Worley
energy | chemicals | resources

Masterclass session

Project development – Conversion, storage and distribution

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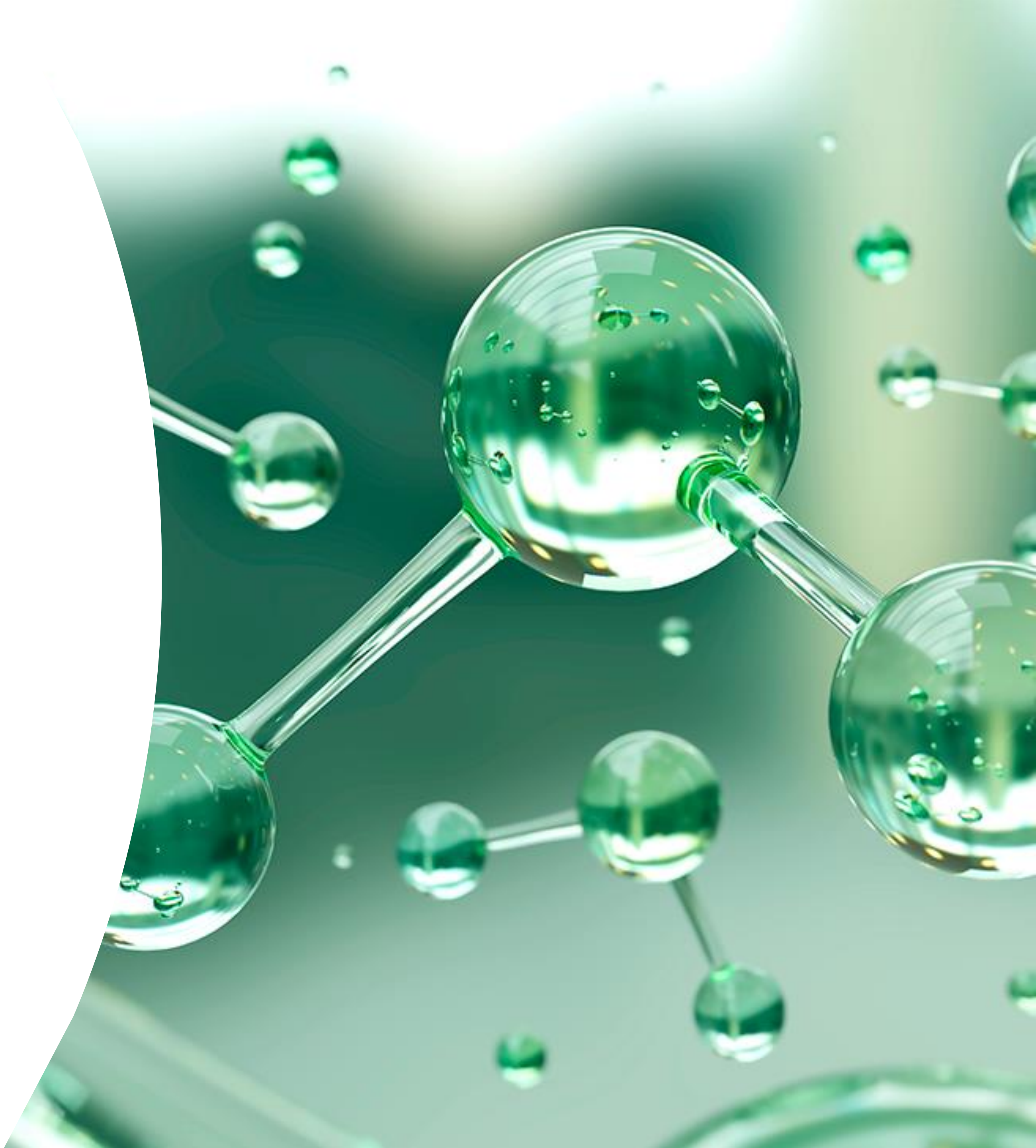


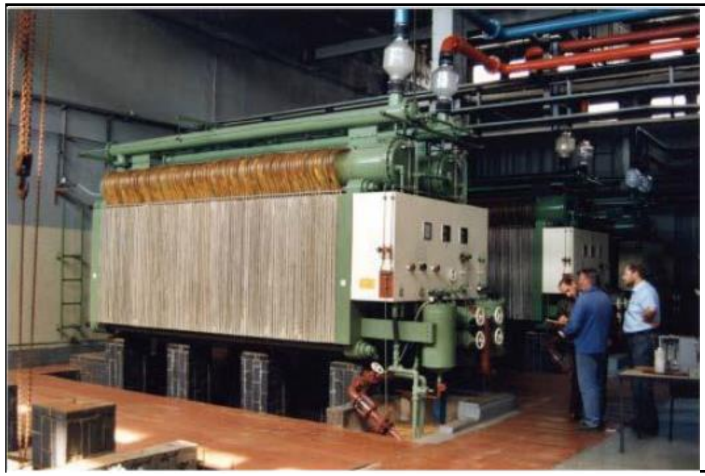
Agenda

1. Technologies
2. Suppliers
3. Competencies
4. Standards
5. Readiness level

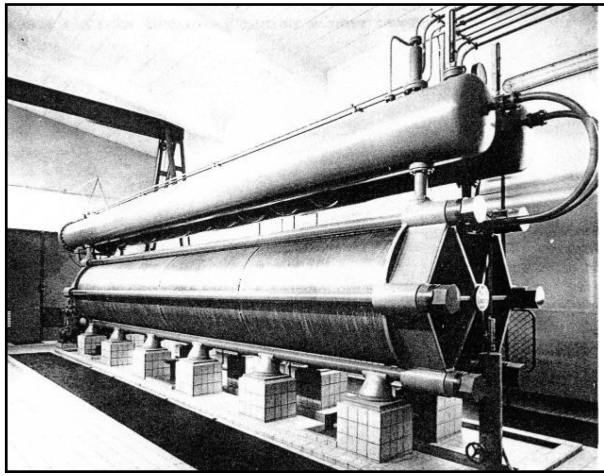
1. Introduction of technologies

1.1 Previous experience with electrolysis and Haber-Bosch

- Rjukan, 1928, 165 MW on 150 modules (27,900 Nm3/h H2)
- Glombfjord, 1949, 160 MW on 150 modules (27,100 Nm3/h H2)



