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Green Ammonia for energy storage and beyond

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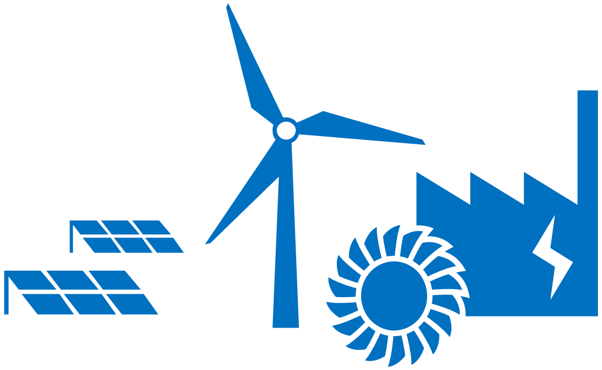
Green ammonia for energy storage and beyond

- Overview: Siemens perspective on energy storage and electrification
- Technology today:
  Ammonia energy systems, and demonstrator project
- Technology developments:
  Synthesis and energy release
- Prospects for "Green Ammonia"



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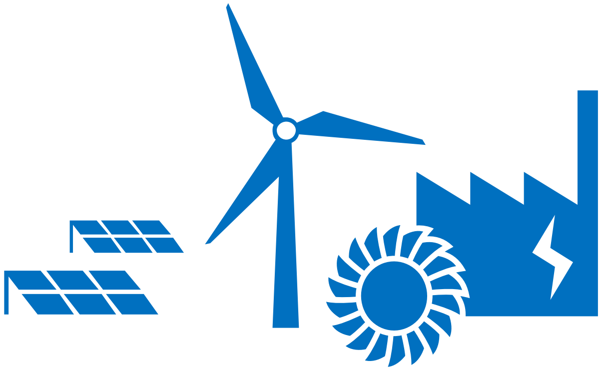

The changing Energy Landscape

Different solutions for different market stages

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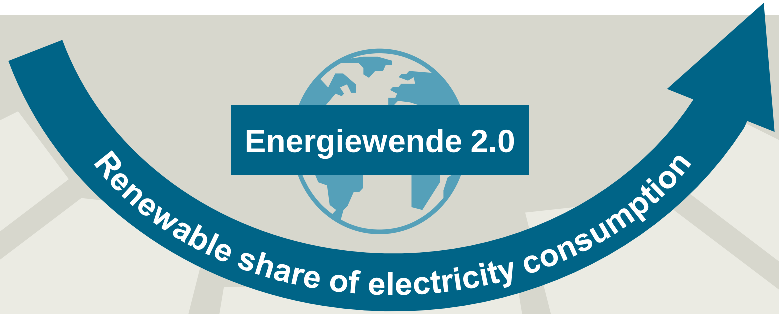


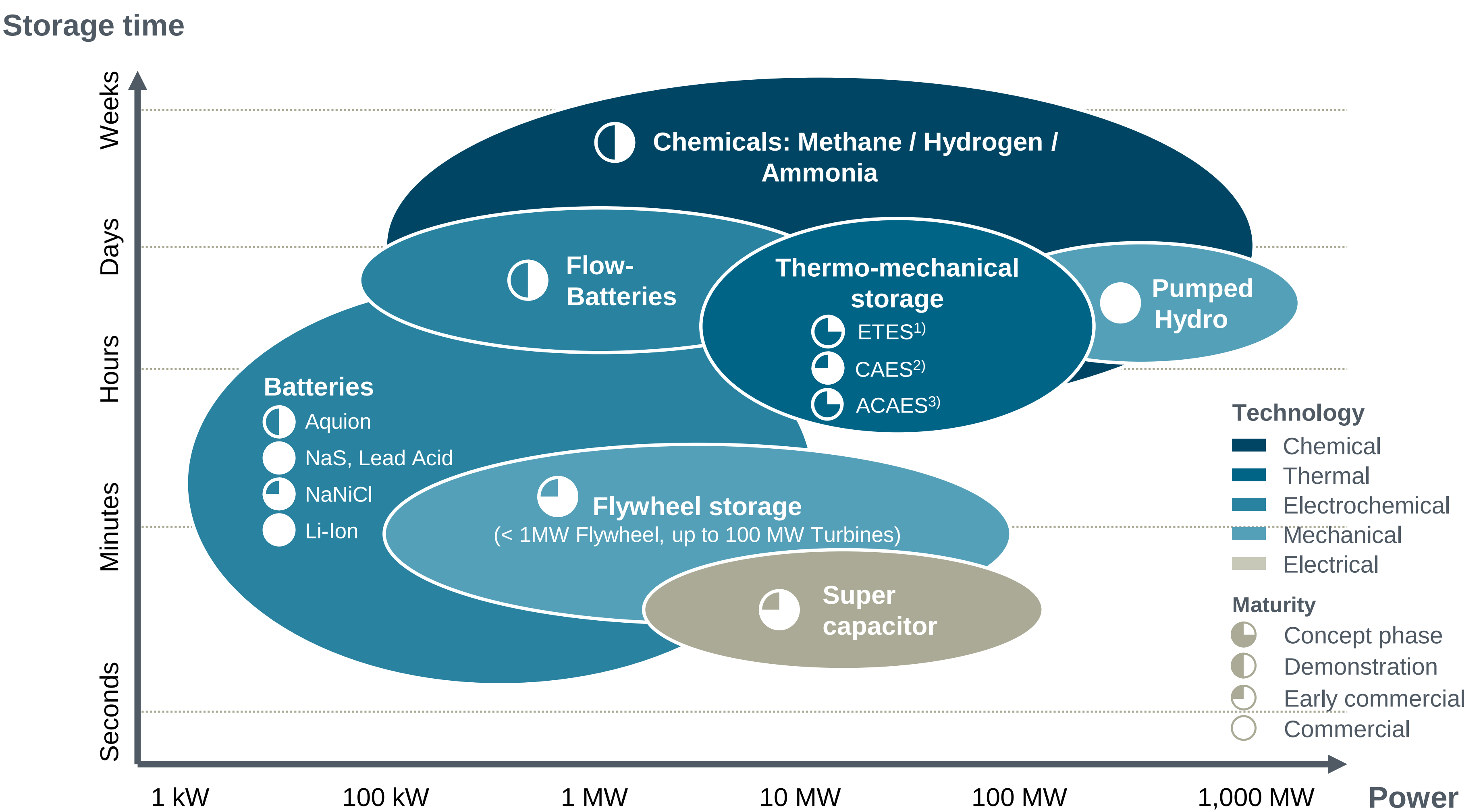
<10%	20+%	40+%	60+%	80+%
Traditional mix	**System integration**	**Market integration**	**Regional autonomous system**	**Decoupled generation and consumption**
– Fossil (coal, gas, oil) – Nuclear – Renewables (mainly hydro)	– Fossil (coal, gas, oil) – Renewables (wind, PV, hydro)	– Capacity markets etc.	– Predictable regional "area generation" (topological plants)	– Interaction of all energy carriers
– Efficiency – LCC reduction – Availability / reliability / security	– Decreasing spot market prices – Subsidized economy – Increasing redispatch[1] operation	– Power2Heat, CHP increasing – Demand side management – ***First storage solutions*** – HVDC/AC overlay	– Regional plants, cellular grids – HVDC overlay and meshed AC/DC systems – ***Power2Chem /*** – Stability challenge	– Complete integration of decentralized power generation – ***Storage systems*** – Return of gas power plants?
Past	**Today**	**Mid-term**		**Long-term**

Fierce competition in traditional businesses, need to set benchmark in new or changed markets

Profitable business for new technologies cannot be shown yet – today's use cases are mainly niche or pilot applications

1) Corrective action to avoid bottlenecks in power grid

Addressing energy storage needs will require a range of technologies



[1] Electro-Thermal Energy Storage [2] Compressed Air Energy Storage [3] Adiabatic Compressed Air Energy Storage

Energiepark Mainz – Project scope and key facts

- 3 x Sylizer 200 electrolysers, with peak power of 2 MW el. each (6 MW peak).
- Connection to 10 MW wind-farm
- 1000 kg H_2 storage (33 MWh)
- Provides:
  - H_2 gas to Linde
  - Demand side response to local grid
  - H2 gas injection into local (natural) gas network

The existing chemical industry emissions conflict with initiatives to avoid climate change

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Chemical Industry Emissions

1255 MT/yr CO_2[1]

➔ 4% world total[2]

1.1TW [1]

➔ 8.2% world total[2]

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Climate Act Requirements

UK target of 80% cut in emissions by 2050

EU wide target of 40% cut in emissions by 2030

Opportunity: carbon – free synthesis of chemicals powered by renewable energy

Ammonia: 1.8% of the world consumption of fossil energy goes into the production of ammonia. 90% of ammonia production is based on natural gas.

