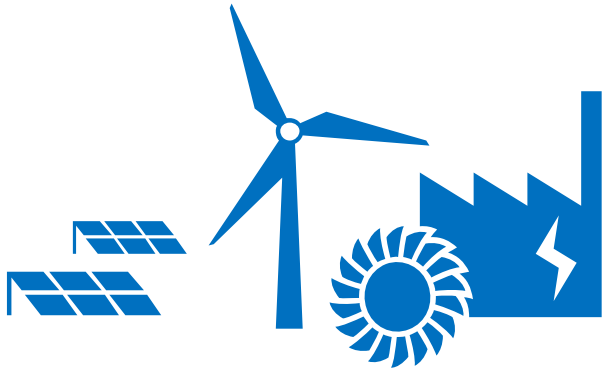
Green Ammonia

November 2017
Ian Wilkinson

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.



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

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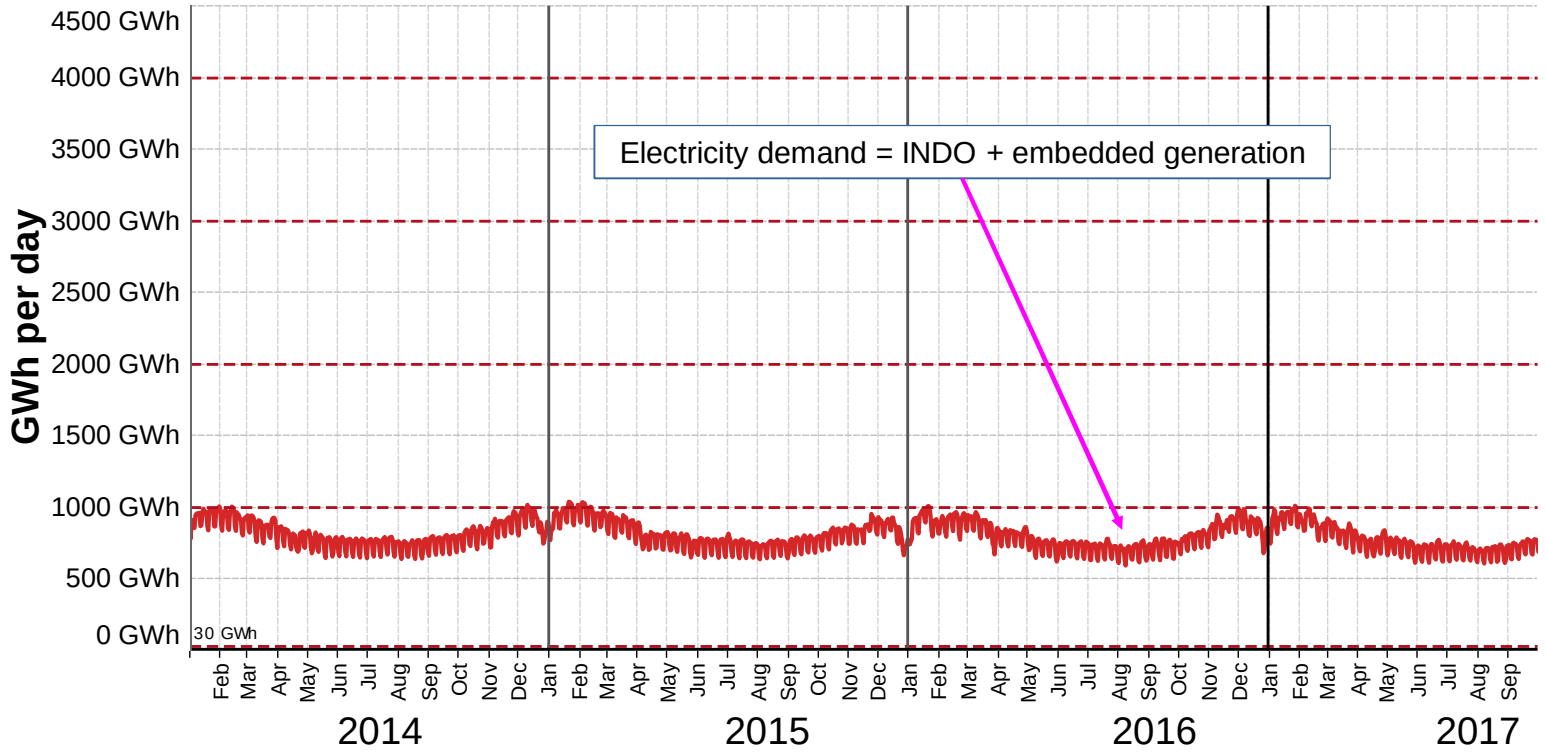
Great Britain's Energy Vectors – in GWh per day



