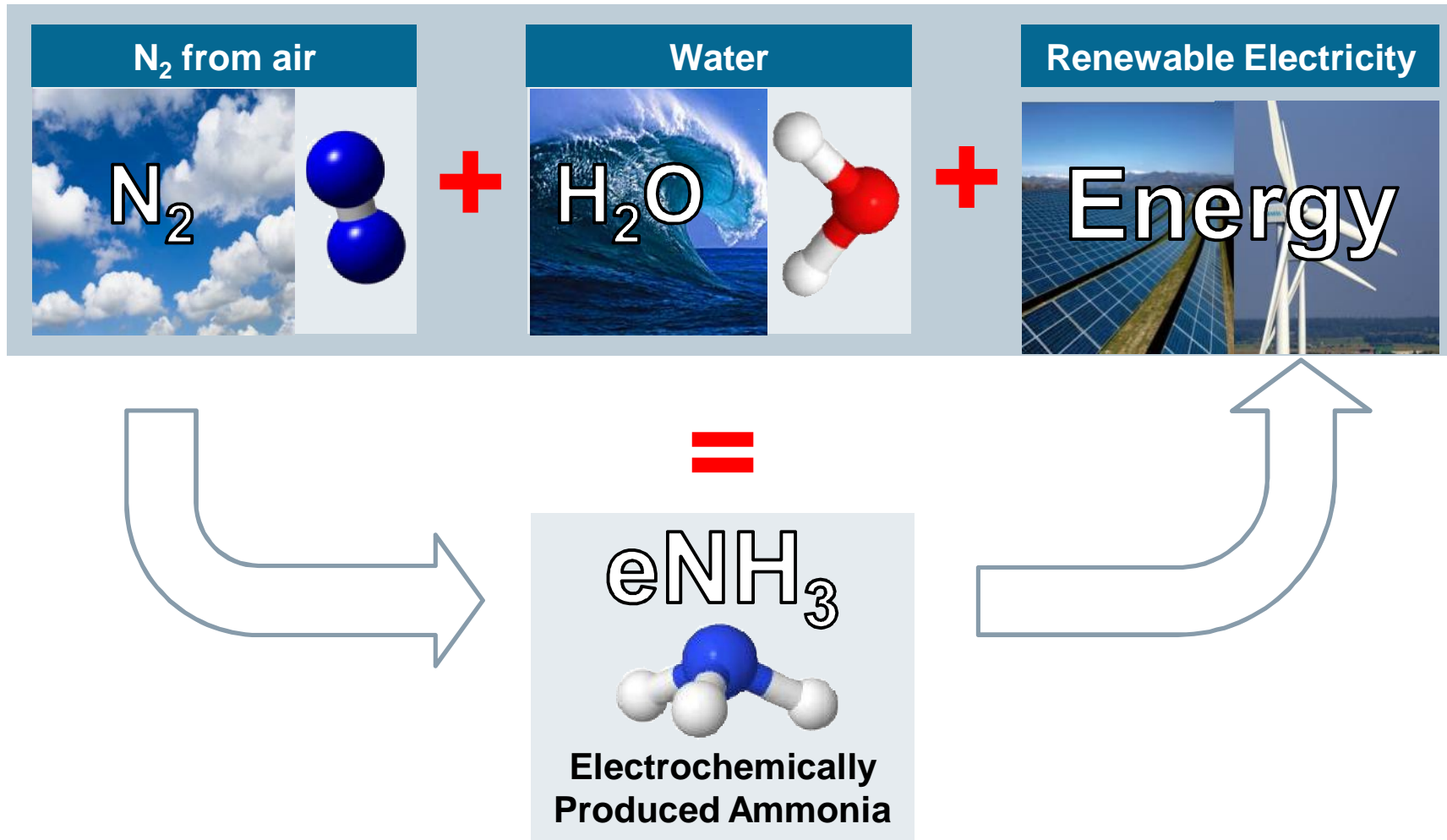


Green Ammonia

18th December 2017
Ian Wilkinson

With renewable energy, the ammonia cycle is carbon free



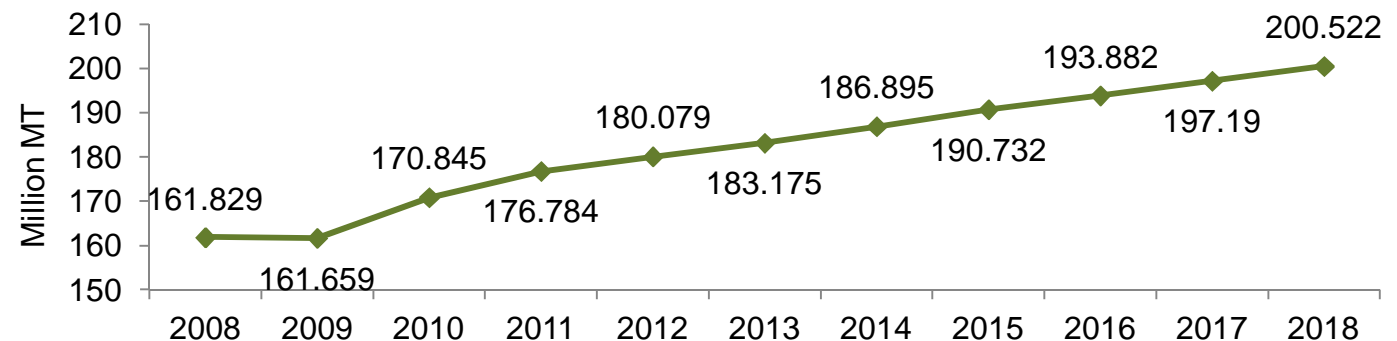
Ammonia is already a significant chemical, with a commodity market value of over €80bn/year

Ammonia

- A gas, produced by the chemical industry. Over 80% of ammonia is used in the fertiliser industry.
- Similar storage properties similar to LPG: liquefies at -33°C (ambient pressure) and around 12bar (ambient temperature); safe handling procedures are well-established.
- Current production levels of Ammonia are about 180m t/year. The historic commodity value is €300-€700/t, leading to a commodity market of over €80bn/year
- Production today uses the Haber-Bosch process and relies on natural gas as a feedstock.