Top 10 Chemicals / Processes:

1) Steam cracking
2) Ammonia
3) Aromatics extraction
4) Methanol
5) Butylene
6) Propylene FCC
7) Ethanol
8) Butadiene (C4 sep.)
9) Soda ash
10) Carbon black

1) Chemical and Petrochemical Sector – IEA2009 2) Key World Energy Statistics – IEA2014

Ammonia is an important chemical with a commodity market value of EUR100bn/year

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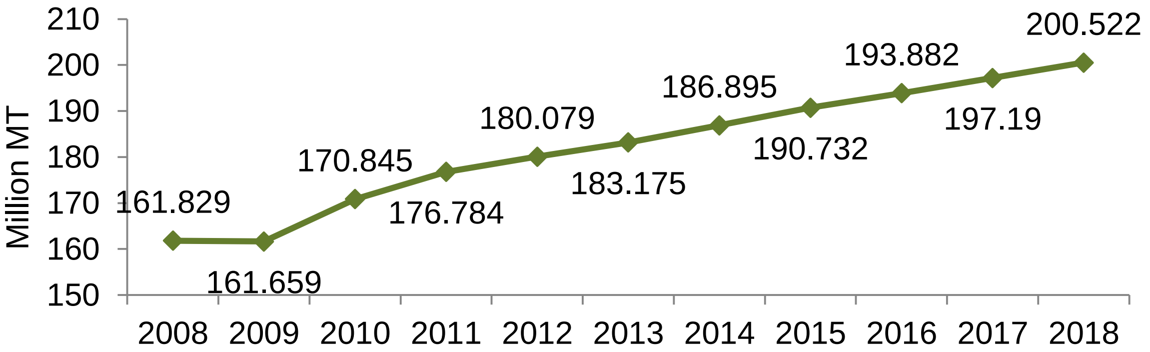
Ammonia

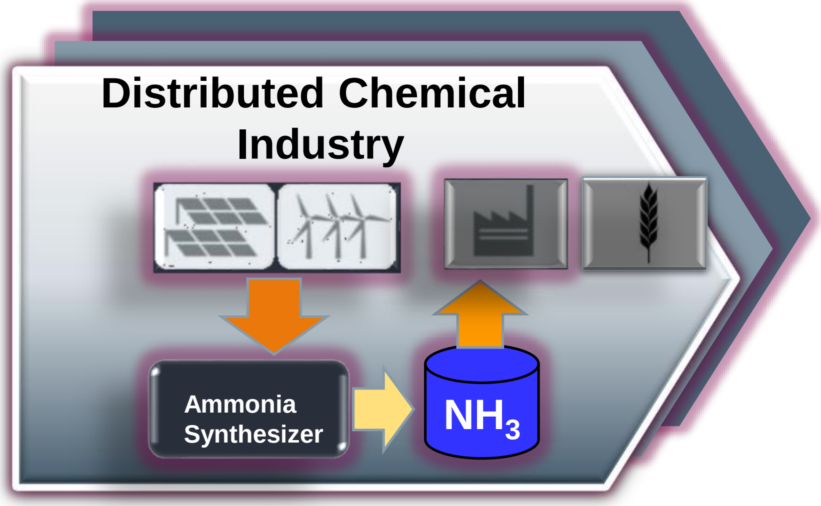
- A gas, produced by the chemical industry. Over 80% of ammonia is used in the fertiliser industry.
- Demand for fertiliser, as shown in the graph (including projected growth to 2018), is growing at +3%pa[1].
- Current production levels of Ammonia are about 180m t/year. The commodity value is €600-€700/t, leading to a commodity market value of over €100bn/year
- Production today uses the Haber-Bosch process and relies on natural gas as a feedstock.

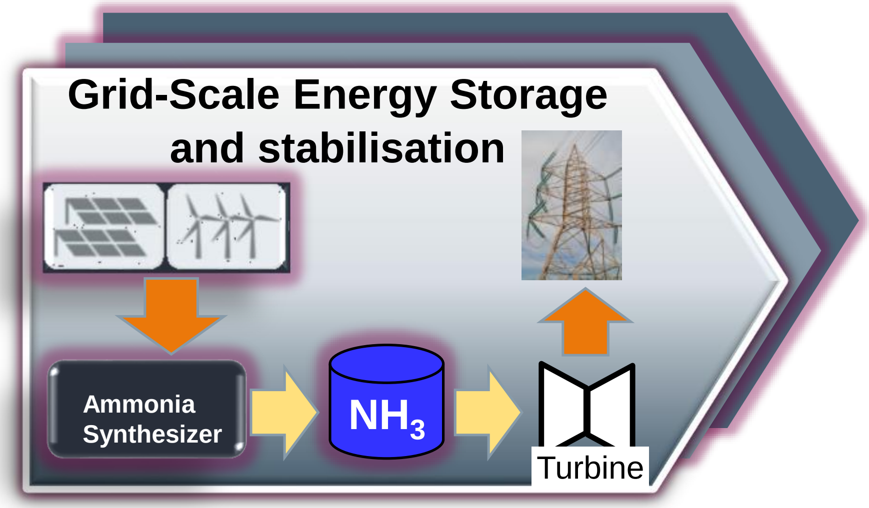
Global fertilizer nutrient consumption

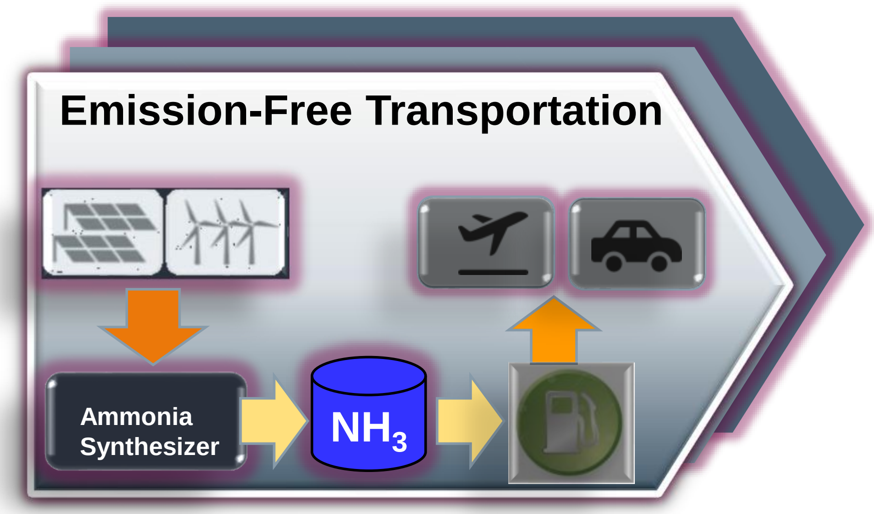


Source: World Fertilizer Trends and Outlook to 2018, Food and Agriculture Organization of the United Nations

Green Ammonia – Carbon Free Flexible Asset







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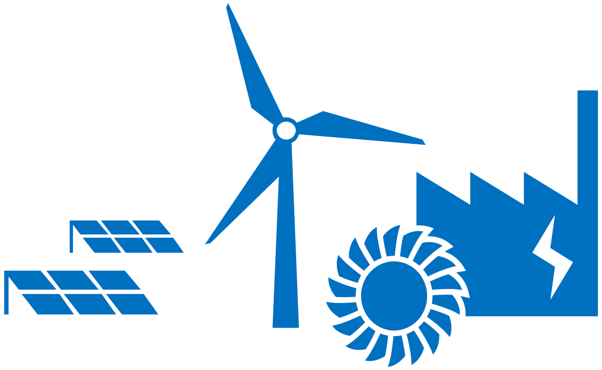