- BBC, 1973
- 144 MW, 144 modules
- 32,000 Nm3/h H2

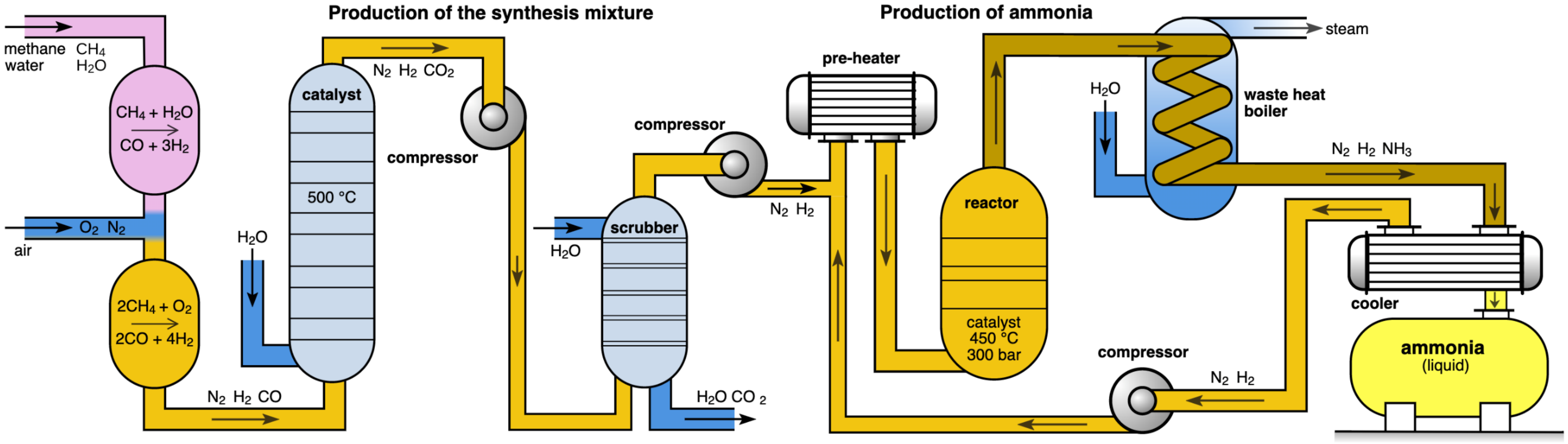


- Demag, 1959
- 203 MW, 288 modules
- 36,000 Nm3/h H2

- Zimbabwe, 1973
- 100 MW, 28 x 3.5MW
- 21,000 Nm3/h H2

1. Technologies

1.2 Main Systems for Ammonia Production Facility

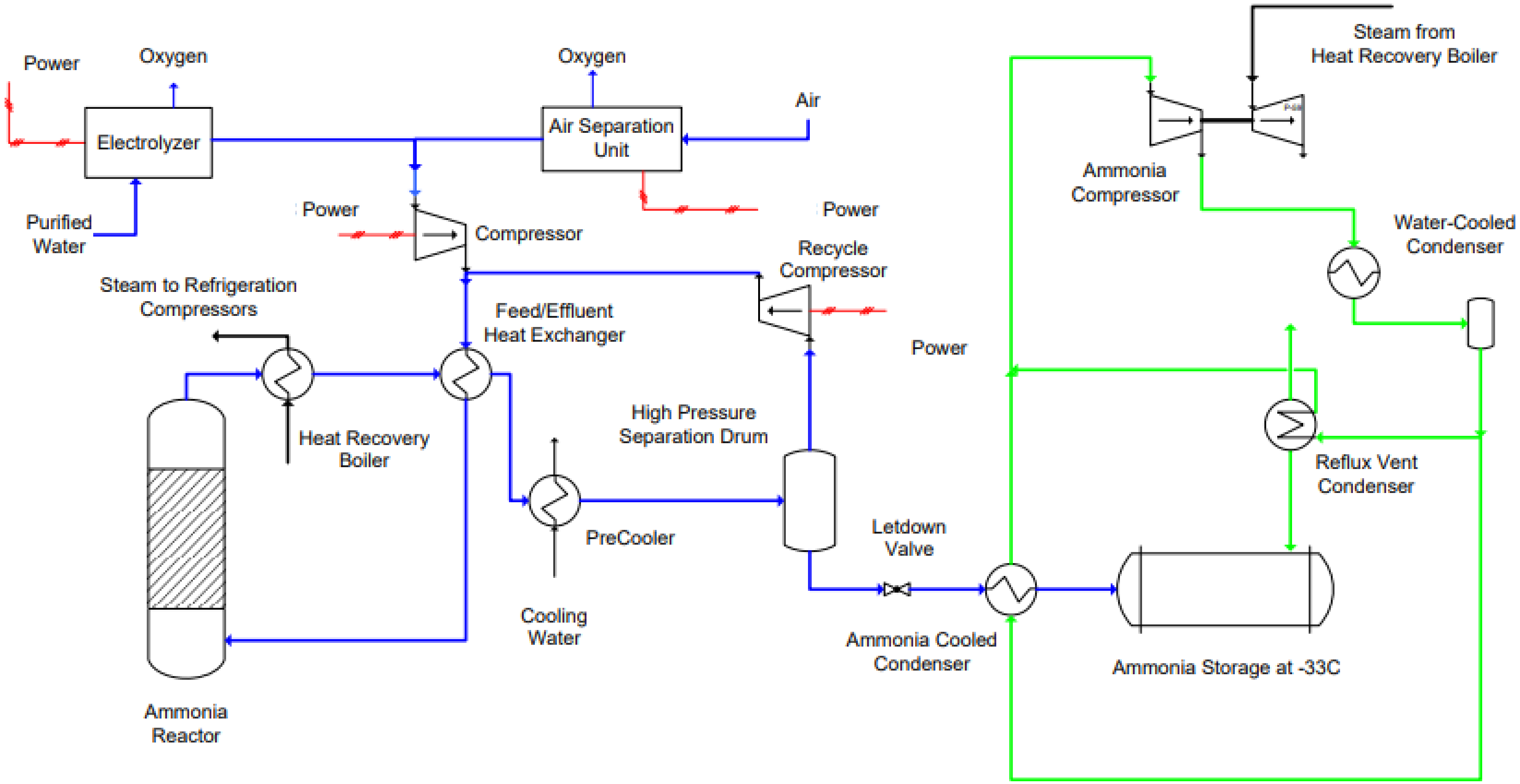


- Ammonia combustion does not generate CO2
- Stored as gas at 20 bar and liquefied at -33ºC
- 1kg H2 in 9.5 L of NH3

- Process heat: 7,250 kWh/Tn NH3
- Electricity: 1,825 kWh/Tn NH3
- **Total: 9,075 kWh/Tn NH3**