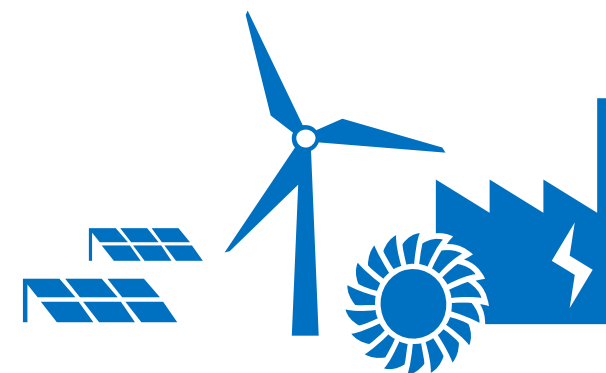
Global fertilizer nutrient consumption



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

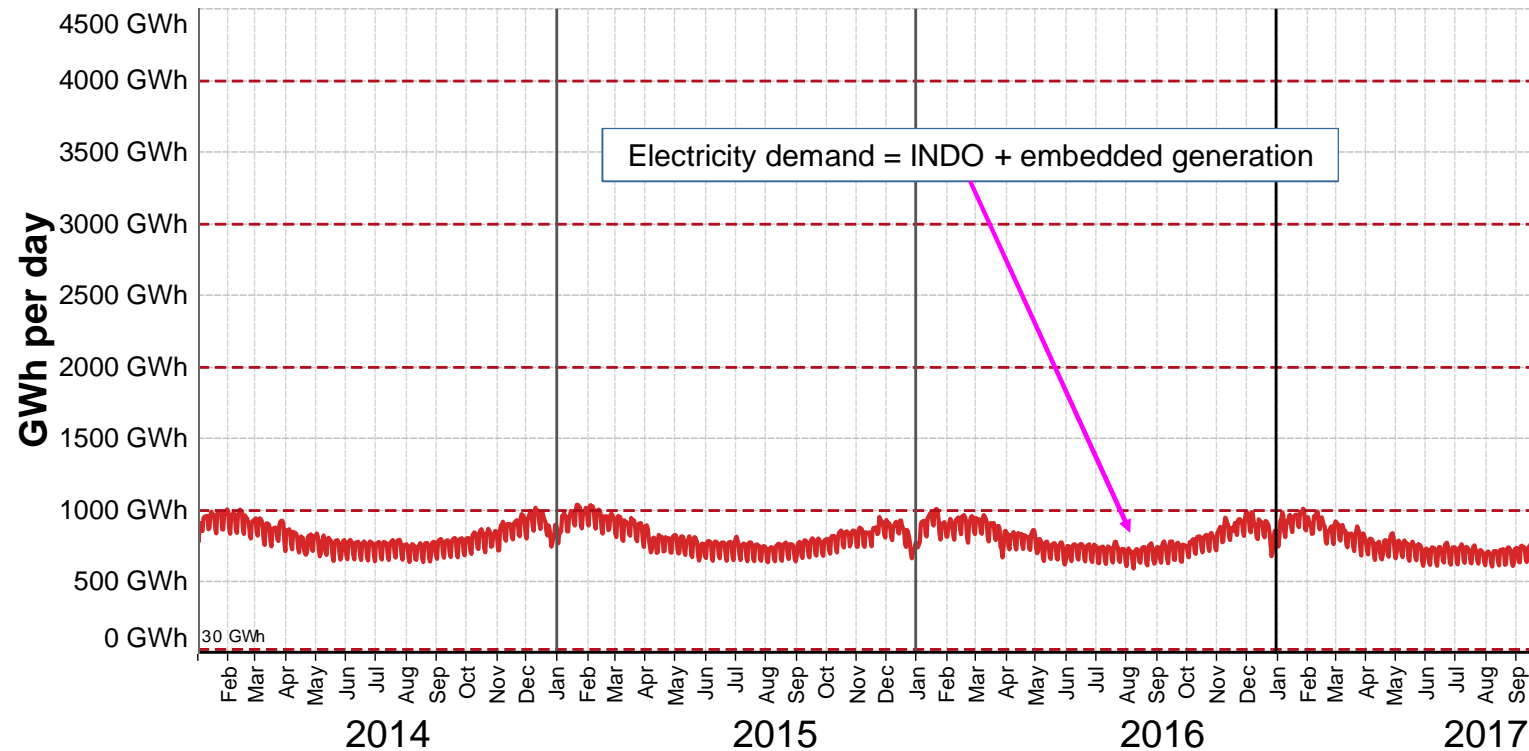
The Role of "Green" Ammonia in Decarbonising Energy Systems

- Why I think ammonia has a role to play – the technical argument;
- How ammonia can play a role – the economic argument;
- Practical demonstration: ammonia synthesis and energy storage system demonstrator at RAL.



The scale of the task to decarbonise is considerable...

Great Britain's Energy Vectors – in GWh per day



Data are from National Grid, Elexon and BEIS. Charts are licensed under an Attribution-NoDerivatives 4.0 International license
 Charts can be downloaded from <http://bit.ly/energycharts>