Charts can be downloaded from http://bit.ly/energycharts

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

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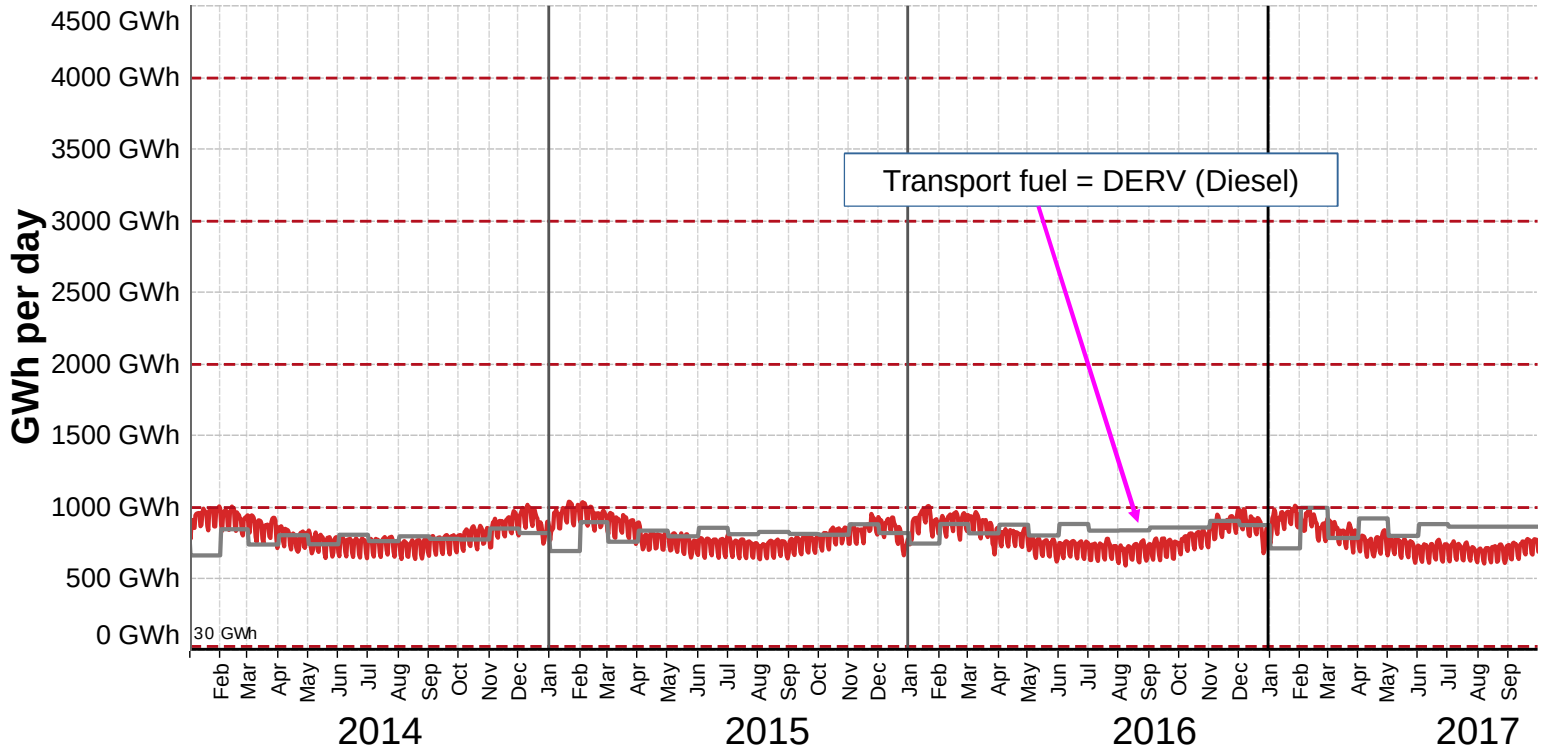