1. Introduction of technologies

1.3 Green ammonia overview



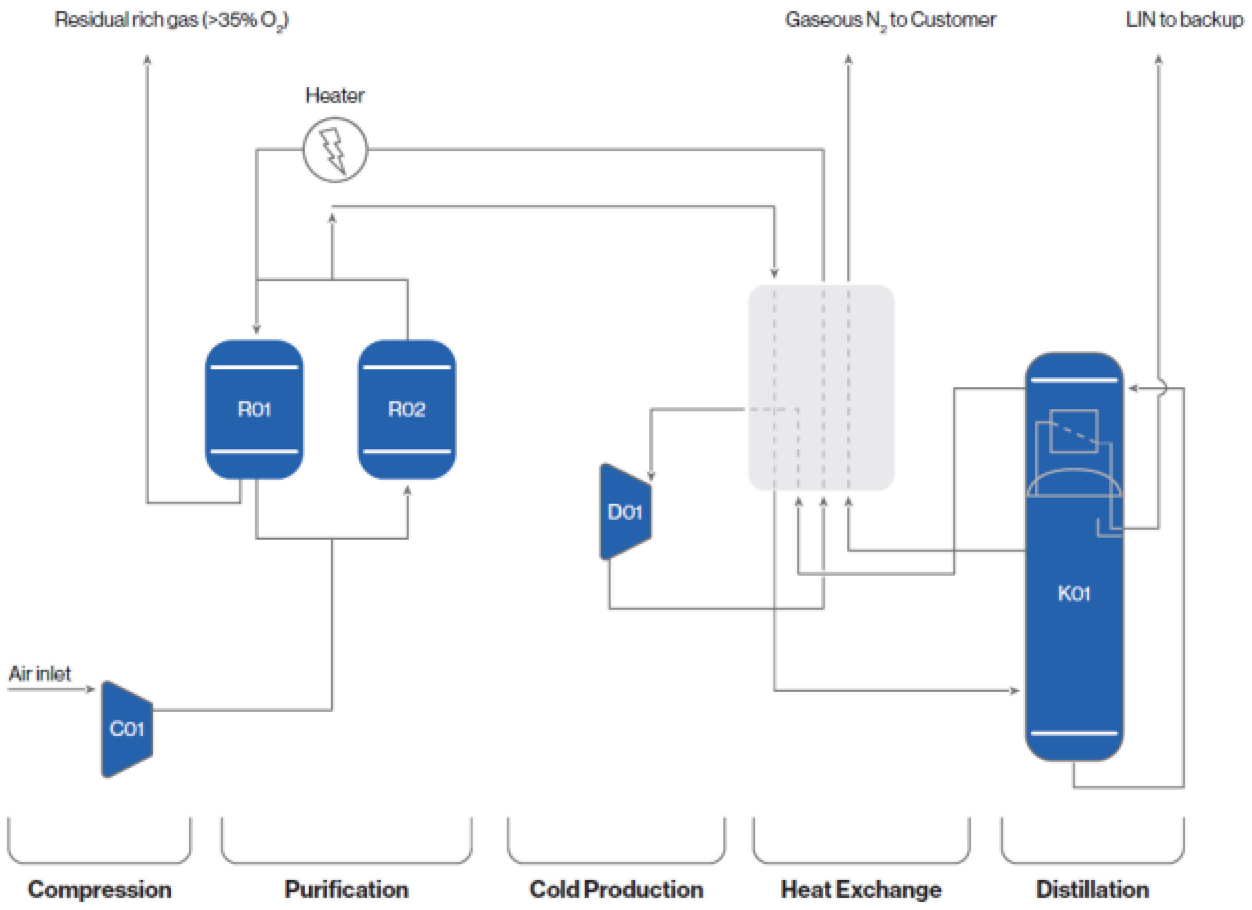
<u>Inputs</u>

- Hydrogen
- Nitrogen (from Air separation unit)
- Power for balance of plant
- Pure water for steam generation, to provide mechanical energy for feed and recycle compressors

Haber-Bosch consumption: 8,917 kWh/Tn NH3

1. Introduction of technologies

1.4 Air separation unit

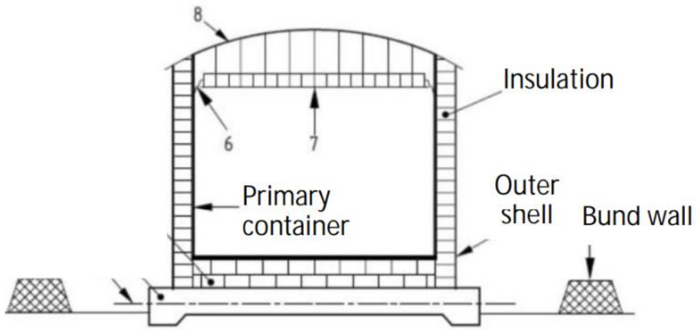


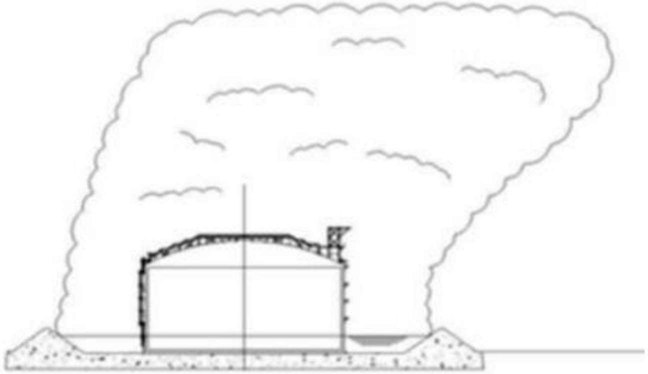
- Air compression
- Drying and CO2 removal
- Inlet air cooling against vented gases
- Inlet air enters reboiler of a single cryogenic distillation column
- Liquid from reboiler is expanded to cool it
- Gas from distillation column is expanded and cooled to provide cooling energy for the system, then vented after recovery
- Liquid and gaseous nitrogen are produced
- Liquid nitrogen can be stored as backup or sold