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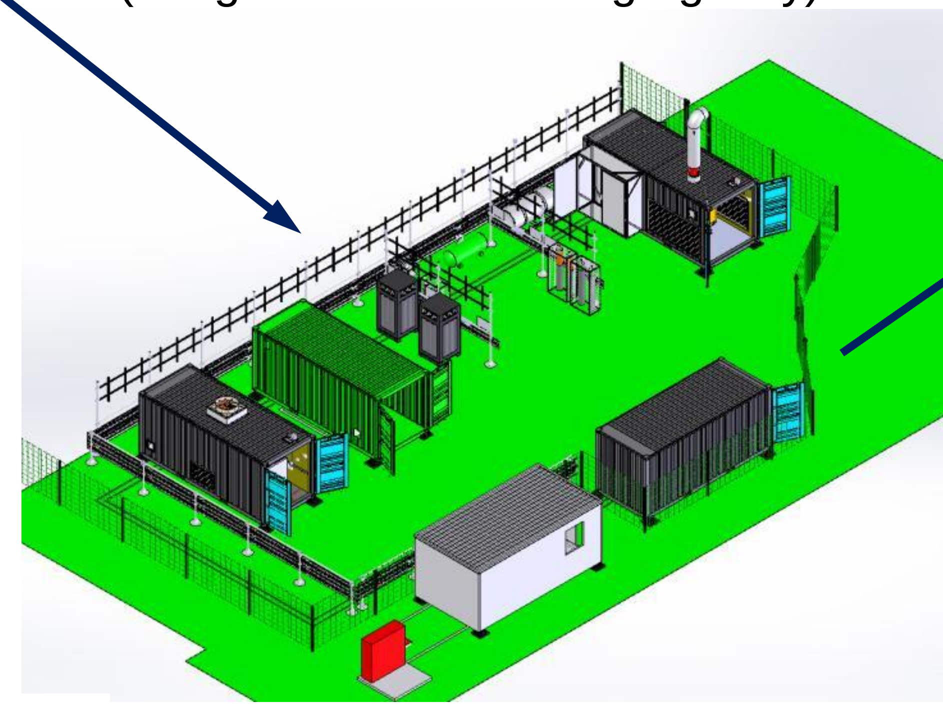
Decoupling Green Energy: “green” ammonia synthesis and energy storage system demonstrator

- Being built at Rutherford Appleton Laboratory, near Oxford, UK.
- Project 50% supported by Innovate UK (UK government funding agency).



- Evaluation of all-electric synthesis and energy storage demonstration system by Dec 2017.

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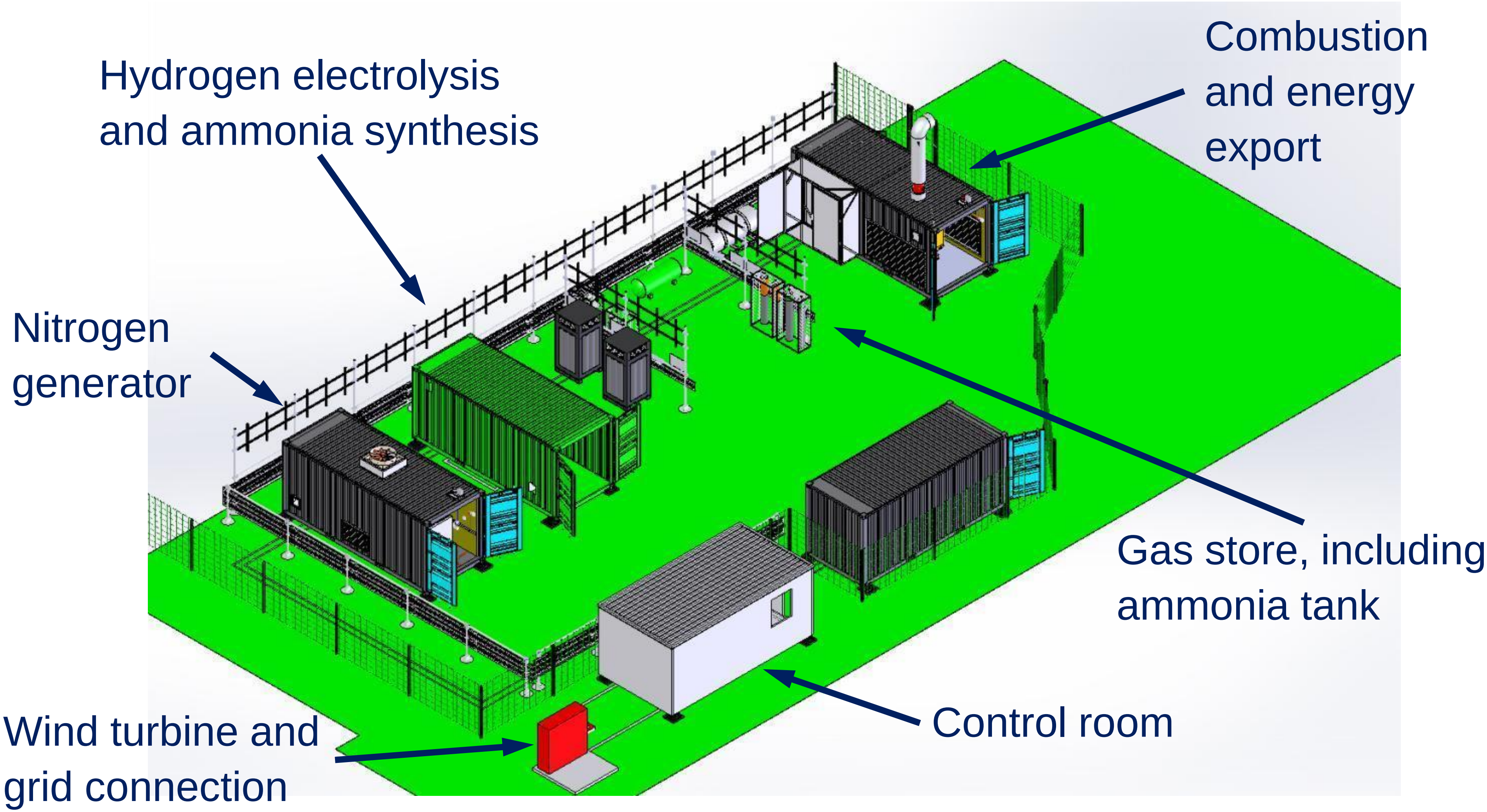
Ammonia test site layout



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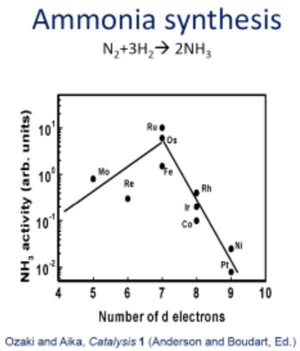
Ammonia energy storage system demonstrator hardware

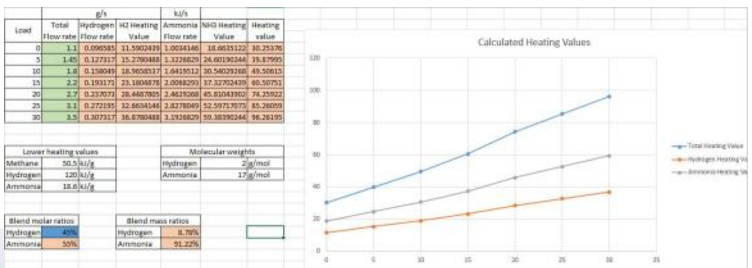
NH_3 H-B Reactor (Bespoke)

System demonstrator technology development

Haber-Bosch synthesis catalyst



Ammonia combustion studies



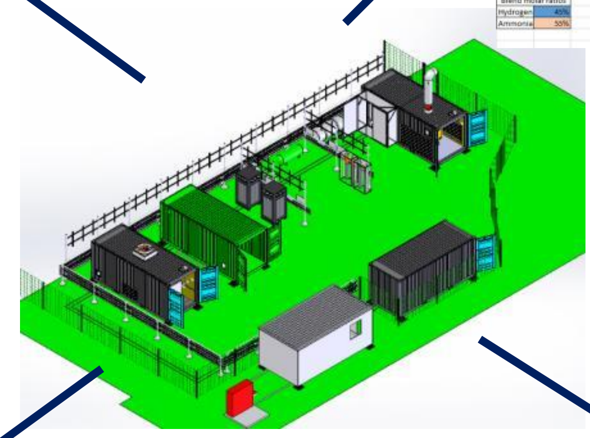
Load	g/s Total Flow rate	Hydrogen Flow rate	H2 Heating Value	kJ/s Ammonia Flow rate	NH3 Heating Value	Heating value
0	1.1	0.096585	11.5902439	1.0034146	18.6635122	30.25376
5	1.45	0.127317	15.2780488	1.3226829	24.60190244	39.87995
10	1.8	0.158049	18.9658537	1.6419512	30.54029268	49.50615
15	2.2	0.193171	23.1804878	2.0068293	37.32702439	60.50751
20	2.7	0.237073	28.4487805	2.4629268	45.81043902	74.25922
25	3.1	0.272195	32.6634146	2.8278049	52.59717073	85.26059
30	3.5	0.307317	36.8780488	3.1926829	59.38390244	96.26195