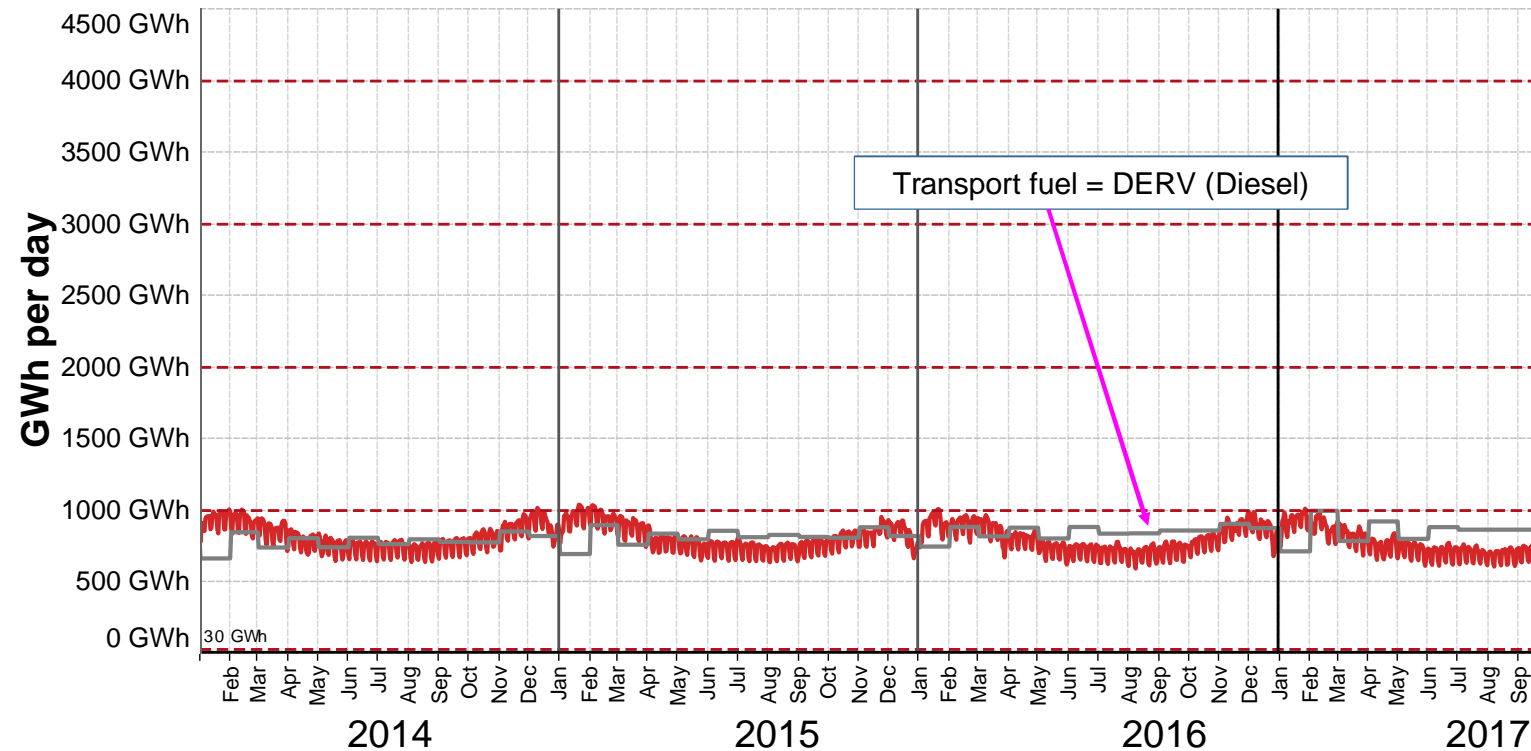


by Dr Grant Wilson grant.wilson@sheffield.ac.uk

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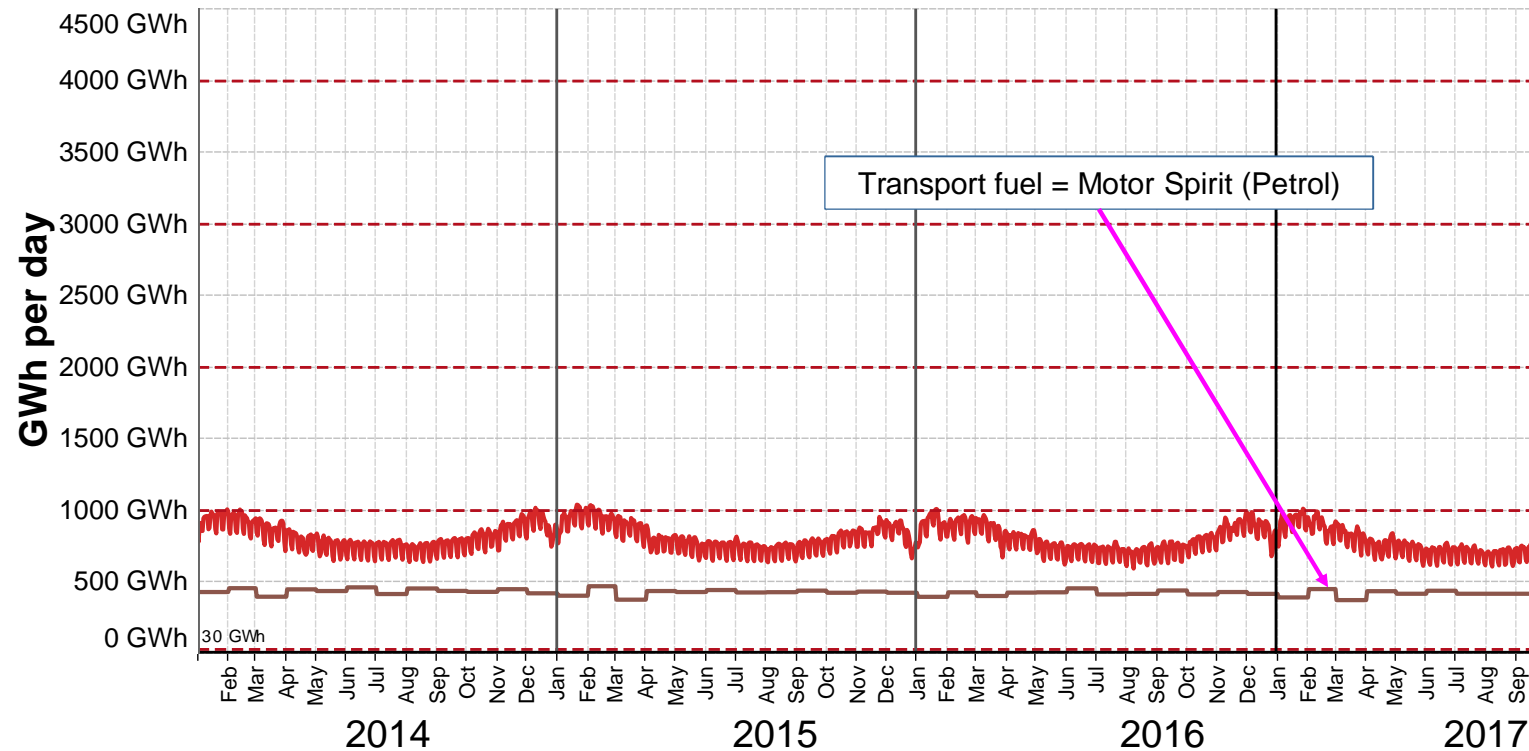


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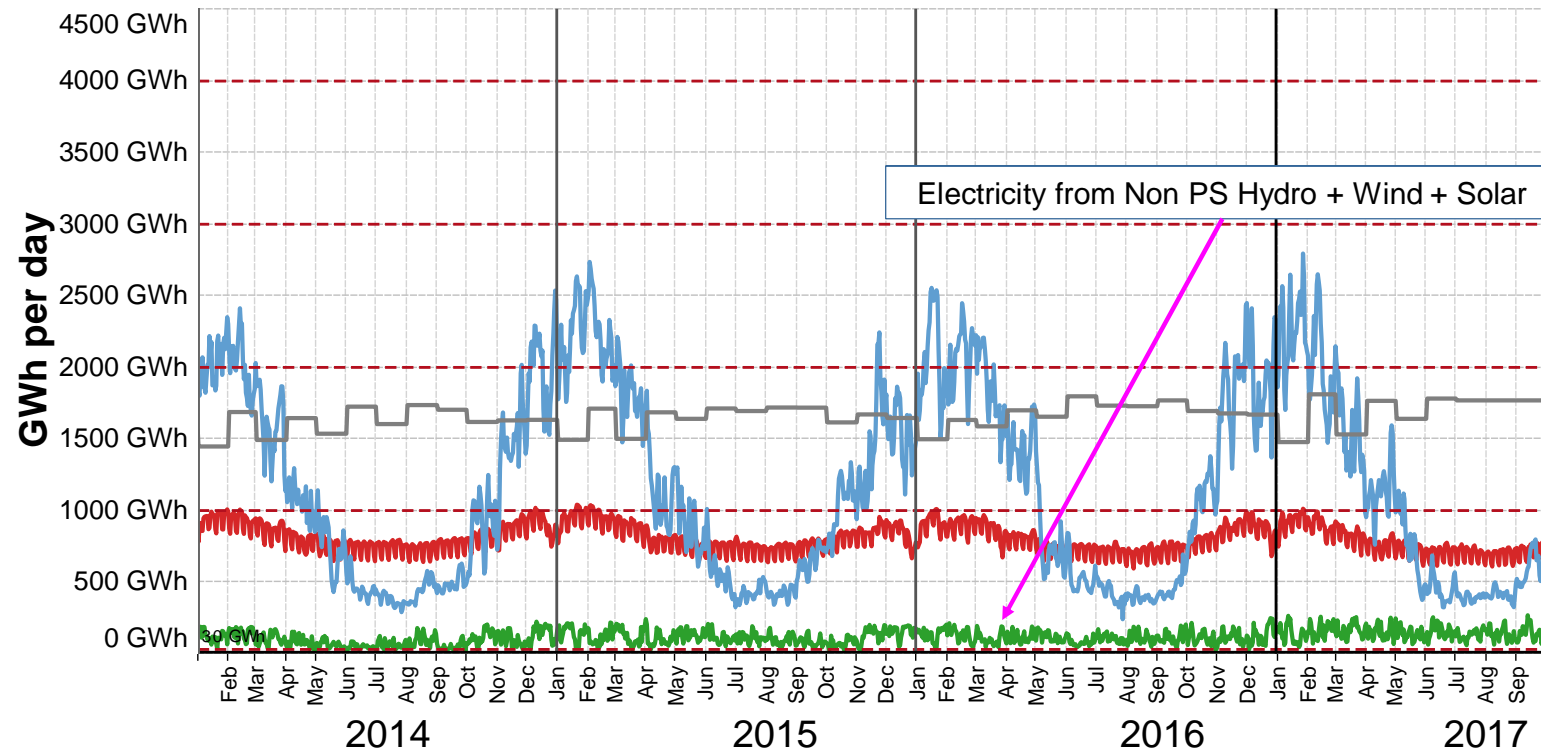