1. Introduction of technologies

1.5 Ammonia storage

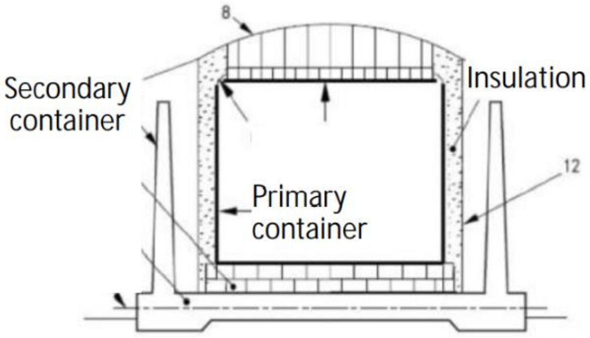
Single containment

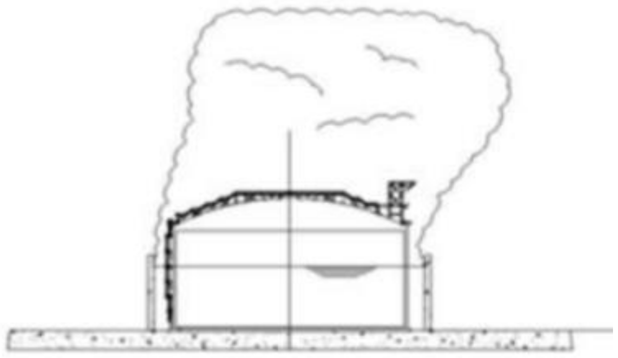




Long site boundary

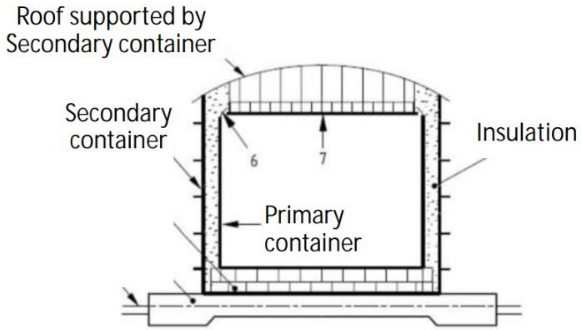
Double containment

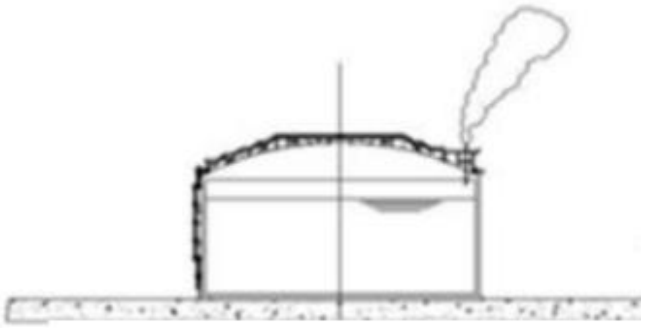




Mid site boundary

Full containment





Short site boundary

1. Introduction of technologies

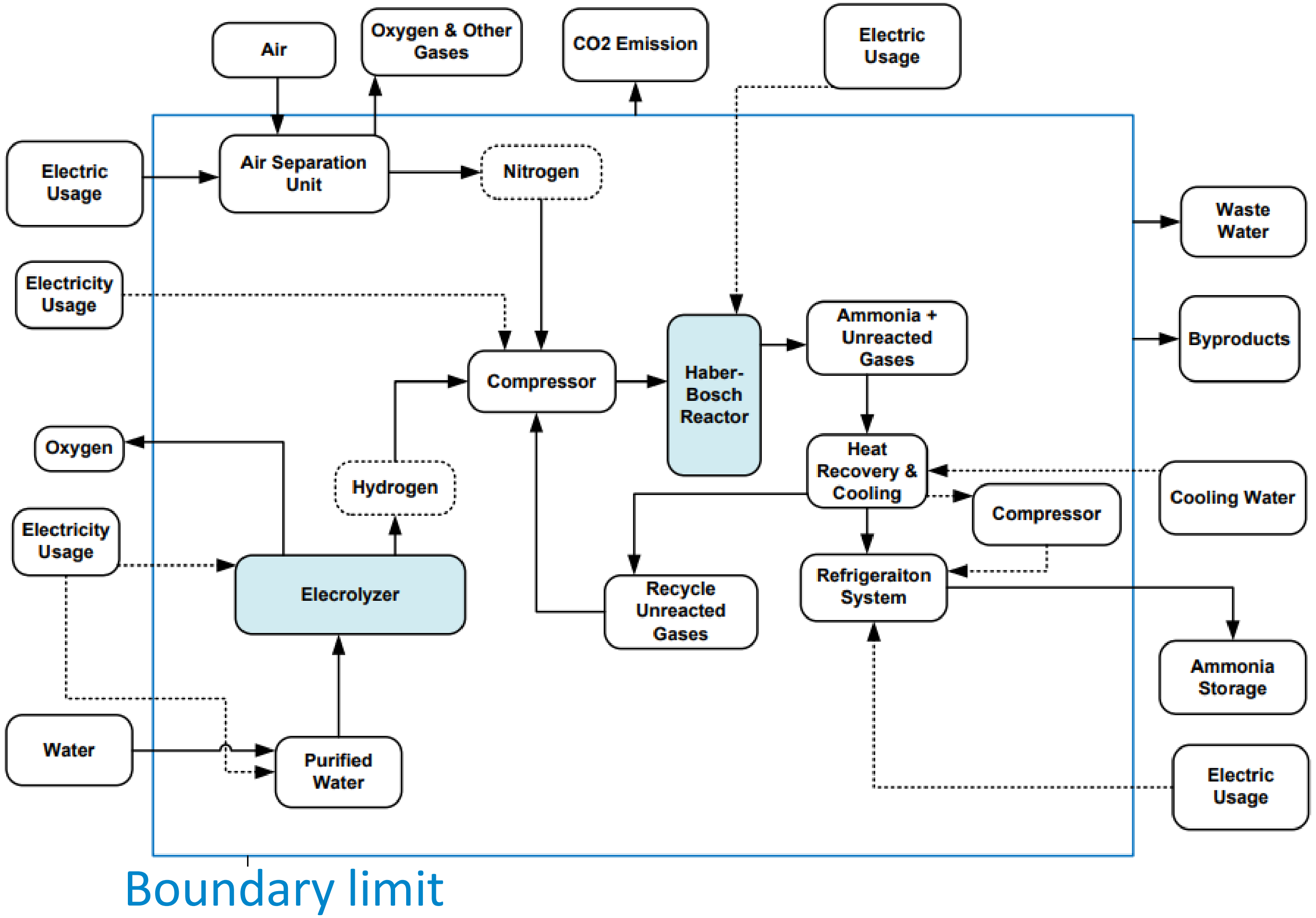
1.6 Significance of carbon footprint

Recommendations

- Focus on realistic scenarios
- Consider life-cycle analysis
- Identify alternative production pathways
- Identify opportunities for energy efficiency