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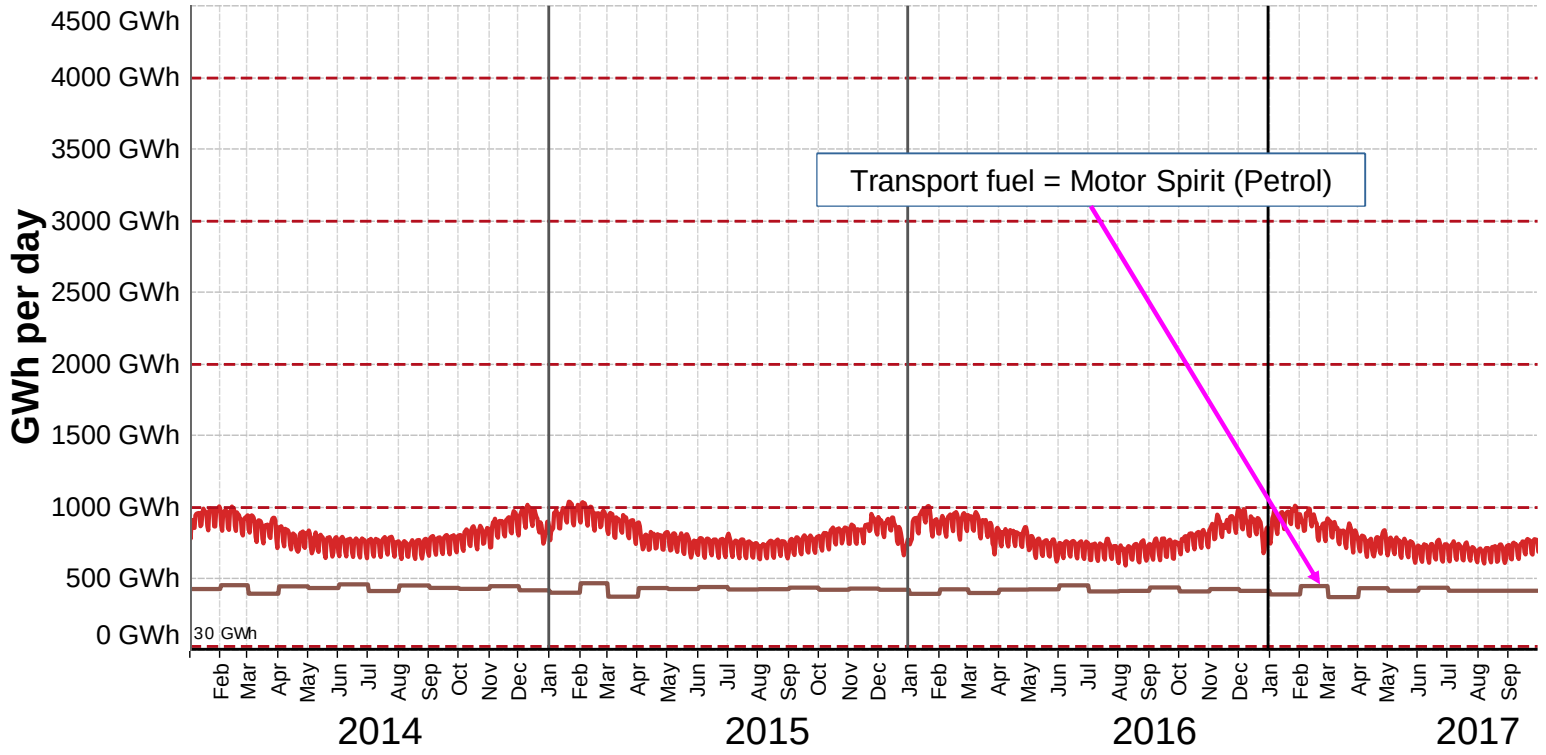