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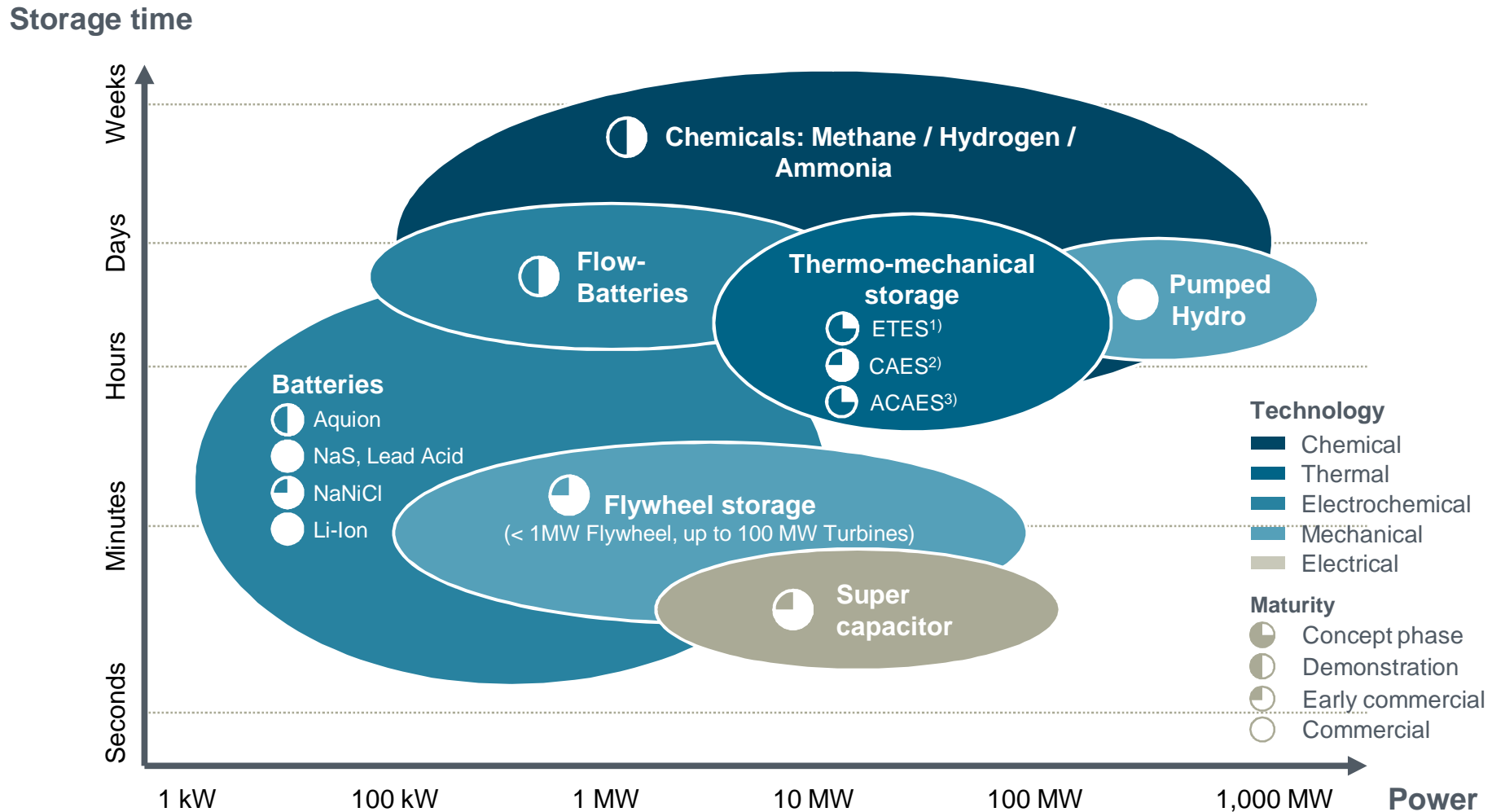
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Addressing energy storage needs will require a range of technologies

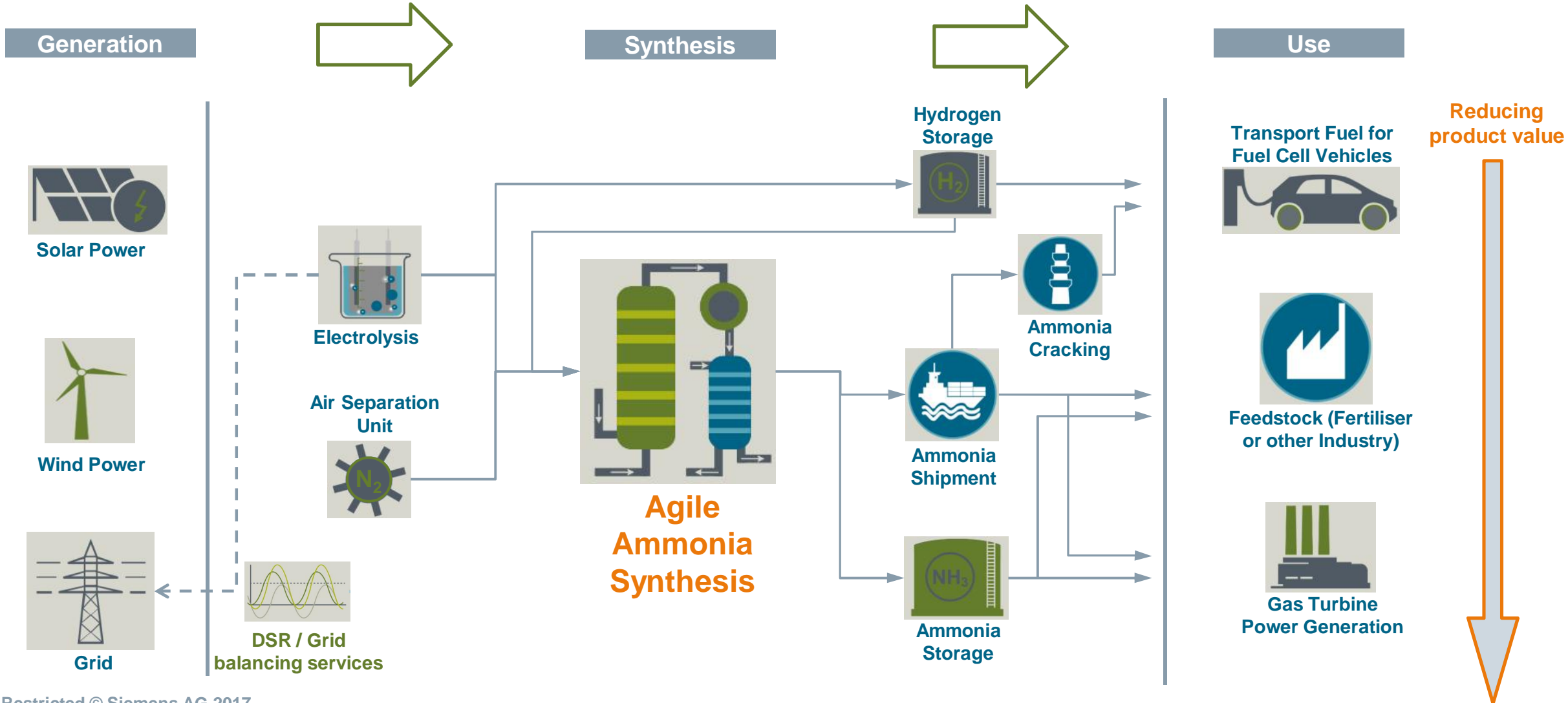


Restricted © Siemens AG 2017 ¹⁾ Electro-Thermal Energy Storage

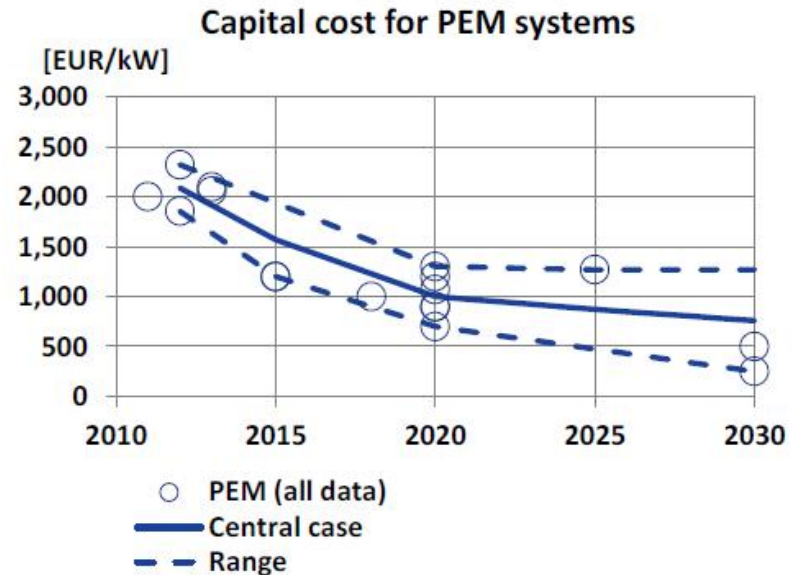
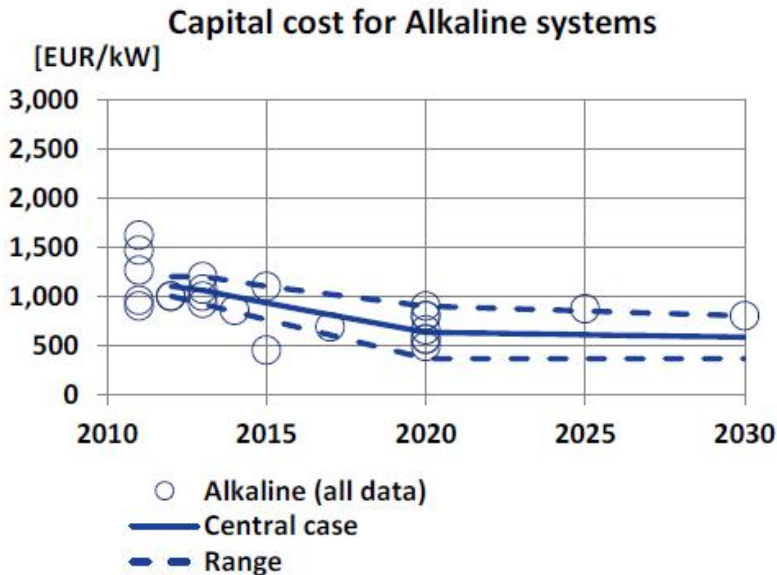
²⁾ Compressed Air Energy Storage