Lower heating values		
Methane	50.5	kJ/g
Hydrogen	120	kJ/g
Ammonia	18.6	kJ/g

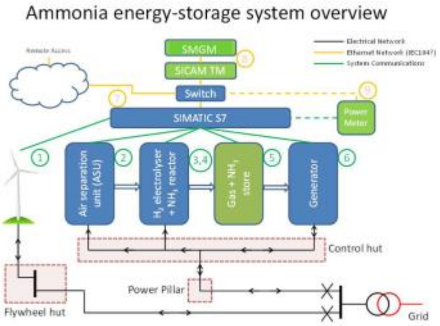
Molecular weights		
Hydrogen	2	g/mol
Ammonia	17	g/mol

Blend molar ratios	
Hydrogen	45%
Ammonia	55%

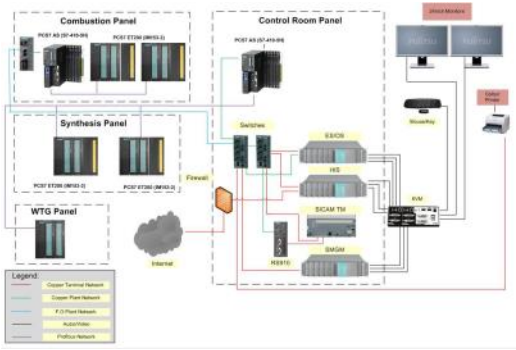
Blend mass ratios	
Hydrogen	8.78%
Ammonia	91.22%



Energy management system



Control system



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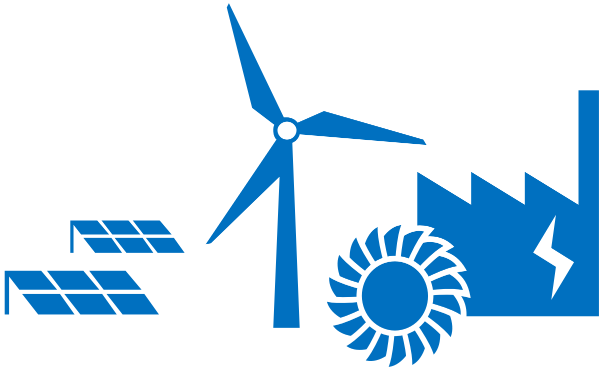
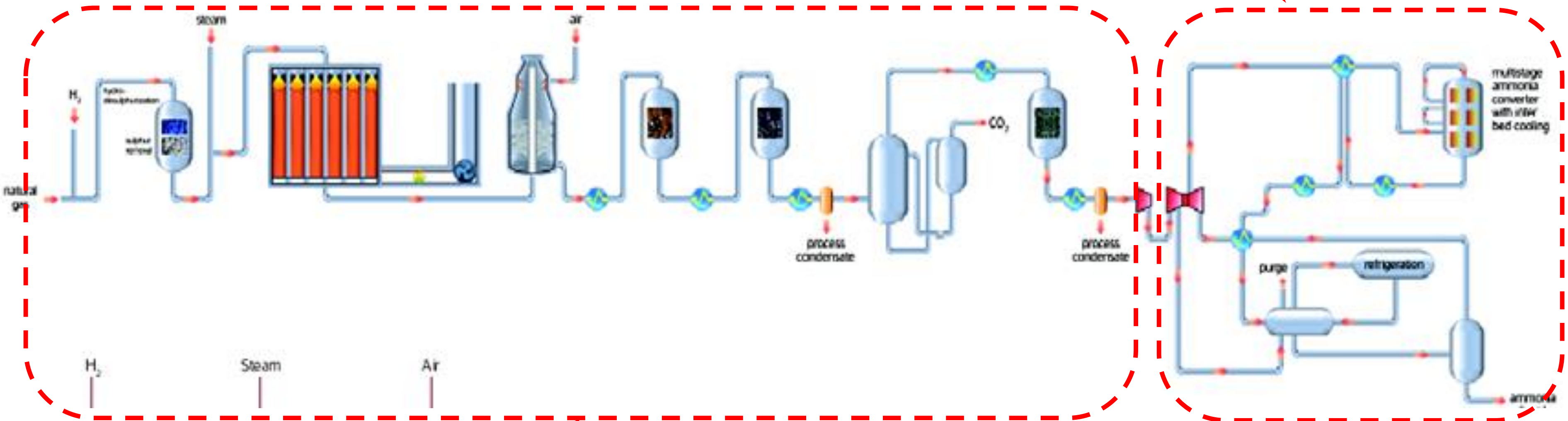


Ammonia Production Today

Typical ammonia plant today[1]

Ammonia conversion and separation here!



$$N_2 + 3H_2 \rightarrow 2NH_3$$

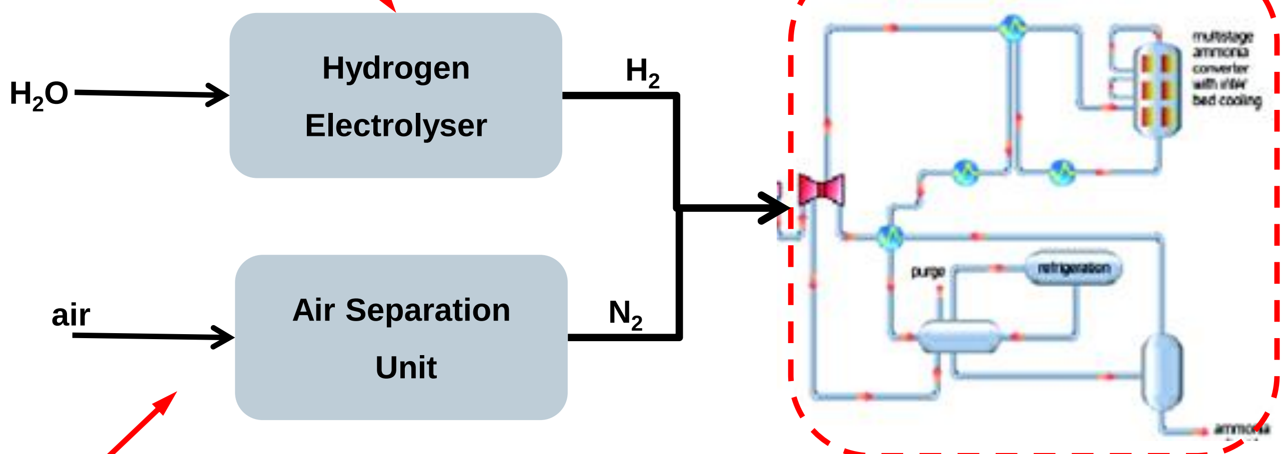
Gas preparation: significant portion of plant exists to produce H2

1) Courtesy of Johnson Matthey

Ammonia Production 2020

Siemens Sylizer

Ammonia conversion and separation here!