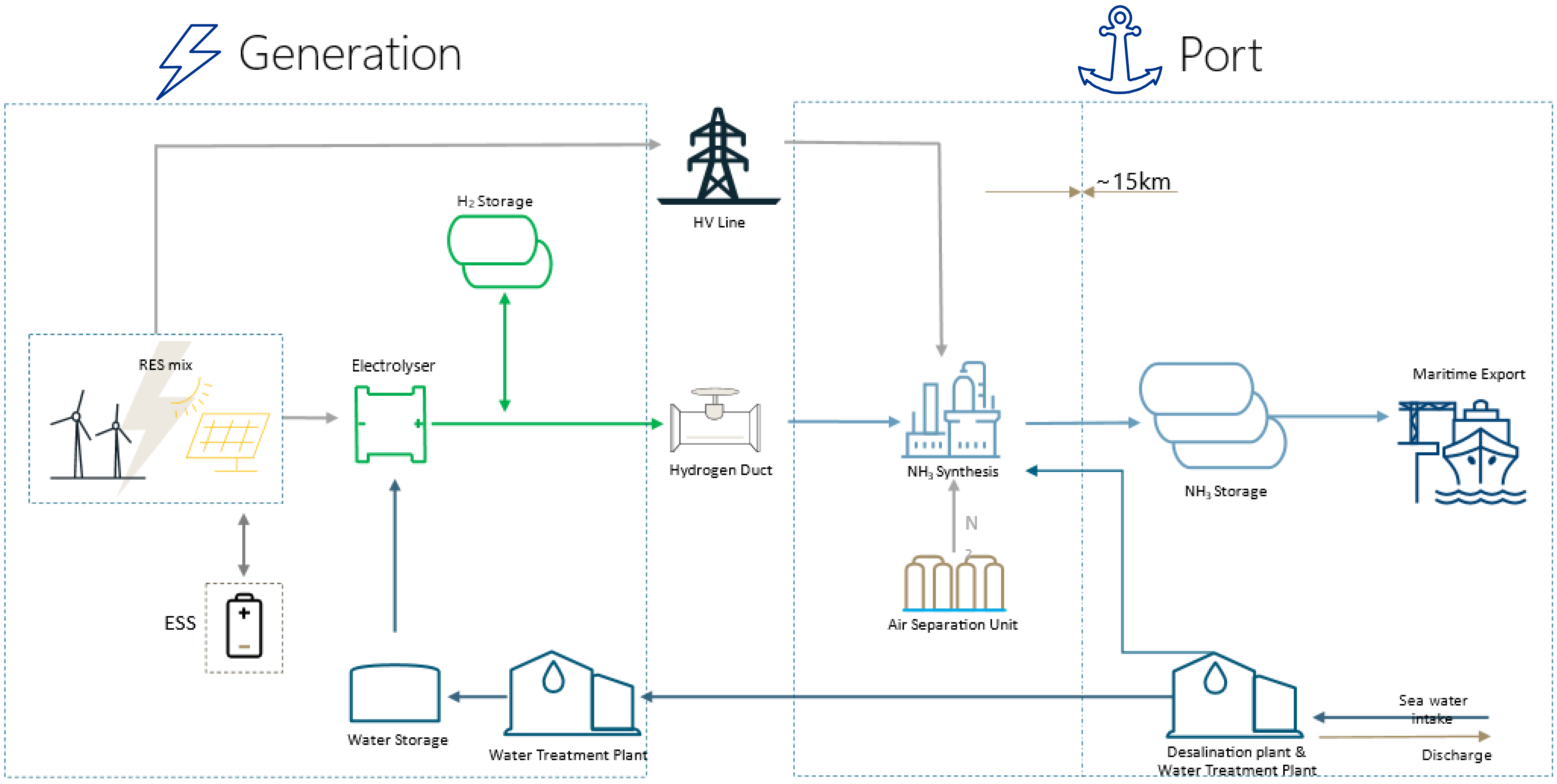
Carbon content

- 2.4 Tn CO_2/Tn NH_3
- 8.9 MWh/Tn NH_3



1. Introduction of technologies

1.7 H2-NH3 interaction



1. Introduction of technologies

1.8 H2-NH3 limitation

Electrolysis

System efficiency	kWh/kg	56.91
MW Module	MW	20
H2 Rated Flow per Module	NM3/h	4,000.00
H2 Density	Kg/Nm3	0.0899
Ely efficiency_BOL	kWh/kg	55.46
H2 purification	kWh/kg	0.27
H2 MP Compressors	kWh/kg	0.00
H2 HP Compressor	kWh/kg	0.90
H2 Utilities	kWh/kg	0.28
Turndown	-	0.05
Max. Flow	kg/h/MW	17.98
Max. Power	MWh/MW	1.02

Ammonia

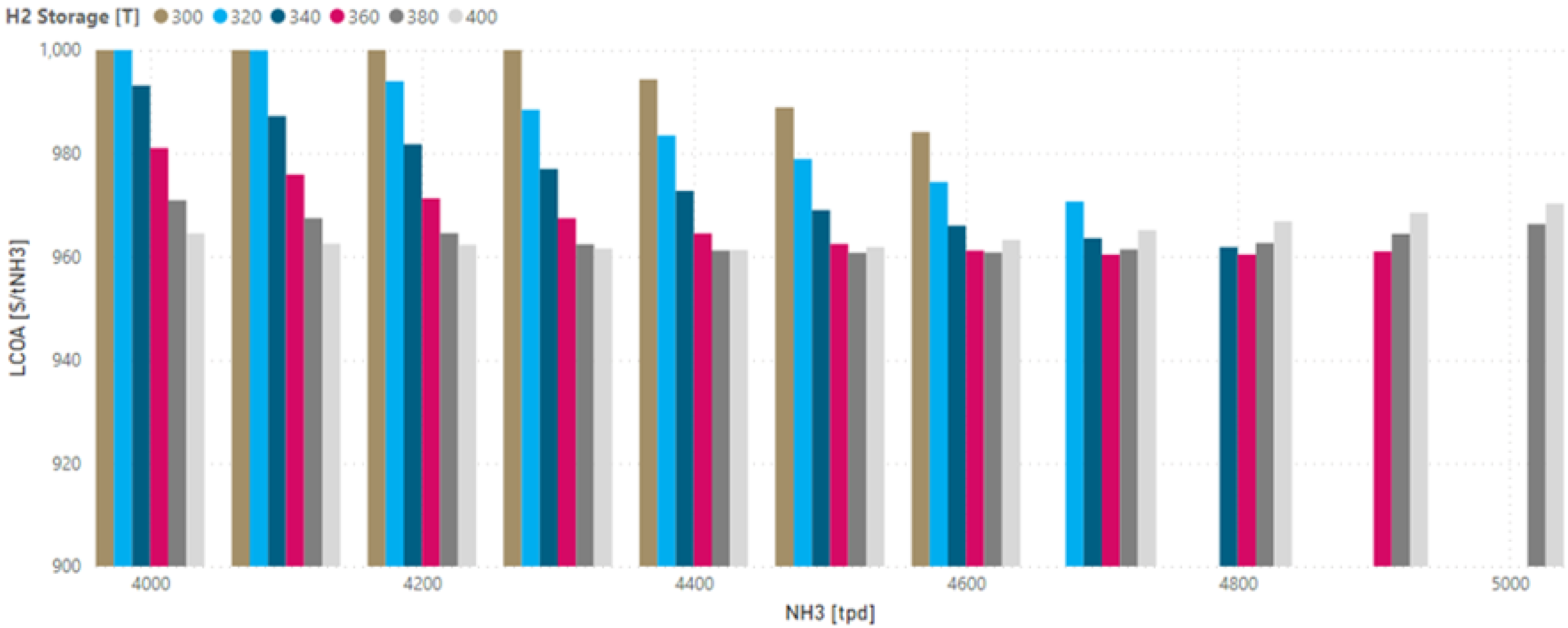
NH3/H2 Conversion	kg NH3 / kg H2	5.63
Specific consumption	kWh/kg	0.28
Electrical max load	-	1.00
Electrical turndown	-	0.75
Plant max load	-	1.00
Plant turndown	-	0.30
Ramp	-	0.20
Min shut_down time	h	12.00
Max. Power	MWh/tpd	0.01
Max. Flow	kg/h/tpd	41.67