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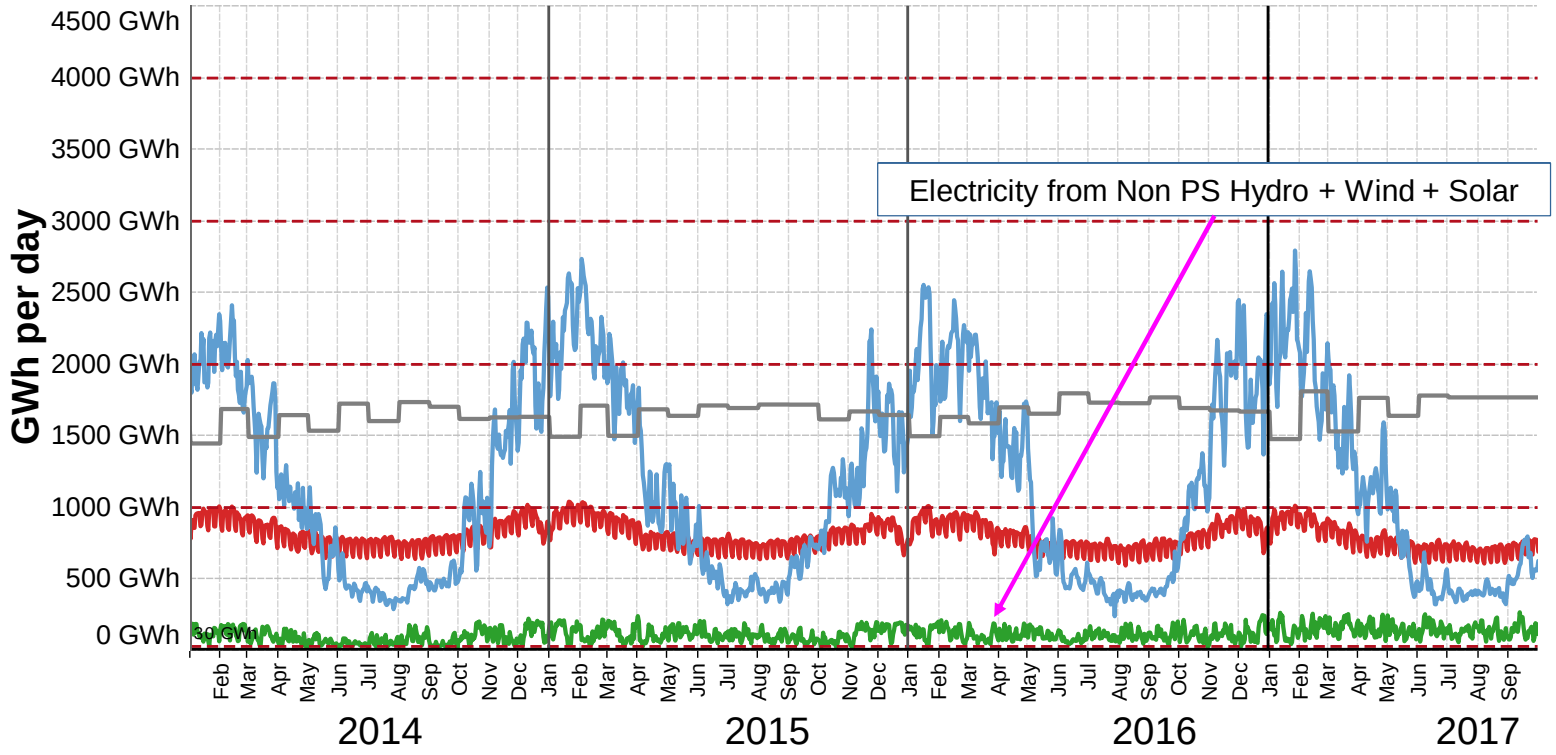

