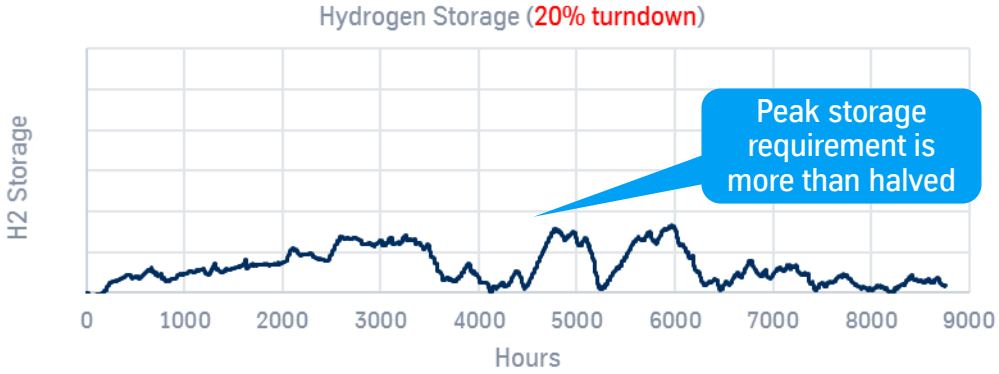
Frequent stoppage requires greater turndown and quick response

Concern for Micro and Mega Scale

- Conventionally constrained by Compressor and Converter
- Bigger issue for mega scale facilities due to diminished ability for higher turndown or to remain on hot stand-by
- Is against the direction of ammonia plant overdesign which is implemented to minimise curtailment at the top end



Solution – Improve ammonia plant turndown



Turndown improvement over conventional 40% is required for most large scale applications to ensure minimal stoppages