Potential scenarios
optimistic vs conservative
according to latest state of the art

1. Introduction of technologies

1.9 System flexibility

High flexibility in electrolyser – Low flexibility in Haber-Bosch



2. Suppliers

2.1 Technology providers

These providers share practically 100% of the market for ammonia production at large scale

Selected technology providers	
Location	**Company**
Germany	ThyssenKrupp
Denmark	Haldor Topsøe
US	KBR, Cummins
Germany	Linde
Switzerland	Casale
Netherlands	Stamicarbon
Netherlands	Proton Ventures
Japan	Tsubame BHB
US	Starfire Energy

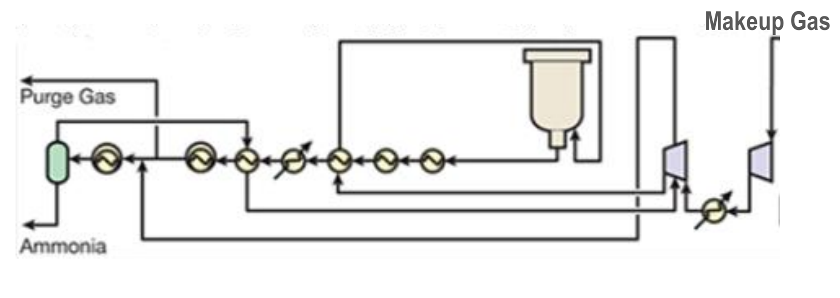
2. Suppliers

2.2 Technology features

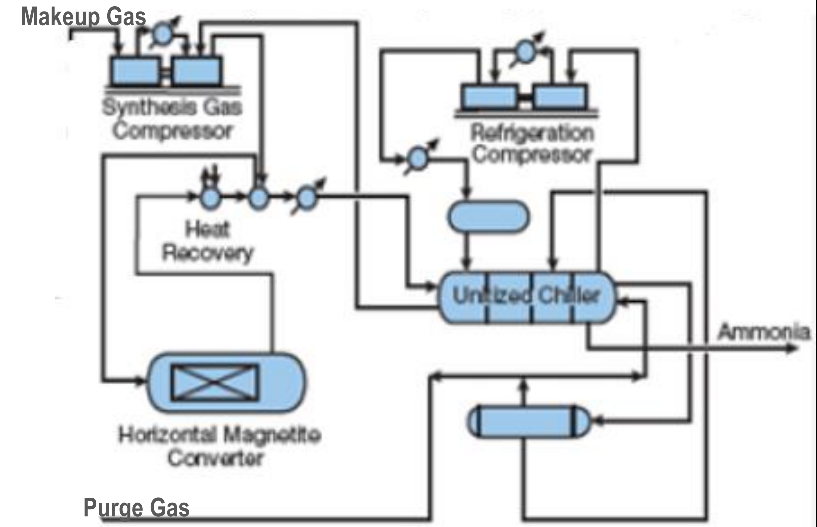
	Unit	TK	KBR	Haldor Topsøe	Casale	Linde
Converter Type		2 Vertical Reactors 3 Radial Beds	1 Horizontal Reactor 3 or 4 Radial and Axial Beds	Single radial flow Ammonia Converter	1 Vertical Reactor 3 Radial Beds (axial radial converter)	By others
Internal Cooling Option		Indirect Cooling in Heat Exchangers	Indirect Cooling in Heat Exchangers	Indirect Cooling in Heat Exchangers	Indirect Cooling in Heat Exchangers and Quench	By Others
Catalyst Type		Magnetite	Magnetite and Ruthenium	Magnetite	Amomax-Casale	By Others
Loop Operating Pressure	bar	180	80-150	140	150	140
Max. proven Capacity	tpd	3500	3000	3000	2000	1200
Steam Generation conditions:						
Temperature	°C	395	370	380	400	390
Pressure	barg	44	45	49	41	42