Gas preparation: ultra pure feedstock gas from water electrolysis and air separation unit

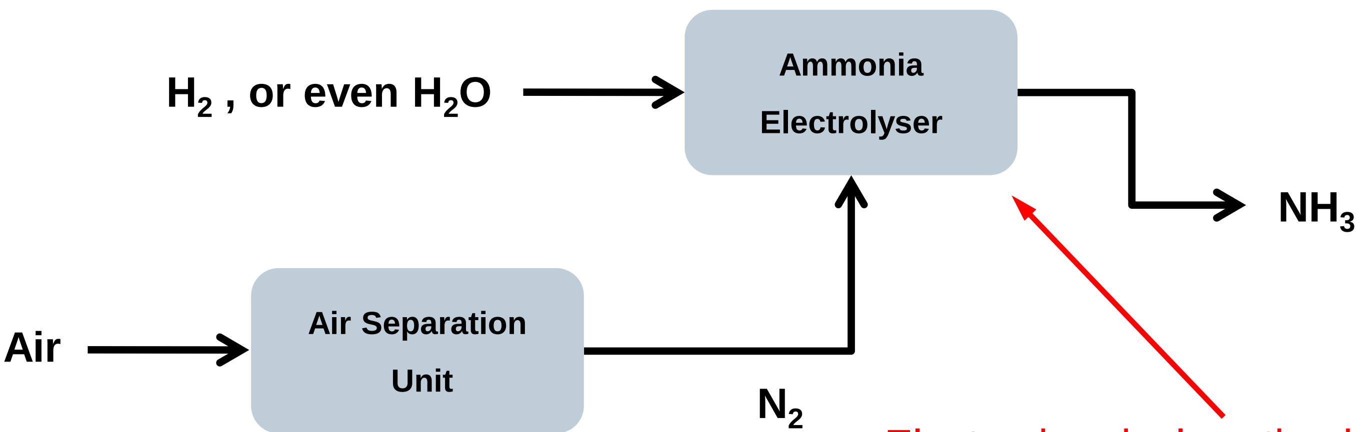
$$N_2 + 3H_2 \rightarrow 2NH_3$$

Ammonia Production 2030

$$N_2 + 3H_2 \rightarrow 2NH_3$$

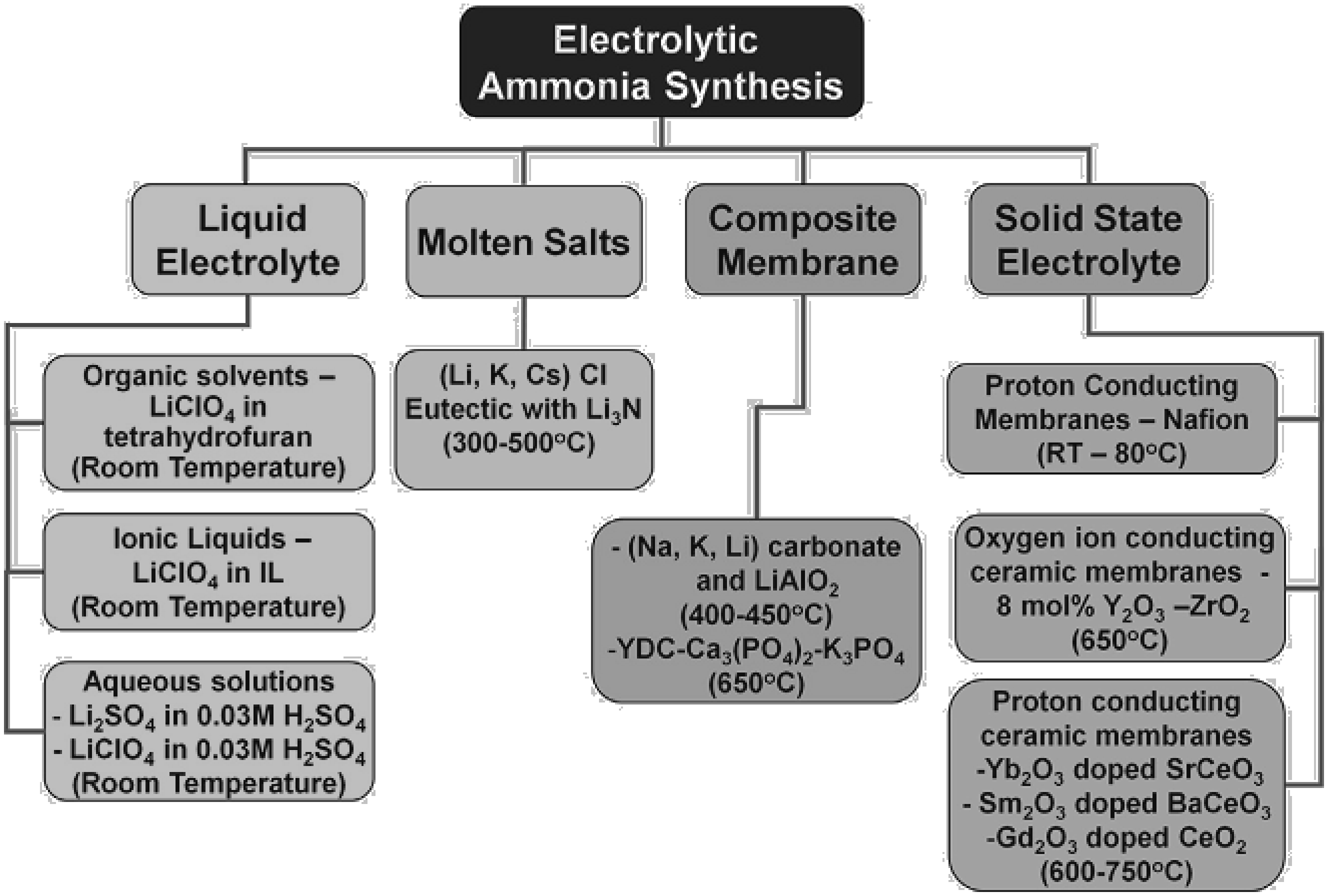
or even

$$N_2 + 3H_2O \rightarrow 2NH_3 + 3/2O_2$$



Electrochemical synthesis of Ammonia from water (directly or indirectly) and nitrogen

Electro-catalytic synthesis of NH3 – 4 focus areas



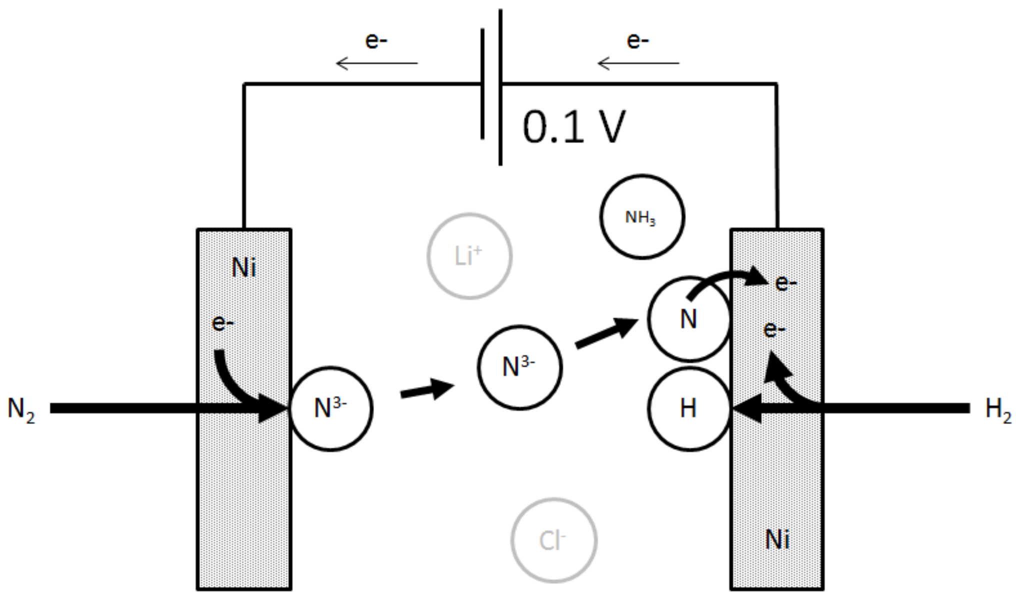
Molten Salt Approach

Stability of N^{3-} in metal halide salts allows direct reduction of N_2 to N^{3-} at ambient pressure

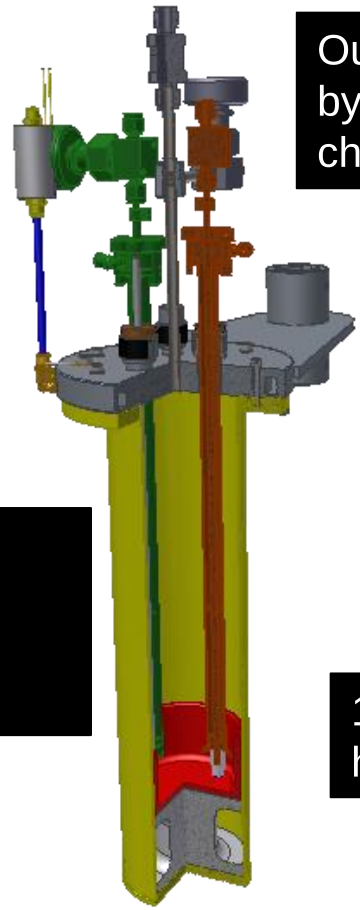
Applied voltage causes migration of N^{3-} fron surface of negative electrode to surface of positive electrode

