Power To Ammonia To Power (P2A2P)

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- Studies for 2050 by the German federal environment ministry and agency:
  - 85 % renewables: Long term energy storage like P2X needed[9]
  - 100 % renewables: Long term energy storage of 624.4 TWh per year[9] (Final energy consumption in Germany in 2018 was 2500 TWh[23])
  - Both scenarios assume a European electricity network[9]

- Versatility:
  - Fertilizer[2][12]
  - Refrigeration, heat pumps and ORC[2][10][12]
  - NO_X reducing agent[12]
  - Polymers[12]
  - Fuel/energy storage[10][12][15][19]

- Infrastructure, regulations and experience of handling already exist[10]

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P2X2P [5][6][7][8][15][24][25][26][27]	H_2	NH_3	CH_4	CH_3OH
	25 °C , 11 bar			
Physical state	Gas	Liquid	Gas	Liquid
Energy density (LHV) [MJ/m³]	107	11 199	363	15 431
CO_2 emissions [g/MJ]	0	0	55	70
Production cost [€/kg_{H_2}]	2.70	3.40	?	?
Storage cost [€/kg_{H_2}] 1 day	0.71	0.03		
15 days	1.78	0.05		
1/2 year	13.48	0.49		
P2X2P roundtrip efficiency [%]	24 – 39	33 – 34	12 – 31	27 – 32

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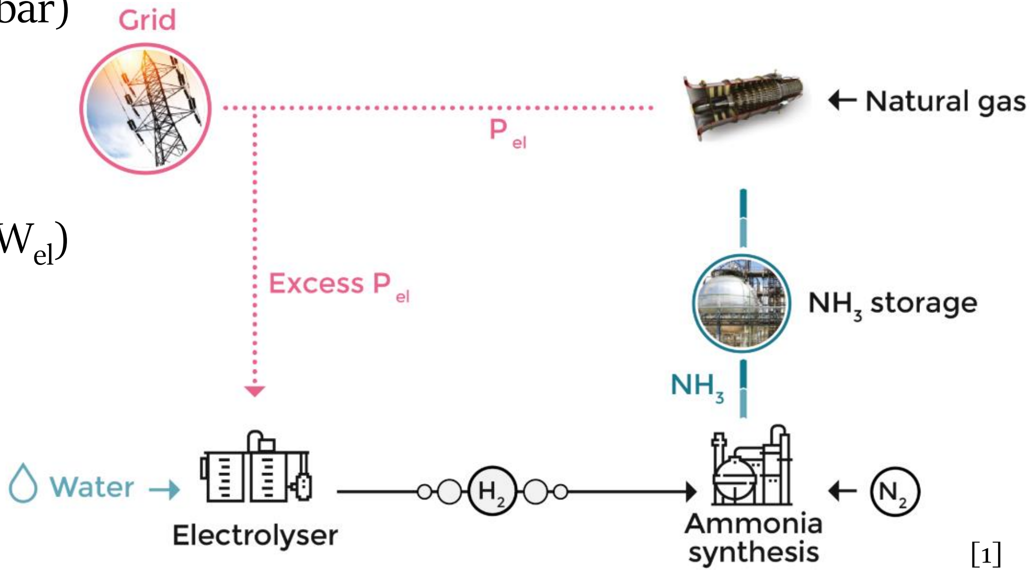
- Modular containerized solution
  - Electrolyser (20 – 50 kW)
  - Reactor (≤ 300 °C & 35 bar)
  - Liquid storage (≤ 70 kg)

- Connected to
  - Micro gas turbine (100 kW_{el})
  - Smart micro grid

- Located at Savona campus, University of Genoa, Italy



[1]

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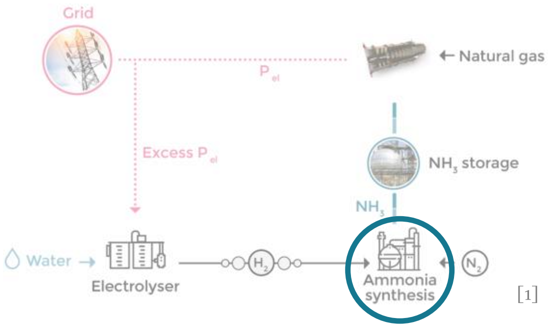
Ammonia synthesis Haber Bosch