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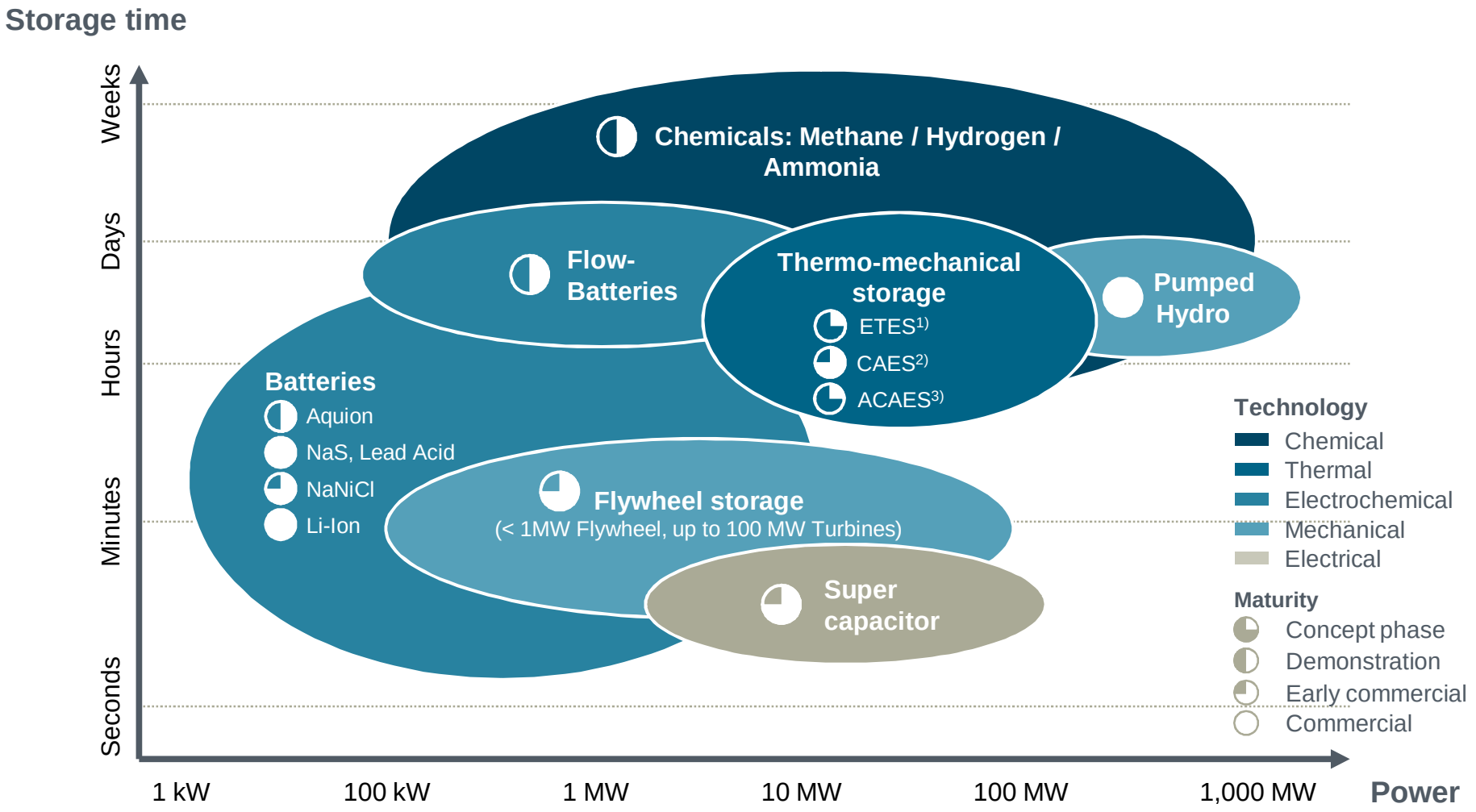
Addressing energy storage needs will require a range of technologies