2. Suppliers

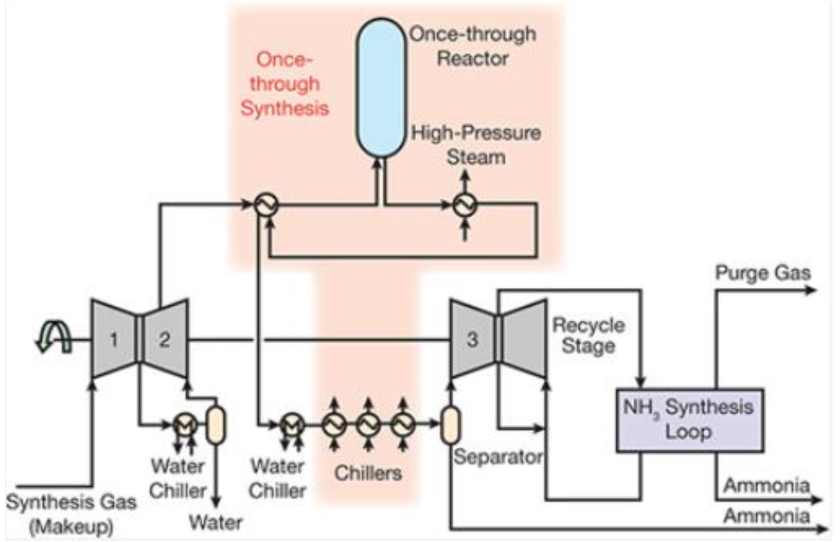
2.3 Licensor loops



Haldor Topsoe conventional ammonia loop



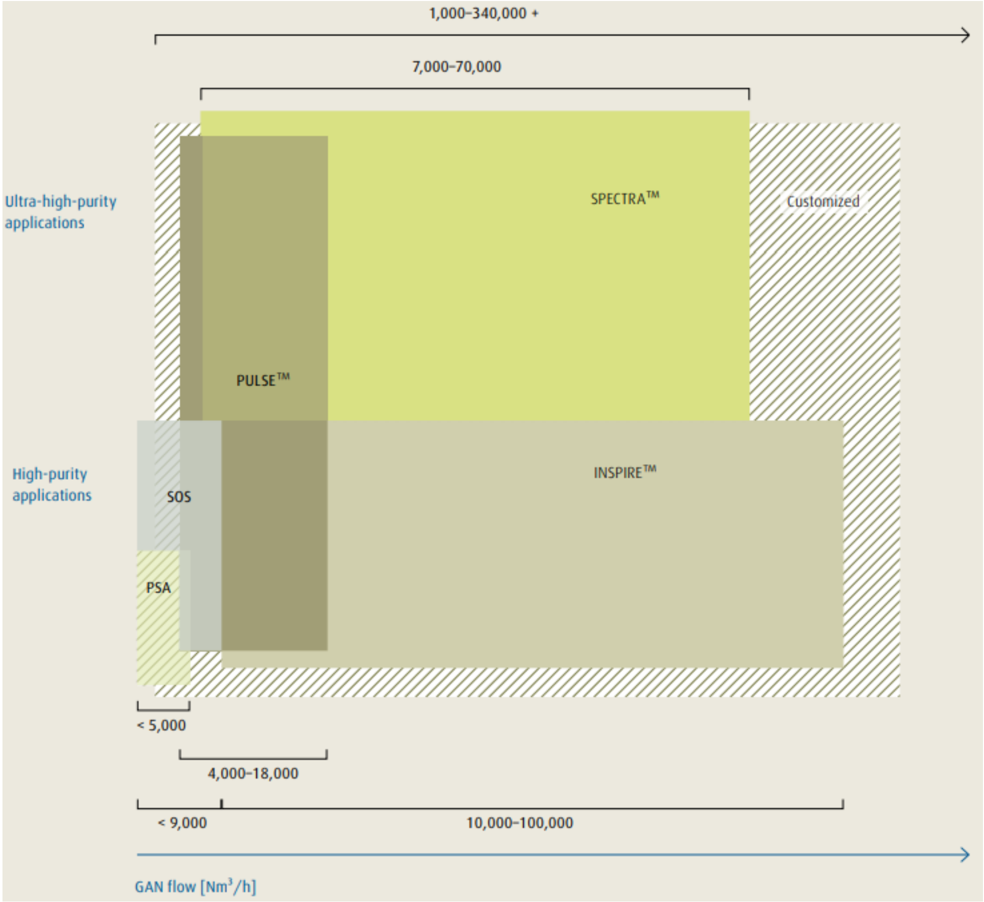
KBR ammonia loop with horizontal reactor



TKIS dual-pressure synthesis loop with once-through vertical reactor

2. Suppliers

2.4 Linde Nitrogen Generation Systems



Ref: Linde ASU product brochure

Linde provide modular nitrogen plant solutions:

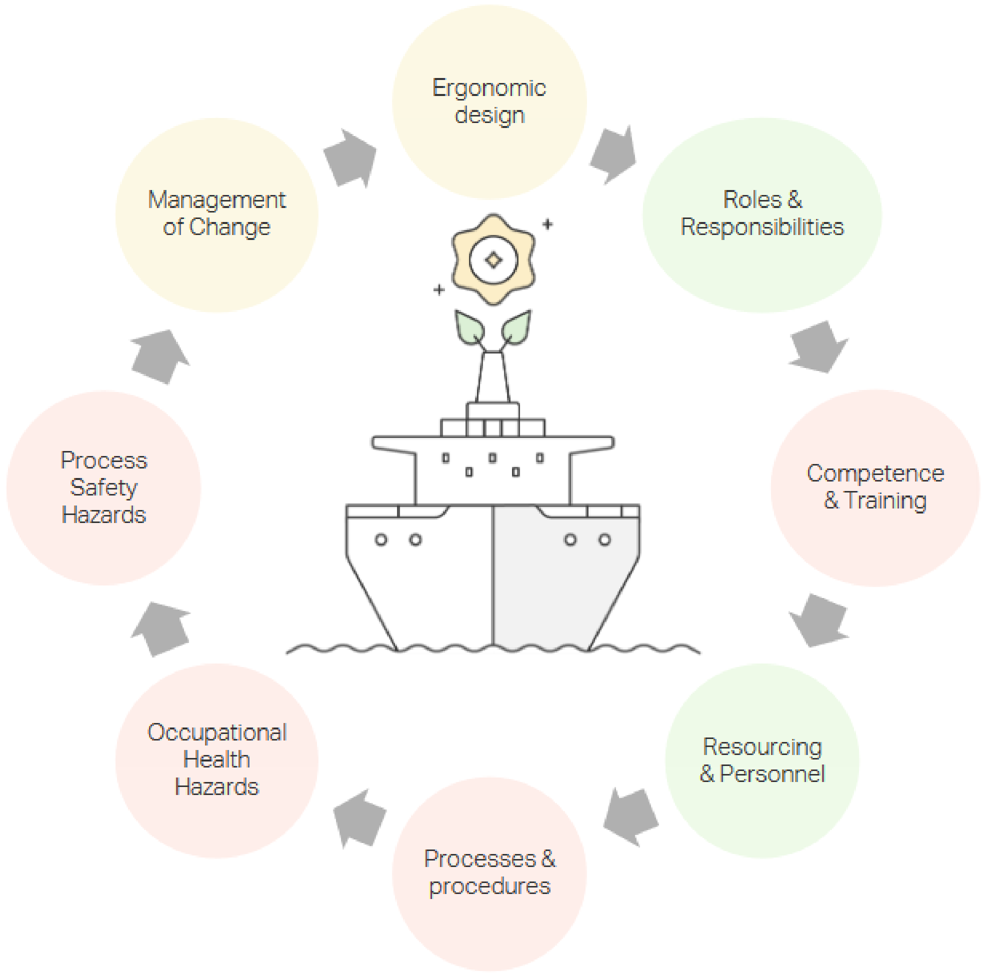
SPECTRA™	Ultra-high purity nitrogen for the electronics industry
INSPIRE™	Nitrogen for applications with industrial purity levels
PULSE™	Nitrogen liquefaction units
PSA	Pressure swing adsorption plants
Customized plants	Tailor-made plants
SOS	Small on-site nitrogen plants

Biggest nitrogen generator even built today by Linde has a capacity of approx. 335 kNm^3/h

e.g. 2,200 MTPD NH_3 plant approx. 61 KNm^3/h N2 → INSPIRE™ product range

3. Competencies

3.1 Anlysis outcome



Impact criteria

- Low – Minor Changes
- Medium - Changes
- High – Significant Changes

- If we are to **reach consensus on the safe implementation of ammonia** as an alternative fuel, the industry will need further detail on the high-impact human factors areas identified in the report.
- **We call for** specific Human Factor studies to **address implications of high impact considerations.**

4. Standards

4.1 Low-carbon ammonia certification

- Currently there is no certification scheme for ammonia
- Using a hydrogen certification, we could obtain a guarantee of origin for the ammonia
  - Green ammonia must be from renewable sources
- Ammonia energy association is seeking to facilitate the establishment of a certification scheme for low-carbon ammonia

4. Standards

4.2 EU taxonomy for ammonia manufacturing

- Design to support transformation of EU economy to meet Green Deal objectives
- Two main criterias:
  - Ammonia is produced from hydrogen that complies with technical screening criteria
  - Design of ammonia plant meets or exceeds requirements of Best Available Techniques Reference Document (BREF) for the manufacture of large inorganic chemicals
- For Hydrogen it must comply with the following requirement:
  - Life-cycle GHG emissions saving requirement of 73.4% of hydrogen (3 tnCO2eq/tnH2)