[1]

- $N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons 2NH_{3\,(g)}\,, \Delta H_R^{\circ} = -92.44\,\frac{kJ}{mol}$ [3]
- ≤ 300 °C & 35 bar (vs. 400 – 500 °C & ≥ 100 bar[3])
- Catalyst:
  - Conventional iron 10.23 €/kg (1996)[3] vs. Ru/C 7000 \$/kg (2020)[21]
  - Kinetics[3][22]
  - Activation energy[3]
  - Ru/Ba-Ca$(NH_2)_2$ not yet commercially available[5][15]
  - Poisons[3][15]
  - Structural and electronic promoters[3][5]

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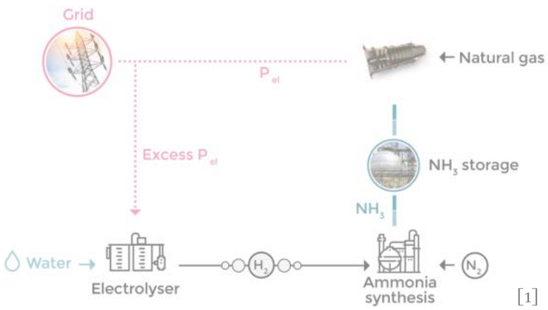
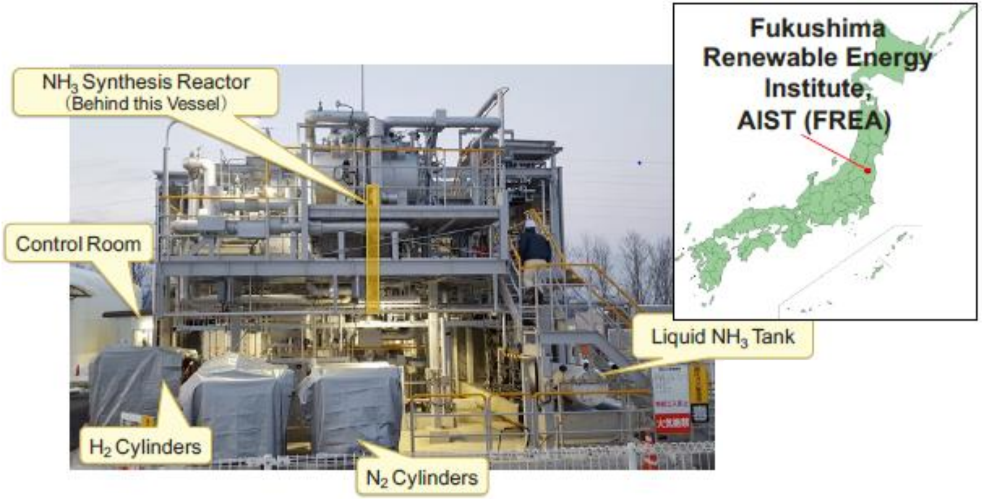
It‘s possible![13][17]

100 %, no prior cracking, 50 kW_{el} gas turbine, 17 kg/h NH_3 (fuel & NO_X removal at outlet)





100% Ammonia Gas Turbine

Ru/CeO_2 catalyst produced on a semi-industrial scale

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It‘s possible!


[10]


[19]


[10]

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MANY THANKS!

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Backup: Safety of ammonia

Safety of liquid ammonia storage?

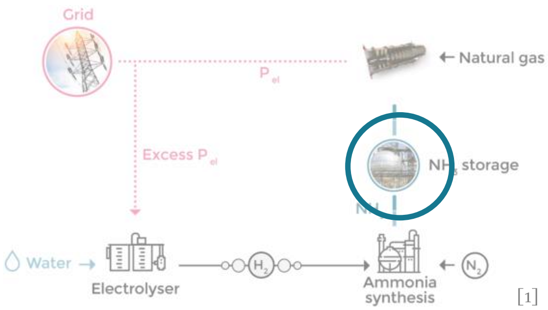
- Compared to H_2 and CH_4 lower explosion and flammability hazard and ignition temperature but like CH_3OH high toxicity and water solubility[2][10][12]

- 10 000 ppm fatal, 200 ppm headache, but 50 ppm easily smelled and not carcinogenic[2][10]

- Lighter than air, so rapidly dilutes in a spill[10]

- Compatibel with cast iron and carbon steel[10]

→ Risks exist, but are known and manageable.