³⁾ Adiabatic Compressed Air Energy Storage

Several potential markets exist for Green Ammonia: it is a carbon-free flexible asset



Electrolyser CAPEX costs - An EU study

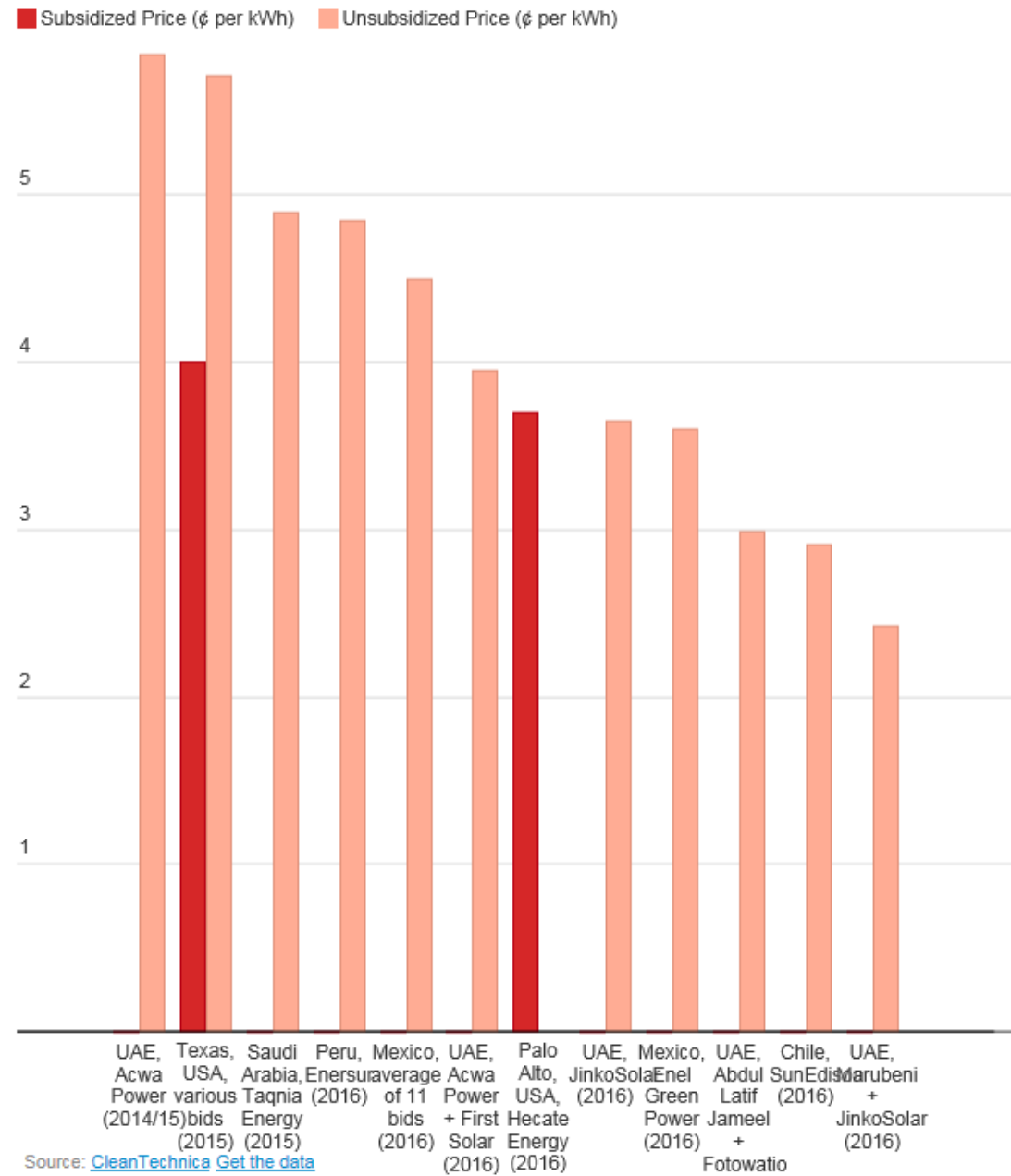


System cost ⁽¹⁾		Today	2015	2020	2025	2030	
EUR/kW	Alkaline	Central	1,100	930	630	610	580
		Range	1,000 - 1,200	760 - 1,100	370 - 900	370 - 850	370 - 800
	PEM	Central	2,090	1,570	1,000	870	760
		Range	1,860 - 2,320	1,200 - 1,940	700 - 1,300	480 - 1,270	250 - 1,270

⁽¹⁾ incl. power supply, system control, gas drying (purity above 99.4%). Excl. grid connection, external compression, external purification and hydrogen storage

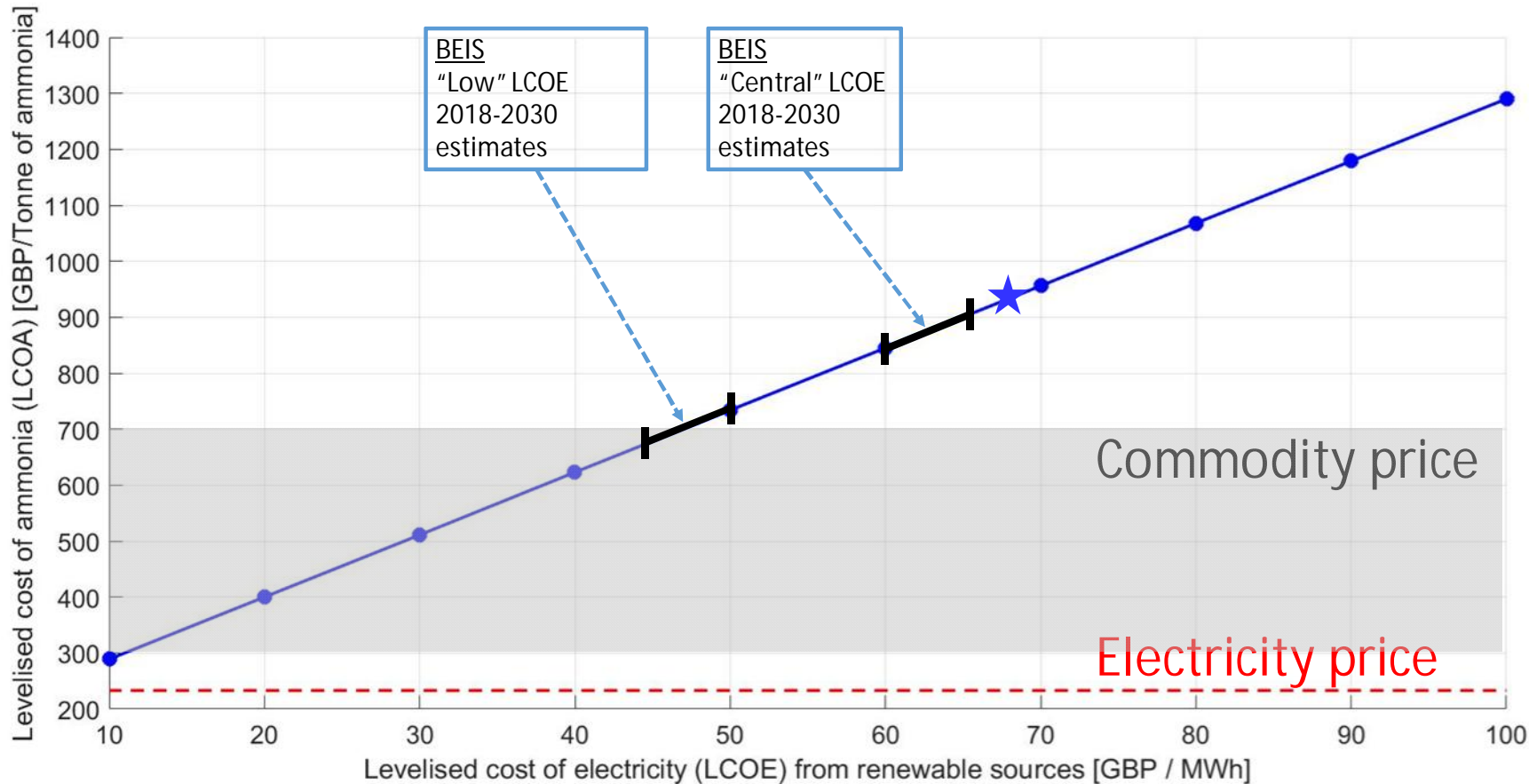
Source:
 "Development of Water Electrolysis in the European Union", E4tech Sàrl with Element Energy Ltd for the Fuel Cells and Hydrogen Joint Undertaking February 2014