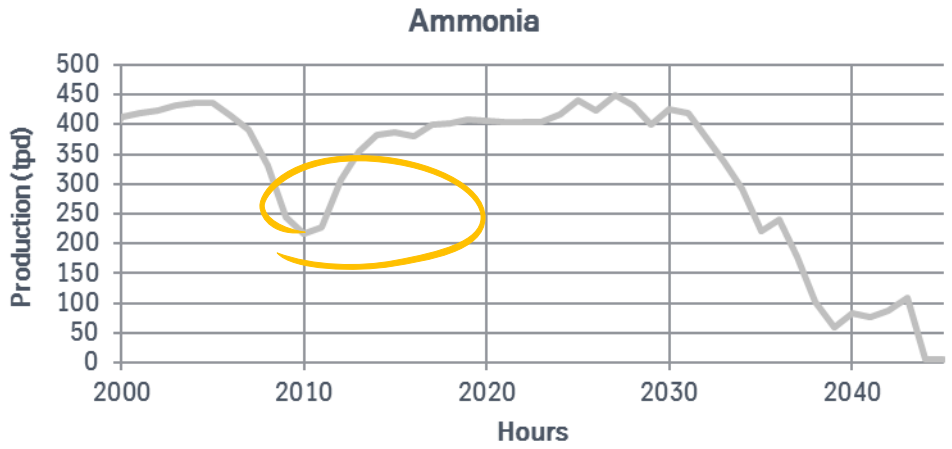
Green Ammonia Synthesis

Frequent stoppage requires greater turndown and quick response

Concern for Micro and Mega Scale

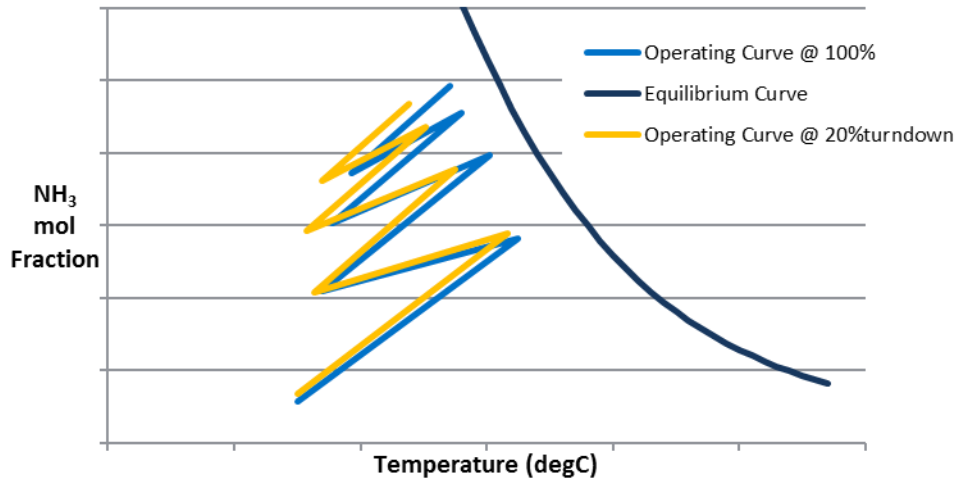
- Quick ramp-up/down required to respond to over and under generation, especially for wind biased farms
- However flow, composition, pressure and temperature perturbations can damage the Converter catalyst so typically limited to 20%/hr
- Smaller facilities more prone to upset and trip due to little buffer volume in form of inventory

Excerpt from Case Study 2



Solution – Plant and facility level turndown

- Stability may be improved by optimising Wind/Solar hybrid mix
- Larger facilities may be benefitted by multiple diversely sized plants however there will be a moderate cost penalty – tkIS offer ammonia plants from 50 mtpd to >5000 mtpd
- Improved Converter turndown and controllability for quick response without pressure cycling