4. Standards

4.3 Fit for 55 package overview (aplicable to ammonia)

Policy Type	Sectors Covered	Policy Name
Regulation	Carbon tax/emissions trading	Revision of the Regulation on the inclusion of GHG emissions and removals from land use, land use change and forestry
Regulation	Carbon tax/emissions trading	Effort sharing regulation
Directive	Renewable energy	Amendment to the Renewable Energy Directive to implement the ambition of the new 2030 climate target
Directive	Energy efficiency	Proposal for a Directive on energy efficiency
Directive	Aviation	Revision of the EU Emission Trading System for Aviation
Regulation	Aviation	ReFuelEU Aviation – sustainable aviation fuels
Regulation	Maritime	FuelEU Maritime – green European maritime space
Directive	Alternative fuels	Revision on the Directive on deployment of the alternative fuels infrastructure
Communication	Alternative fuels	Strategic rollout plan to support rapid deployment of alternative fuels infrastructure
Regulation	Automotive	Amendment of the Regulation setting CO_2 emissions standards for cars and vans
Regulation	Carbon tax/emissions trading	Carbon border adjustment mechanism
Directive	Carbon tax/emissions trading	Revision of the Energy Tax Directive
Directive	Carbon tax/emissions trading	Revision of the EU Emission Trading System
Directive	Aviation	Notification on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
Decision	Emissions trading	Revision the Market Stability Reserve
Regulation	Investment/innovation	Social Climate Fund
Communication	Forest credits/land use	New EU Forest Strategy for 2030

Direct impact on ammonia/fertiliser imports into the EU.

Incentivises use of low carbon ammonia as a fuel.

Incentivises / requires use of low carbon hydrogen in industry as feedstock and fuel within EU.

4. Standards

4.4 CBAM cost impact

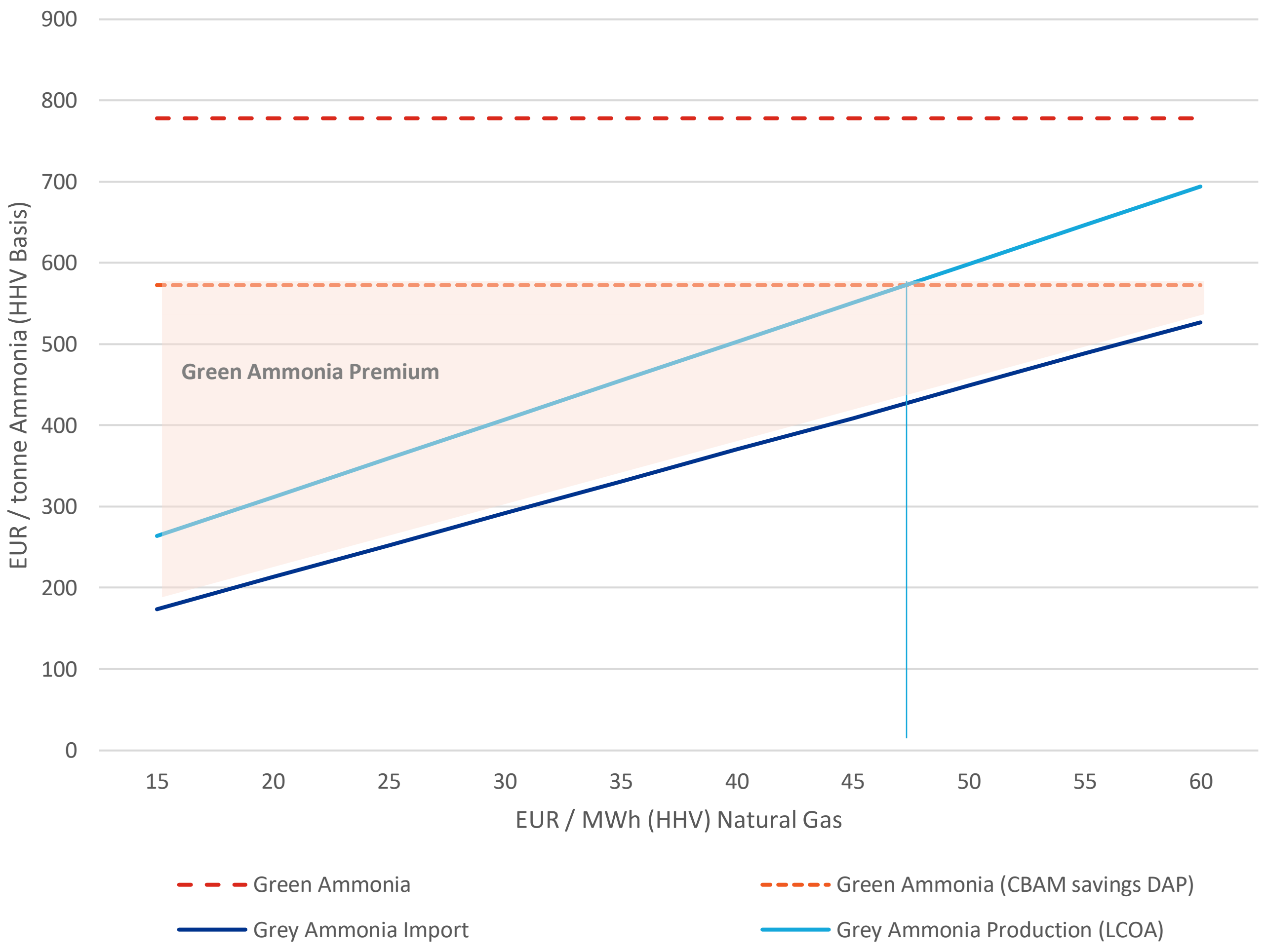
This analysis is conducted on DAP production only because currently no AN is exported between Tunisia and the EU.

Assuming all DAP produced by GCT is exported to a country implementing the CBAM regulation, 205 €/tonne price premium on green ammonia is can be accepted based on the 71 €/tonne penalty on DAP.

At a natural gas price of approximately 47 €/MWh, the LCOA for a green-field plant in Tunisia intersects with that of green ammonia subject to CBAM savings. However, the cost of imported ammonia remains consistently low and does not intersect with the reduced green ammonia price.

Imported ammonia price remains consistently low and does not surpass green ammonia price despite CBAM savings.

CBAM Cost Savings on Price of Green Ammonia



5. Namibias’ position

5.1 Opportunities for the country

Regulations	Market	Technology	Infrastructure
- Adoption of subsidies for low-carbon products - Carbon pricing	- Focus on end-market - Price vs LCOA	- Scale-up projects to make green products competitive	- Required infrastructure will be developed in line with market growth

Q&A