Low Bids for Solar PV



Source: <https://cleantechnica.com/2016/09/20/lowest-ever-solar-price-bid-2-42%C2%A2kwh-dropped-abu-dhabi-jinkosolar-marubeni-score/>

Green Ammonia production cost estimate – 200 MW plant

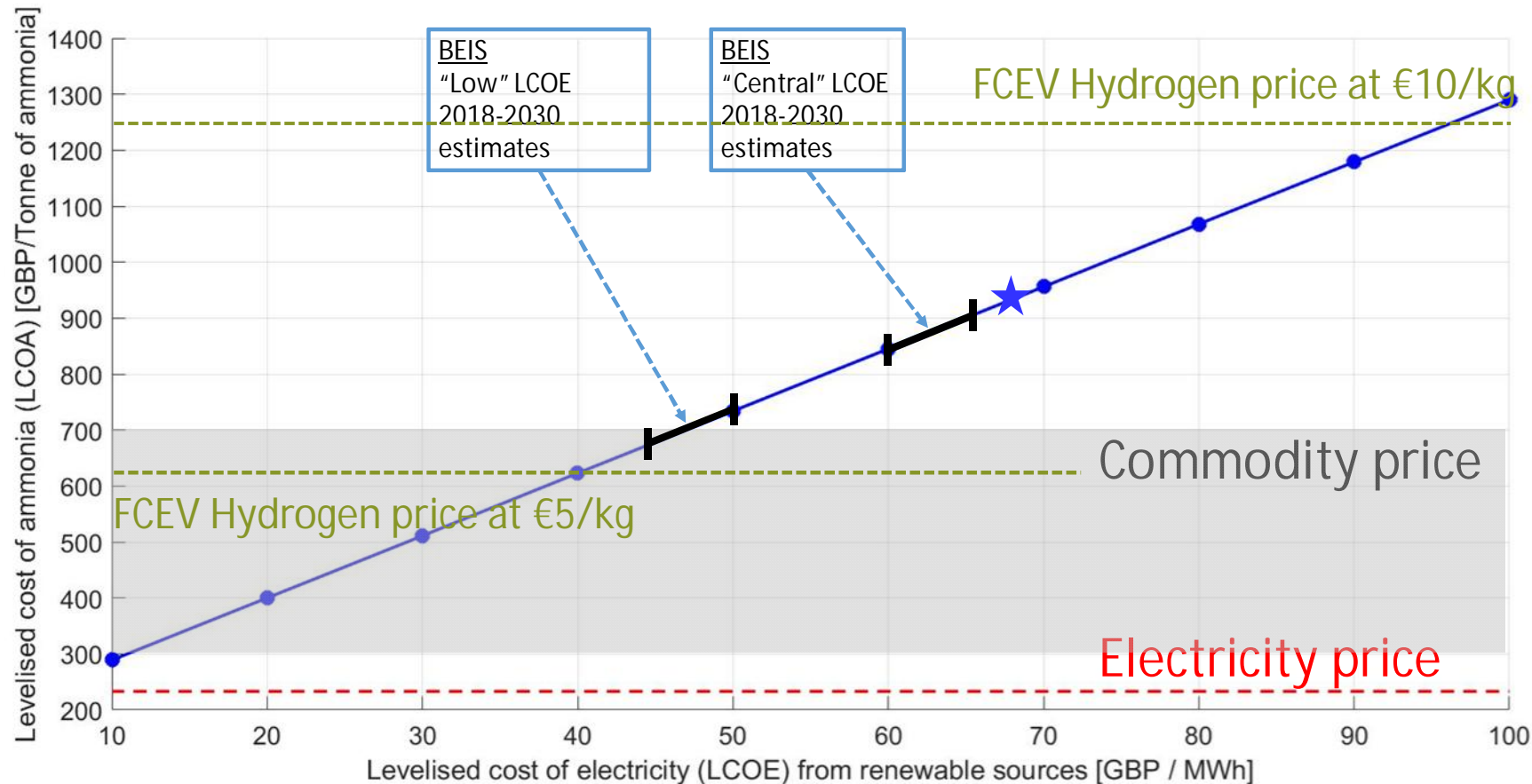


Electricity price has been calculated using 90 GBP/MWh and a 50% ammonia-to-electricity conversion efficiency

- ★ Control plant
- Variables held constant:
- Location: Lerwick, Scotland
 - Supply power magnitude: 100MW average
 - Supply power mix: 90% Wind; 10% Solar
 - $P_{MIN} = P_{Rated_ASU/ HB}$ (i.e. no ASU/HB ramping)
 - Electrolyser size: 209 MW
 - HB size: 5.38MW
 - ASU size: 0.88 MW
 - Electrolyser CAPEX: 528 GBP/kW (600 EUR/kW)

Source: "Islanded power-to-ammonia production process: Key variables and their sensitivity"; R. Banares-Alcantara, R. Nayak-Luke, I. Wilkinson; Submitted to Computers & Chemical Engineering October 2017 with manuscript number CACE-D-17-00766.

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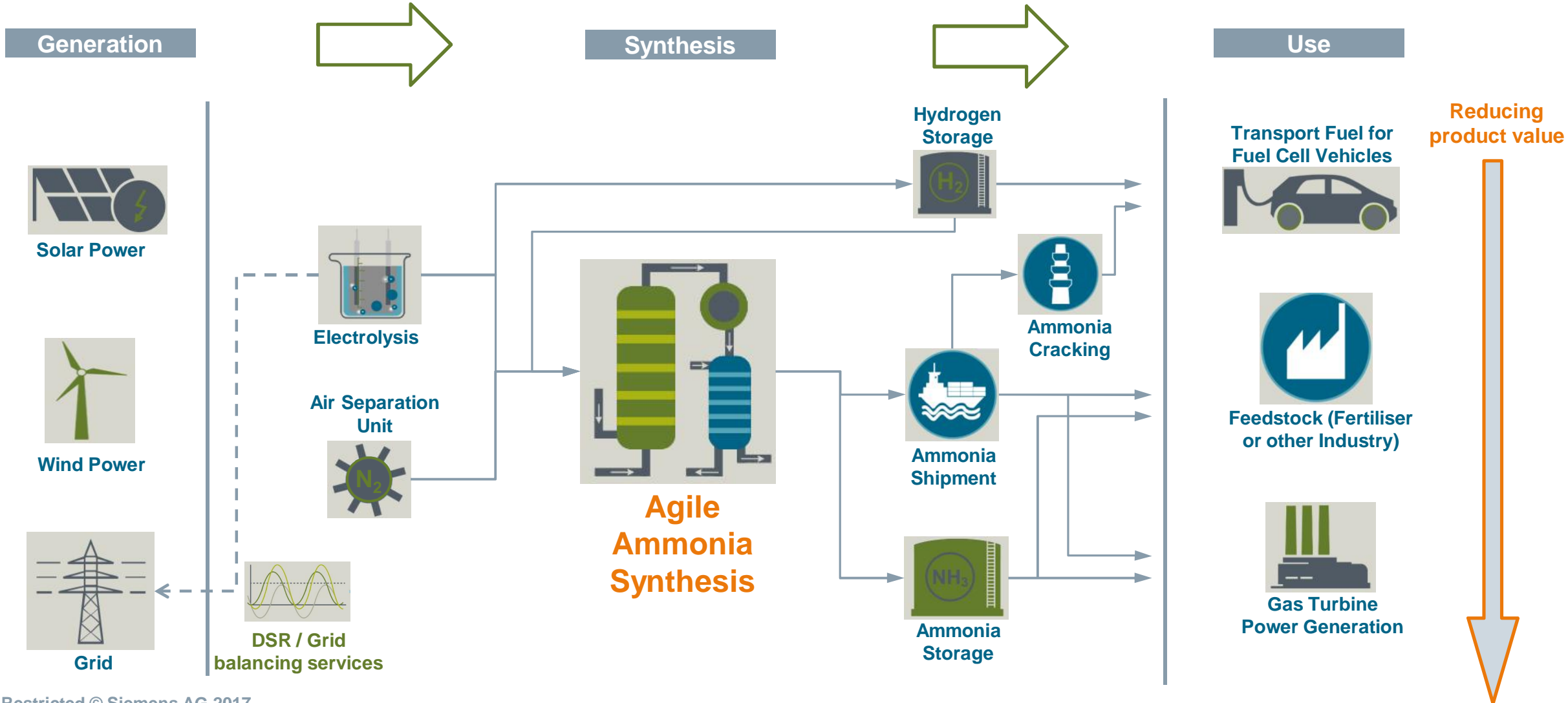