Facile dissociation of H_2 occurs on positive electrode to generate surface H
Surface N and H combine to produce ammonia

Equivalent to high pressures used in thermal route



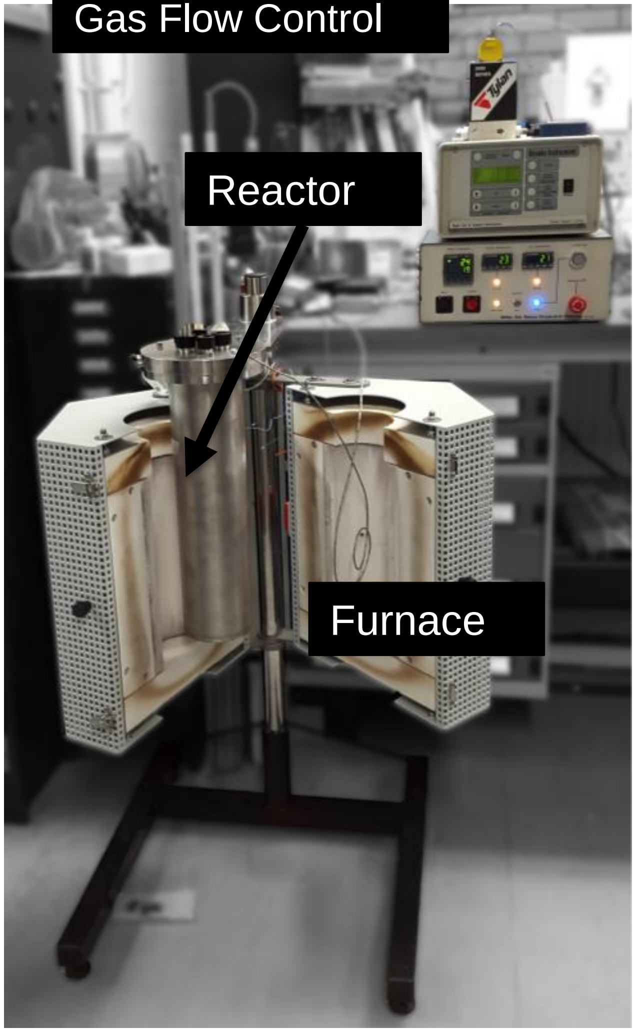
Molten Salt Experimental Program



Outlet gas analysed by gas chromatography

Gas supplied to porous electrodes (orange and green tubes)

100 mL molten salt held in crucible



Solid Electrolyte Ammonia Electrolysis

Anode

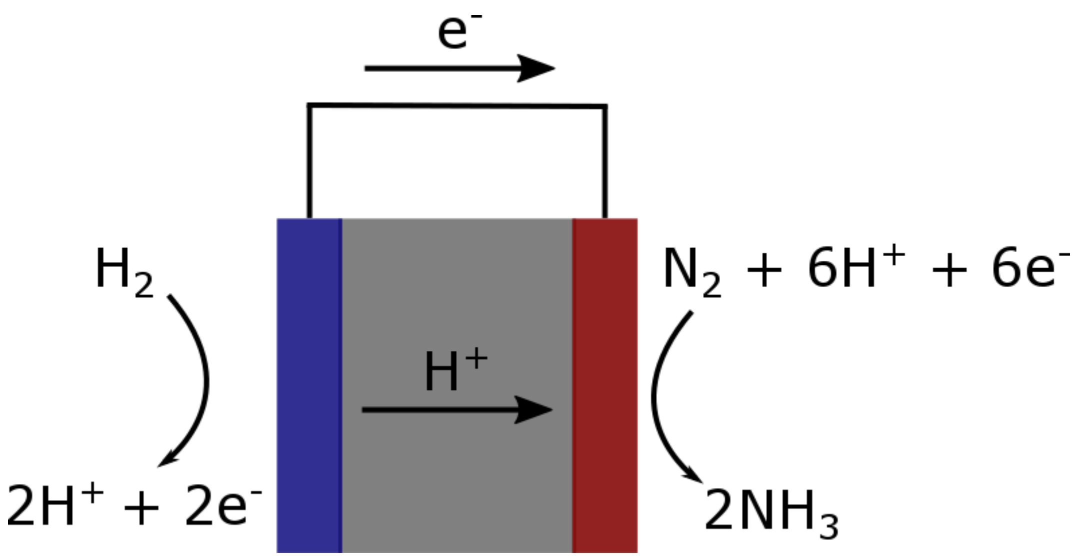
- Oxidation of hydrogen
- Electrically conducting
- Proton conducting

Electrolyte

- Proton conducting
- Electrically insulating

Cathode

- Reduction of nitrogen
- Formation of ammonia
- Electrically conducting
- Proton conducting



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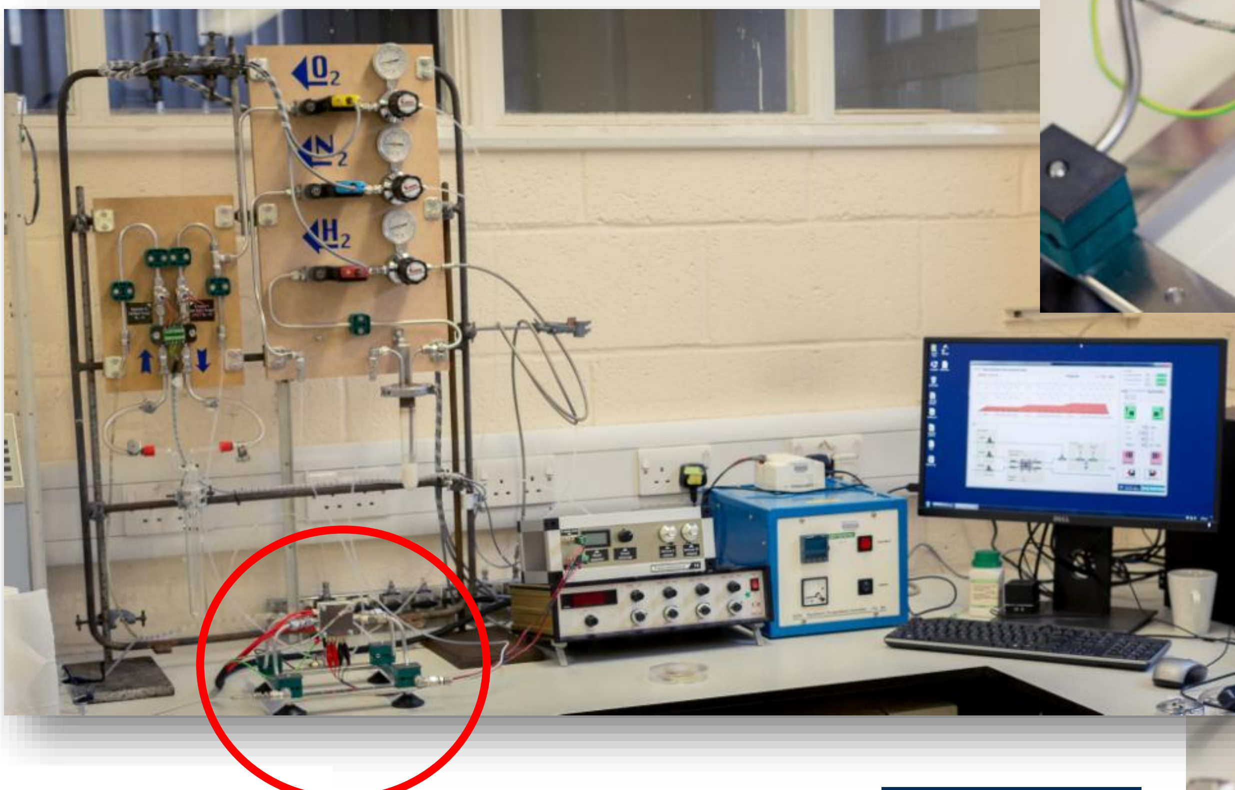
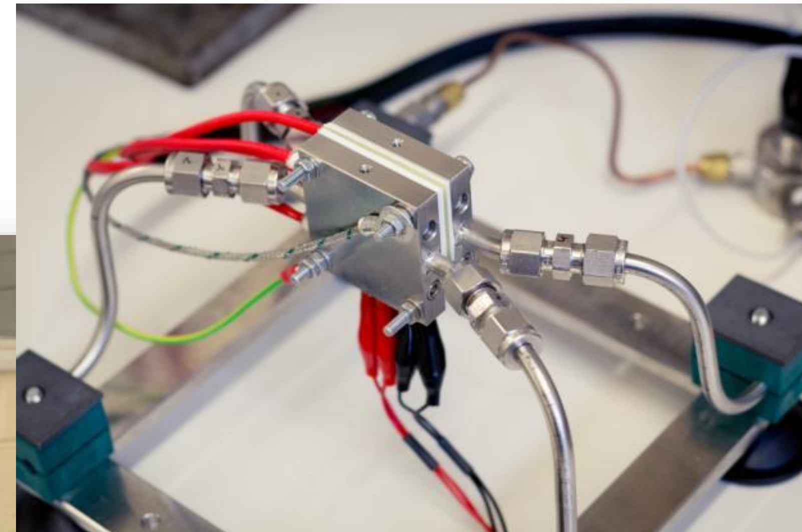
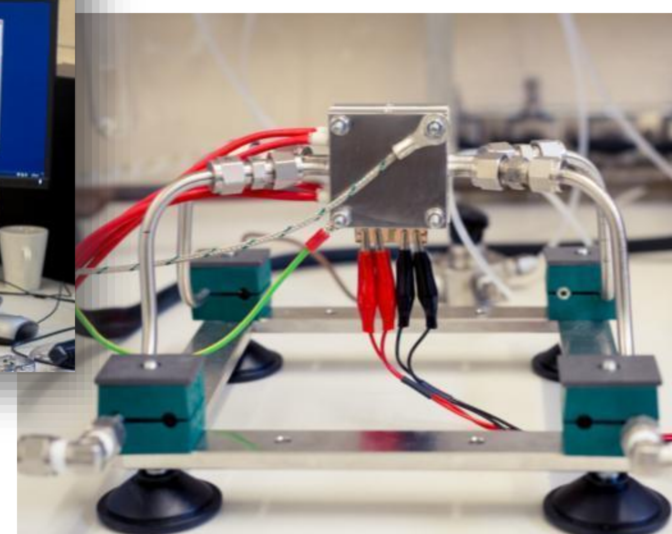
Solid electrolyte experimental programme