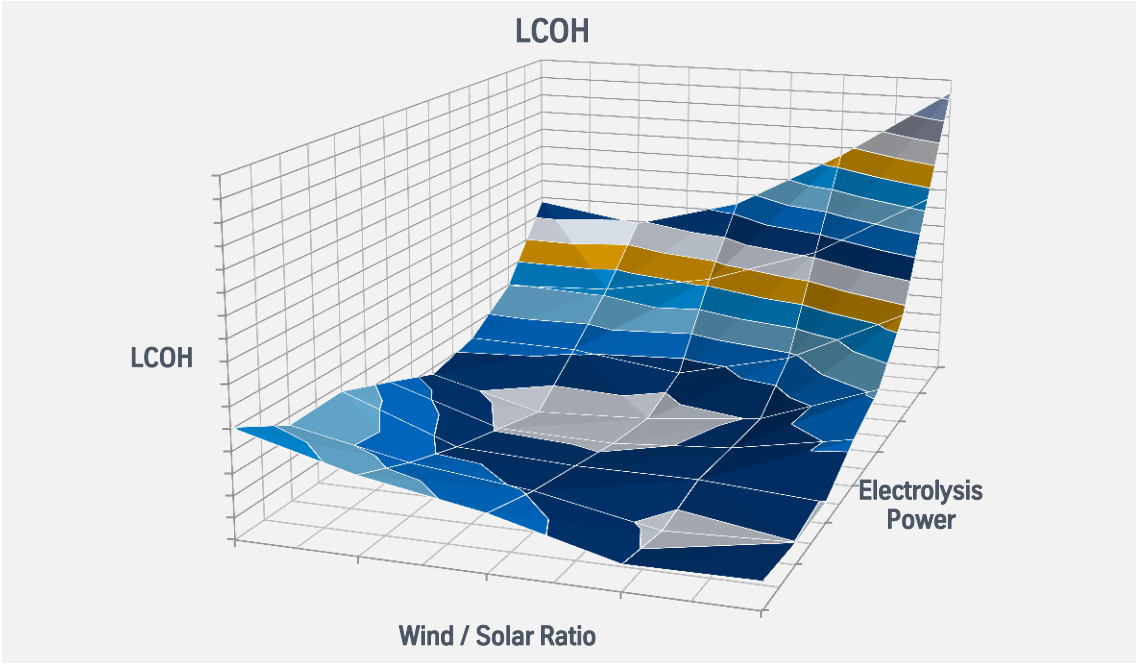


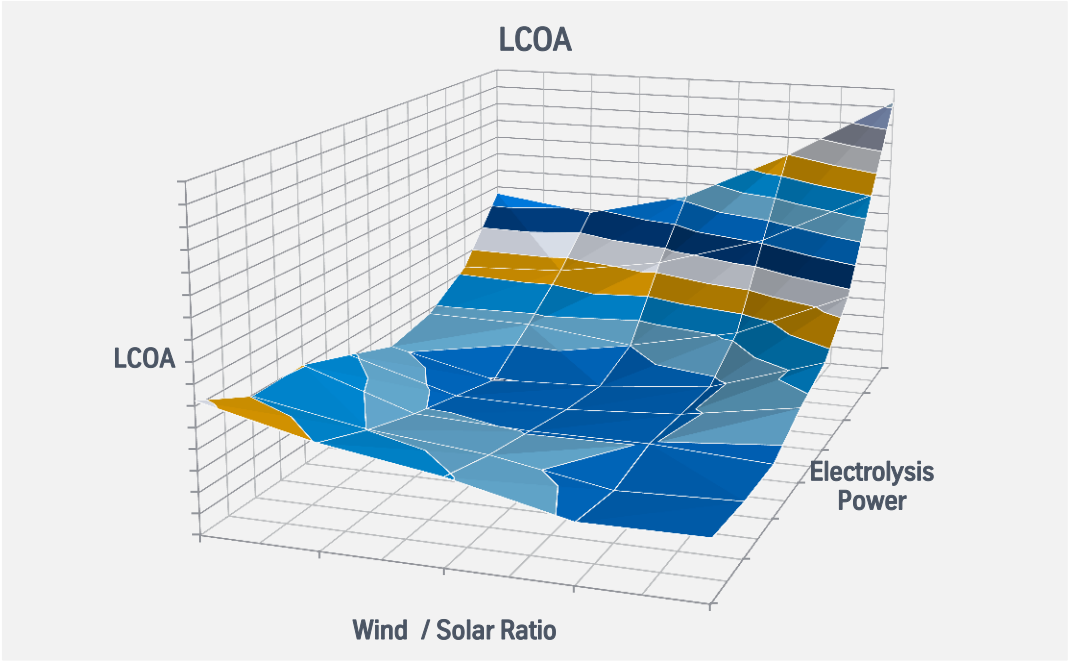
Green Ammonia Synthesis

tkIS-AU Proprietary Tool for Renewable Ammonia Facility Modelling

RHAMFS© – Techno-Economic tool for modelling renewable hydrogen and ammonia facilities

- Only raw generation profile required as input to conceptually model facility from power generation to product export
- Determines ideal hybrid generation mix (Solar/Wind) to maximise stability
- Full hydrogen and ammonia value chain, including utilities modelled to estimate levelised cost
- Can evaluate multiple concepts for sensitivities e.g. curtailment and spilled power





RHAMFS © output for Case Study 1

Green Ammonia Synthesis

tkIS Technology and Engineering Solutions

	tkIS Technology Solutions	tkIS-AU Engineering Solutions
1 Turndown and intermittency	• Dual pressure concept allow greater turndown for short or long term. In longer shut-down periods the ammonia loop is kept warm by circulating nitrogen using heater device. Start-up within minutes	• Sophisticated facility modeling using tkIS-AU proprietary tool RHAMFS© to determine ideal energy source mix, hydrogen storage, LCoH and LCoA
2 Controllability	• Quick ramp up/down enhanced with predictive control based on forecast	• Process modeling to determine required ramp profile, customised to the characteristics of the generation profile
3 Efficiency	• Use of waste heat to provide refrigeration for micro concept. Larger plants use mechanical refrigeration	• Other efficiency enhancement measures may be introduced via integration, depending on the facility concepts
4 Scalability from micro to mega	• Already the Licensor for world's largest ammonia plants, same scalability principles applied for micro to mega renewable concept. • tkIS built small scale electrolysis based ammonia plant in 1960s	• tkIS-AU has experience in concept development of micro to mega ammonia facilities based on renewable power

Thank you for your attention

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