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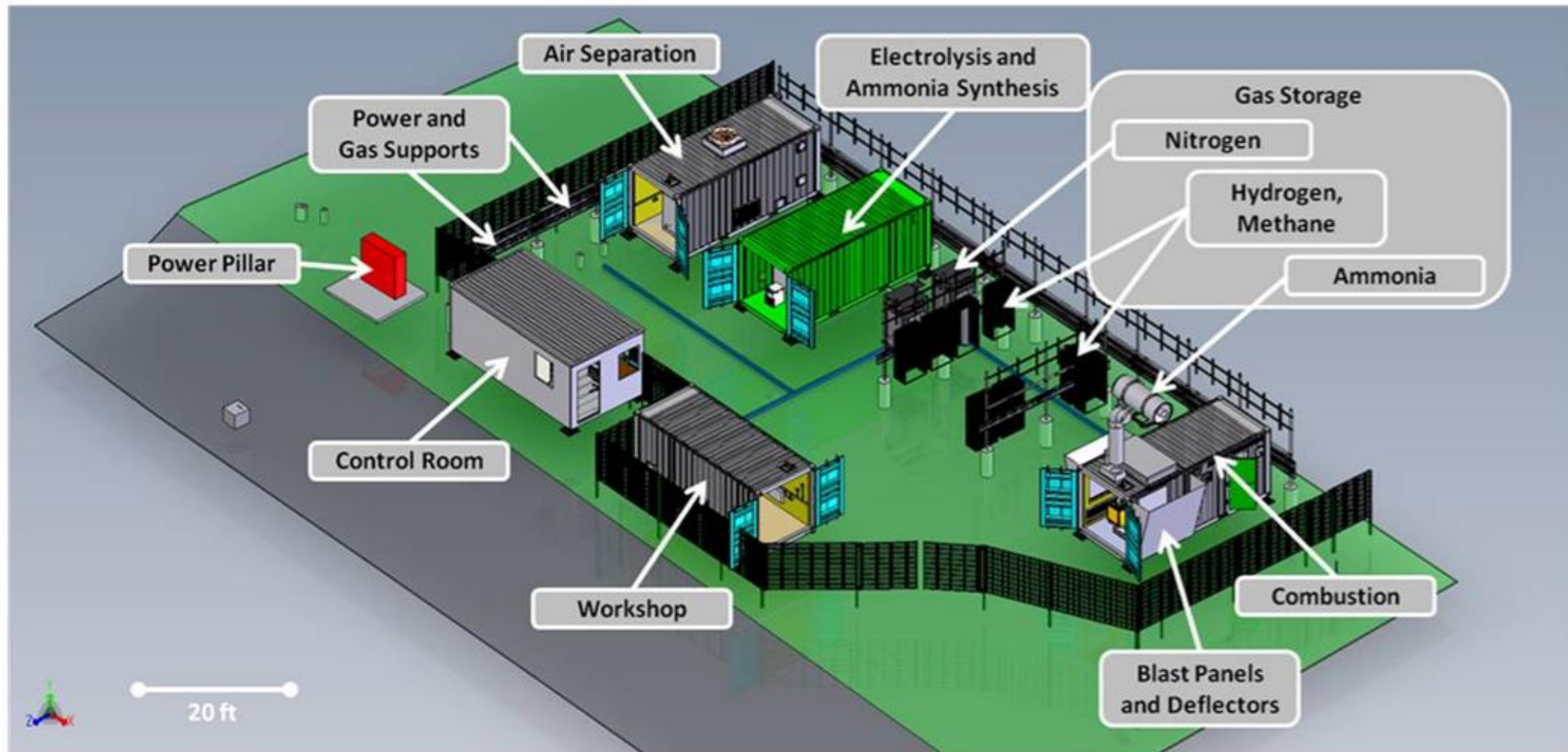
Source: "Islanded power-to-ammonia production process: Key variables and their sensitivity"; R. Banares-Alcantara, R. Nayak-Luke, I. Wilkinson; Submitted to Computers & Chemical Engineering October 2017 with manuscript number CACE-D-17-00766.

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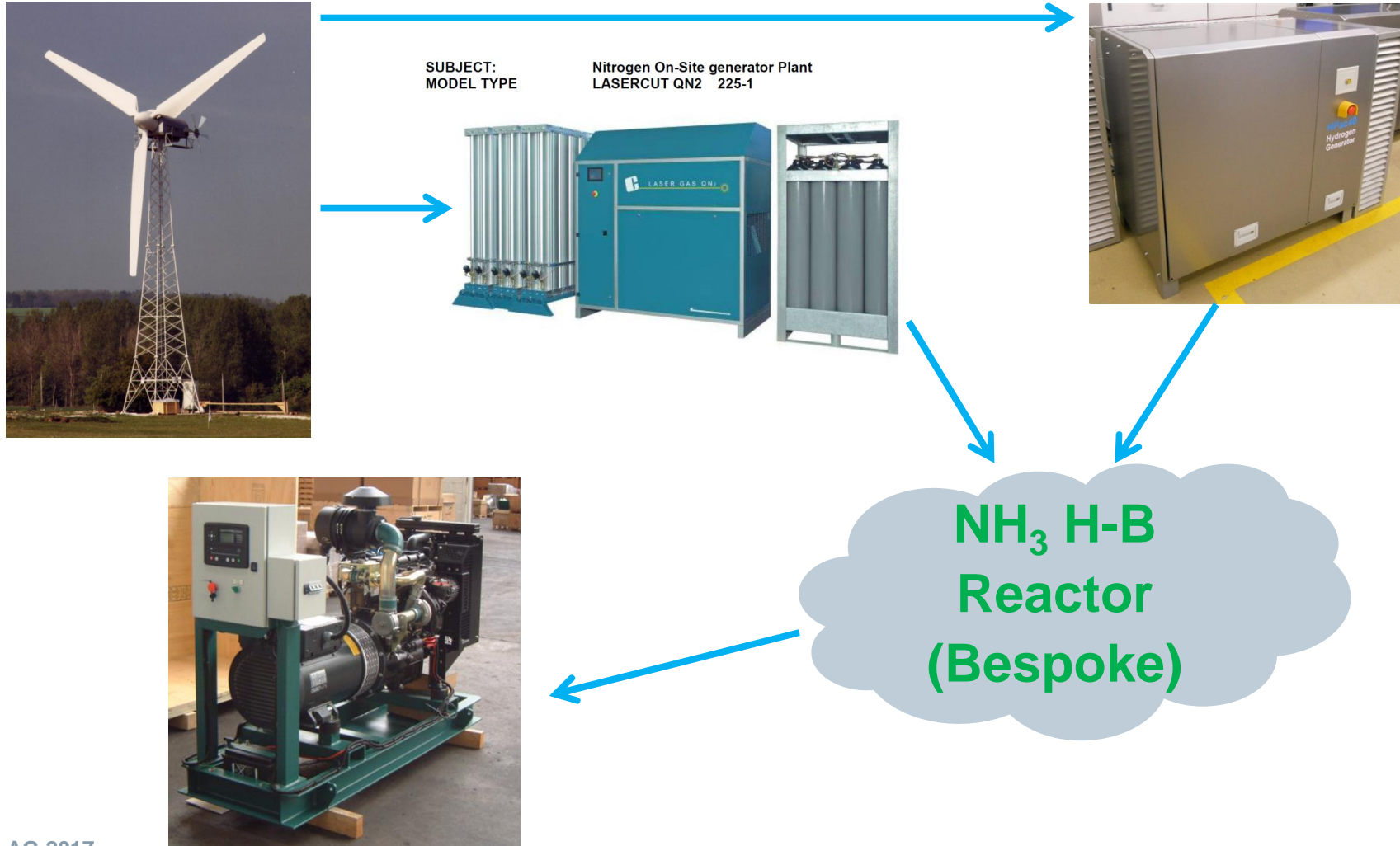