[1]

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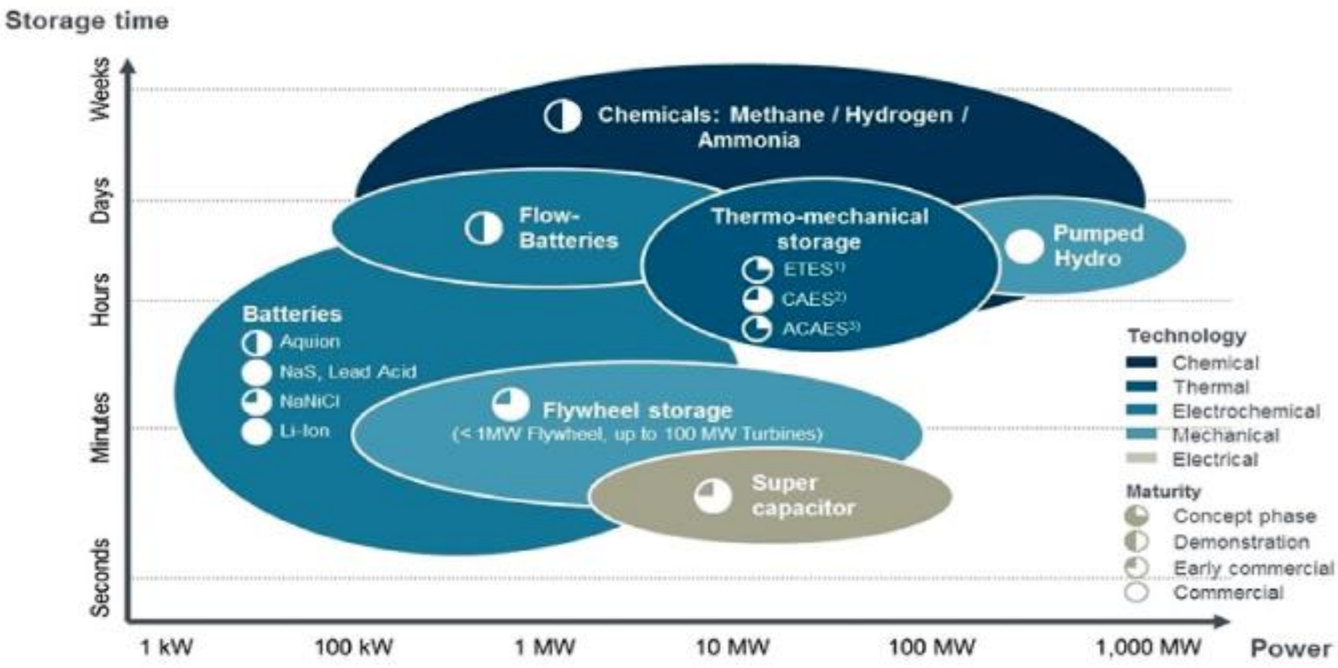
Backup: Energy storage systems



1) Electro-Thermal Energy Storage 2) Compressed Air Energy Storage 3) Adiabatic Compressed Air Energy Storage [10]

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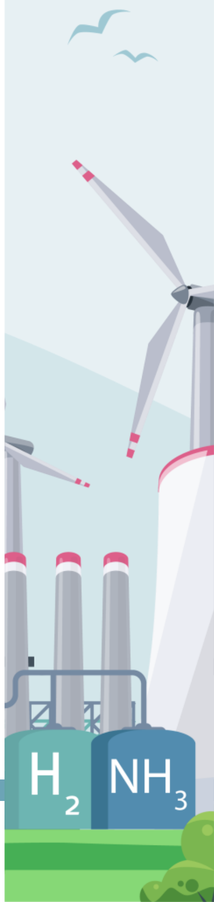

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