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Preliminary studies of ammonia combustion for gas turbines

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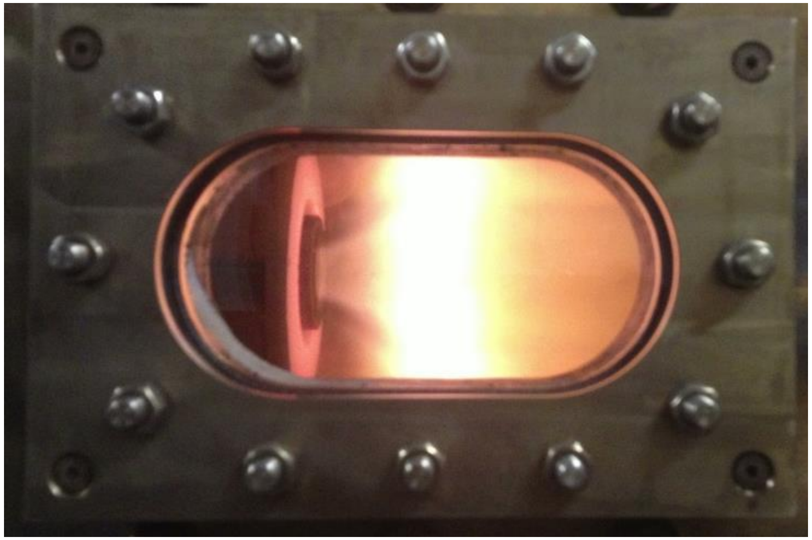

- Flame with a 62% ammonia, 38% methane blend at an air / fuel equivalence ratio of 1.31 in Cardiff's HPOC test rig.

- High equivalence ratios showed a reduction in NOx emissions, but suffered unstable flames in high swirl regime of conventional industrial combustor.

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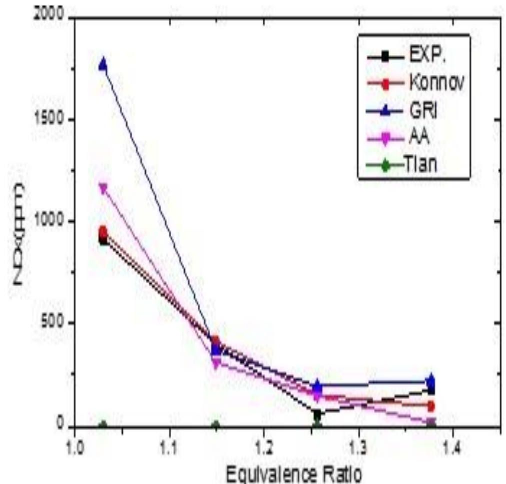
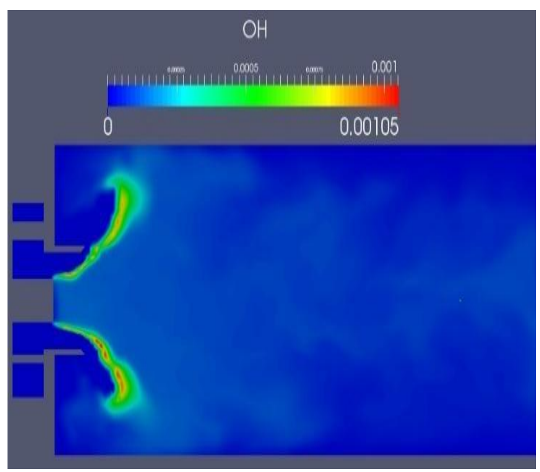
Ammonia Gas Turbine Development

Generic burner, high pressure.



Comparison between models and trials.

Lab combustor. Thermoacoustics.



CFD model using NH_3-CH_4 with GRI-Mech

- Evaluation of current reaction models to determine accuracy and restrictions.
- Modelling of generic swirl burners through CFD studies to study combustion and emission patterns.
- Recommendation of first ideas for technology improvement: stratified injection.

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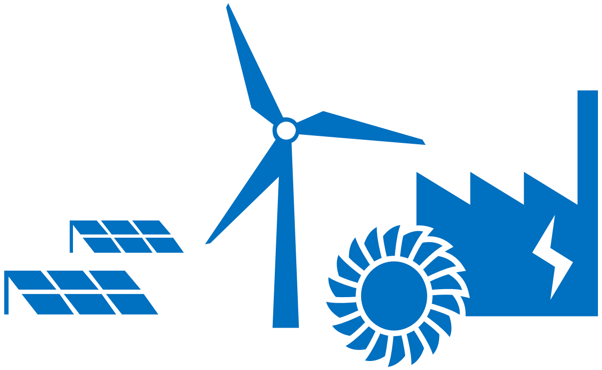