The Green Ammonia Demonstrator will show the complete cycle of renewable power, storage as ammonia, and conversion back to electricity

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The main components of the Green Ammonia energy storage system demonstrator are: wind turbine, N₂ generator, H₂ electrolyser, ammonia reactor, and an internal combustion engine



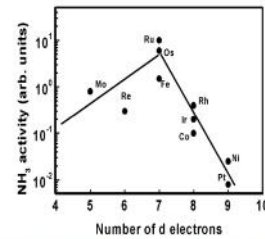
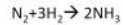
RAL test site, Combustion and Synthesis Containers



The demonstrator will be used to explore 4 development areas – and provide a platform for future development work

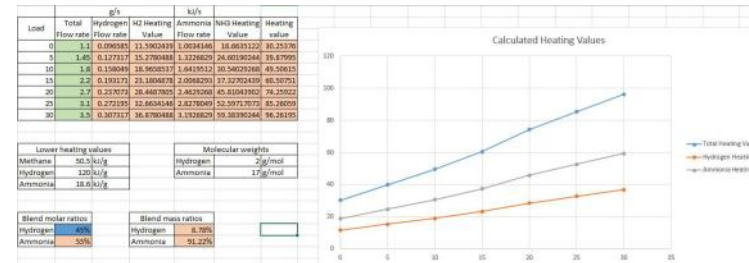
Haber-Bosch synthesis catalyst

Ammonia synthesis

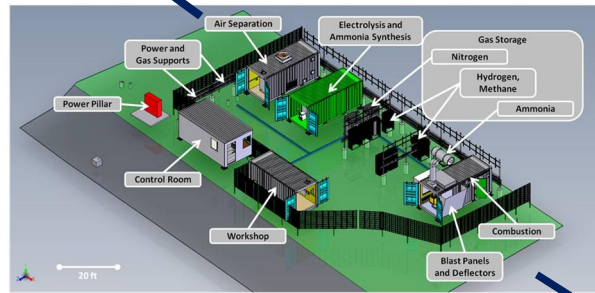
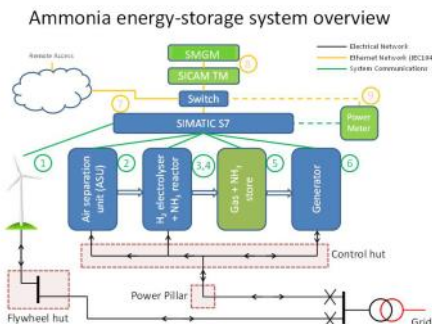


Ozaki and Aika, Catalysis 1 (Anderson and Boudart, Ed.)

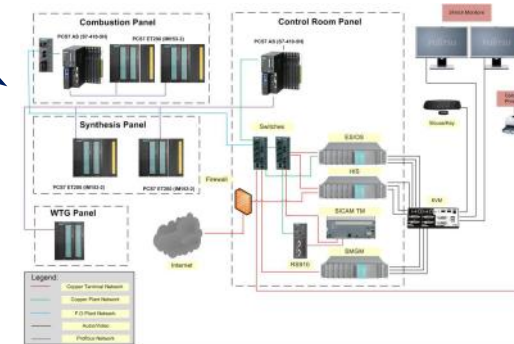
Ammonia combustion studies



Energy management system



Control system



For further information, see

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

'Green' Ammonia

Green ammonia is key to meeting the twin challenges of the 21st century.



By 2050 there will be ten billion people on the planet.



Using ammonia as fertilizer makes land more productive. Increasingly vital as the population grows and living standards improve.

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People need food and energy and it must be CO₂ free – that's where green ammonia comes in.

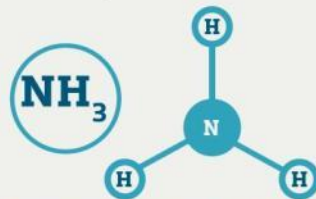
Ammonia

Ammonia is a compound made of nitrogen and hydrogen. Chemical formula NH₃. Ammonia's main use is in fertilizer.



Nitrogen is a harmless odourless gas that makes up 78% of the air around us.

Hydrogen is the most abundant element in the universe. There are 2 hydrogen atoms in every molecule of water.

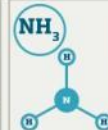


By using water electrolysis and renewable electricity, ammonia production can be made completely carbon-free.

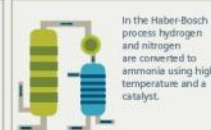
Ammonia

180 Million Tonnes

Ammonia feeds the world: 180 million tonnes were produced in 2015, mainly for use in fertilizers. Growing demand for food means this must rise 3% each year.



Today, ammonia is made using the Haber-Bosch process invented and perfected in the early 1900s. Its two inventors won Nobel prizes in 1918 and 1931.

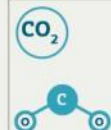


In the Haber-Bosch process hydrogen and nitrogen are converted to ammonia using high temperature and a catalyst.



The global trade in ammonia means we already know how to transport and store it safely.

But there is a problem



Today the lowest cost way to get hydrogen is from natural gas but this produces carbon-dioxide (CO₂) which is a cause of manmade climate change.

Over 1%

Ammonia production requires energy, and today this energy also comes from fossil fuels. Together with the fossil hydrogen feedstock, current ammonia production accounts for over 1% of global CO₂ emissions.

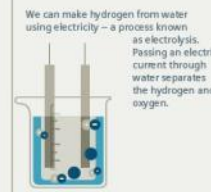


To keep under 2 degrees warming humans must emit no more than 600 billion tonnes more CO₂. That's less than 25 years at the rate today.



Once CO₂ is released into the atmosphere it will change the climate for the next 10,000 years.

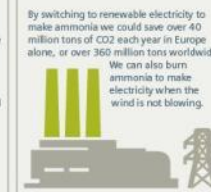
The good news – innovating to create carbon free "green" ammonia



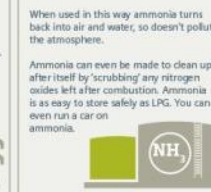
We can make hydrogen from water using electricity – a process known as electrolysis. Passing an electric current through water separates the hydrogen and oxygen.



Green ammonia can support the business case for renewables, by providing an alternative revenue stream that is not dependent on a grid connection (particularly relevant in remote areas), and by being used for load-balancing.



By switching to renewable electricity to make ammonia we could save over 40 million tons of CO₂ each year in Europe alone, or over 360 million tons worldwide. We can also burn ammonia to make electricity when the wind is not blowing.



When used in this way ammonia turns back into air and water, so doesn't pollute the atmosphere. Ammonia can even be made to clean up after itself by 'scrubbing' any nitrogen oxides left after combustion. Ammonia is as easy to store safely as LPG. You can even run a car on ammonia.

Thank you for your attention!



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