Development path for ammonia synthesis and energy release

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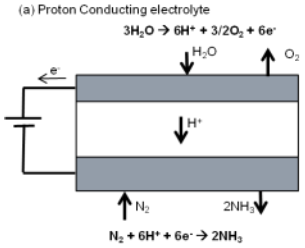
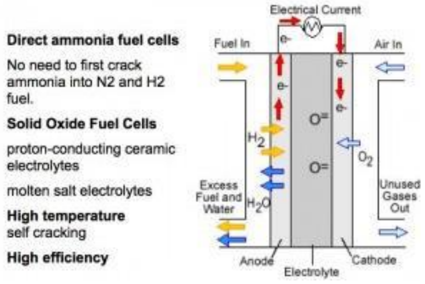
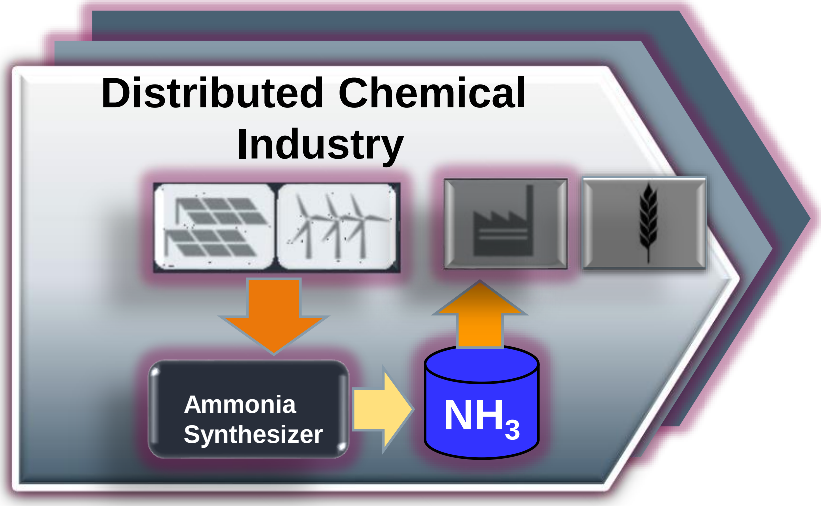
2015	2020	2025
Centralised Haber-Bosch synthesis	All electric Haber Bosch dynamic, distributed	Large scale, distributed electrochemical synthesis

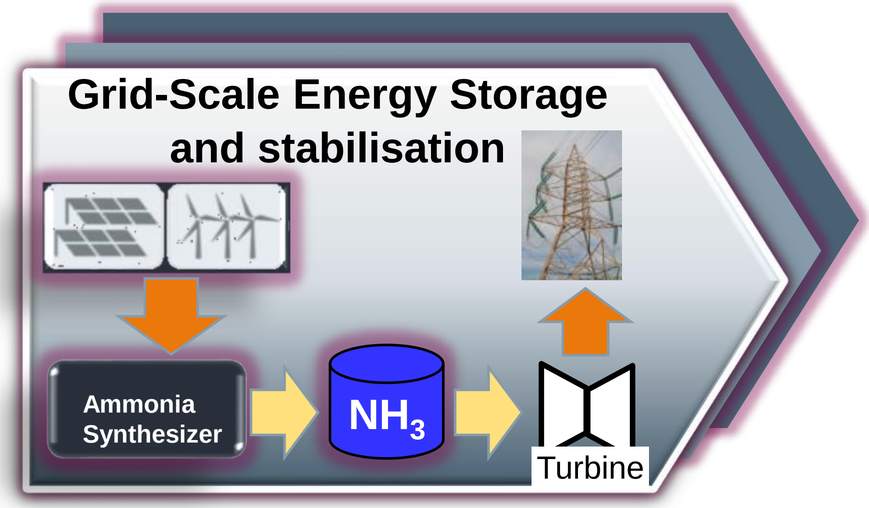


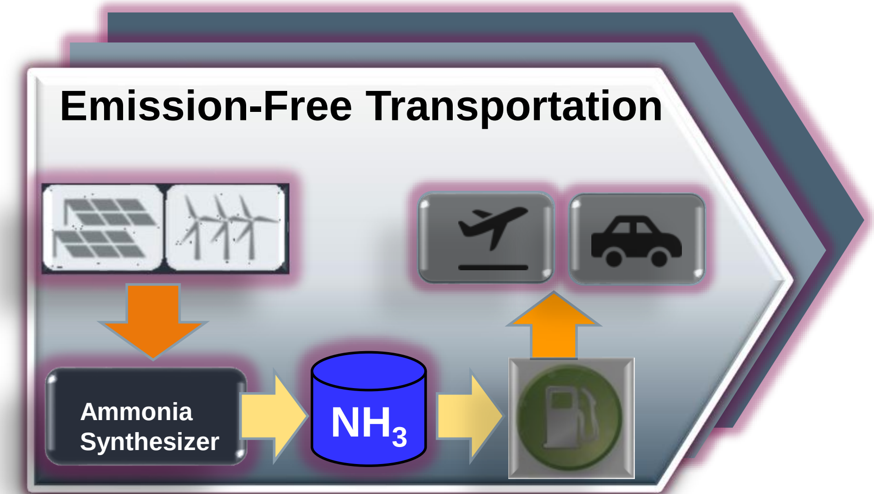


NH3 internal combustion engine	NH3 Gas Turbines	NH3 Fuel Cell

Green Ammonia – Carbon Free Flexible Asset

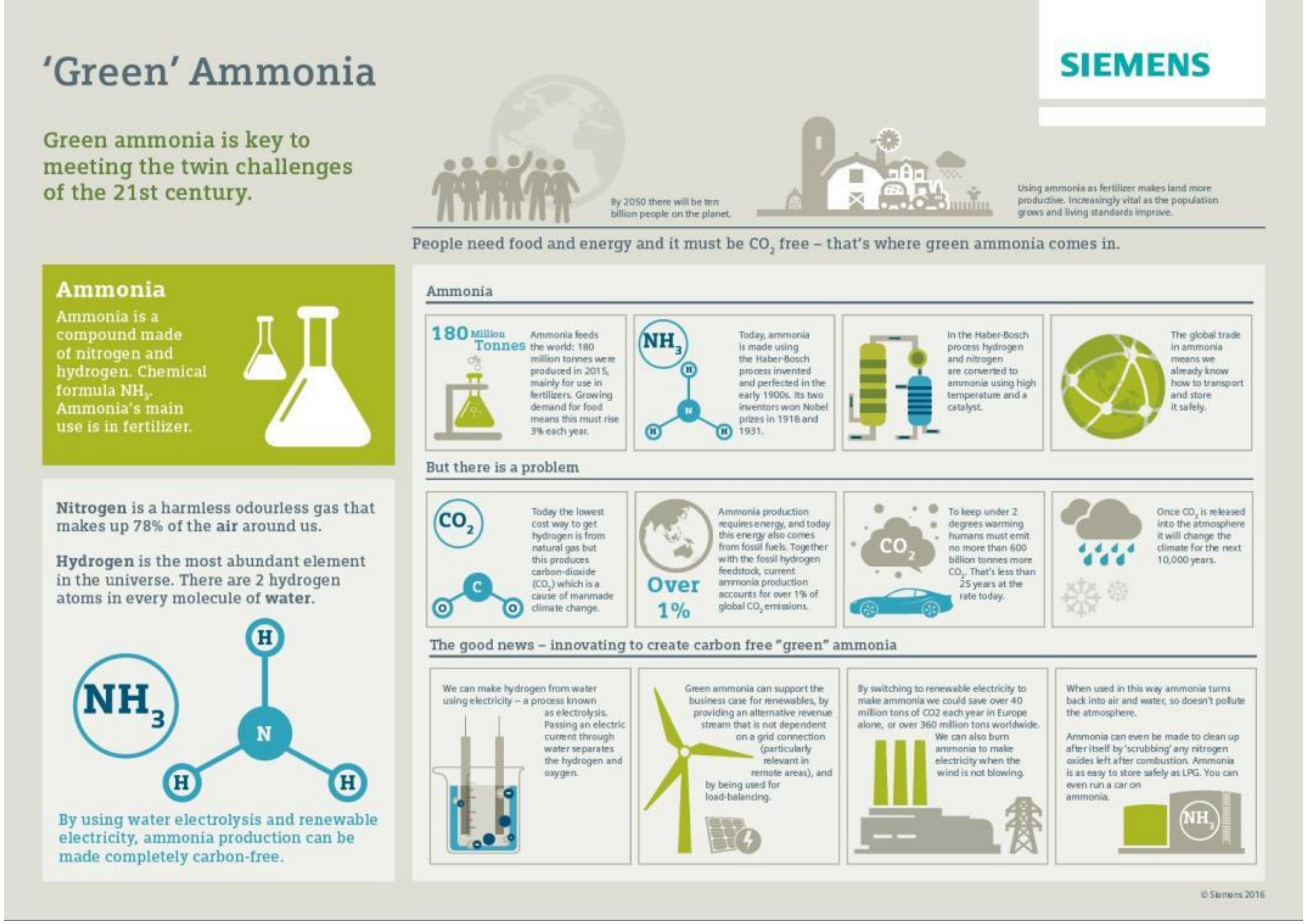






For further information, see

http://www.siemens.co.uk/green-ammonia



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