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

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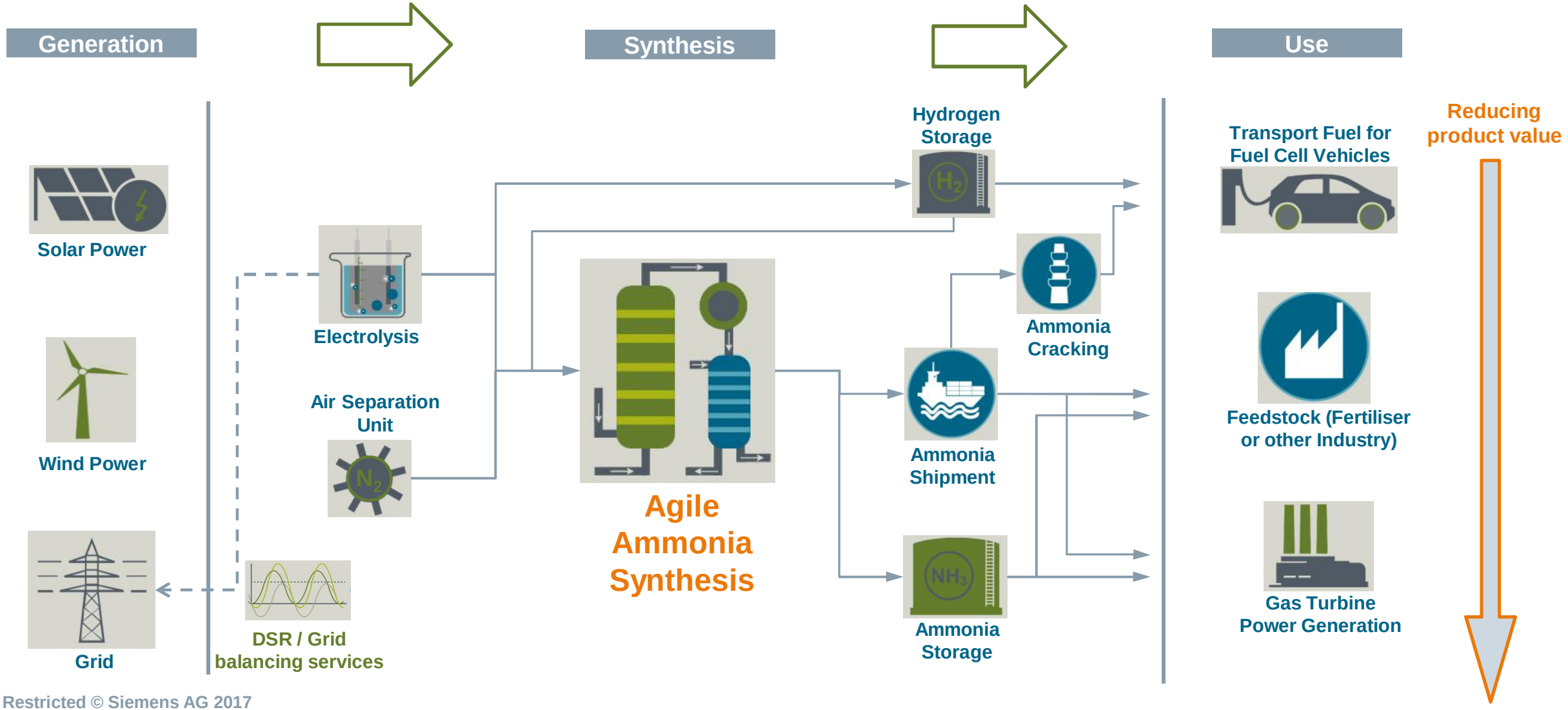
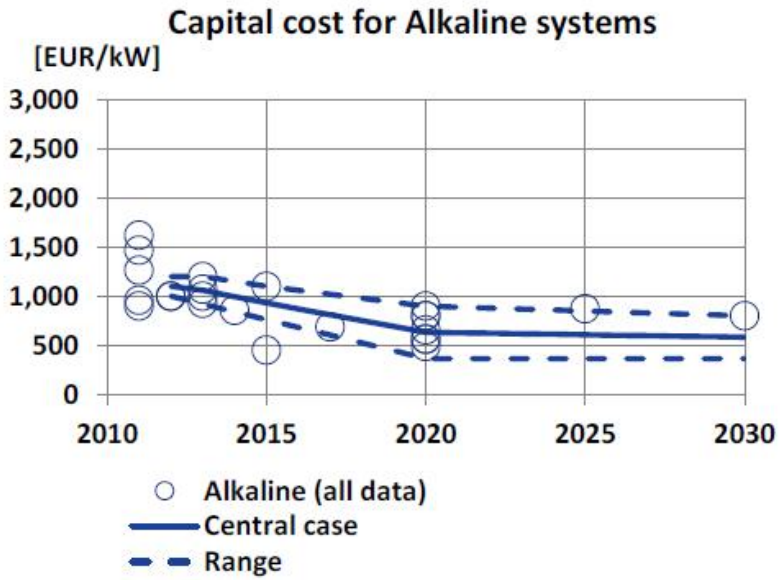
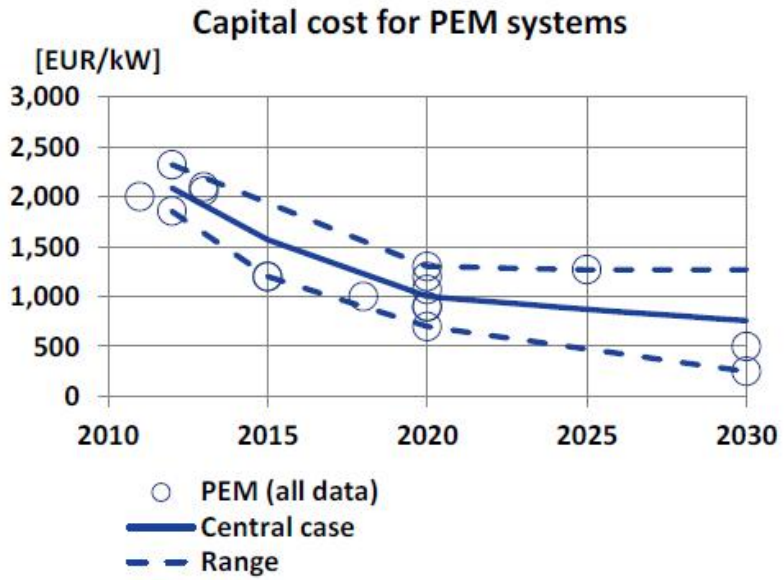


Electrolyser CAPEX costs - An EU study





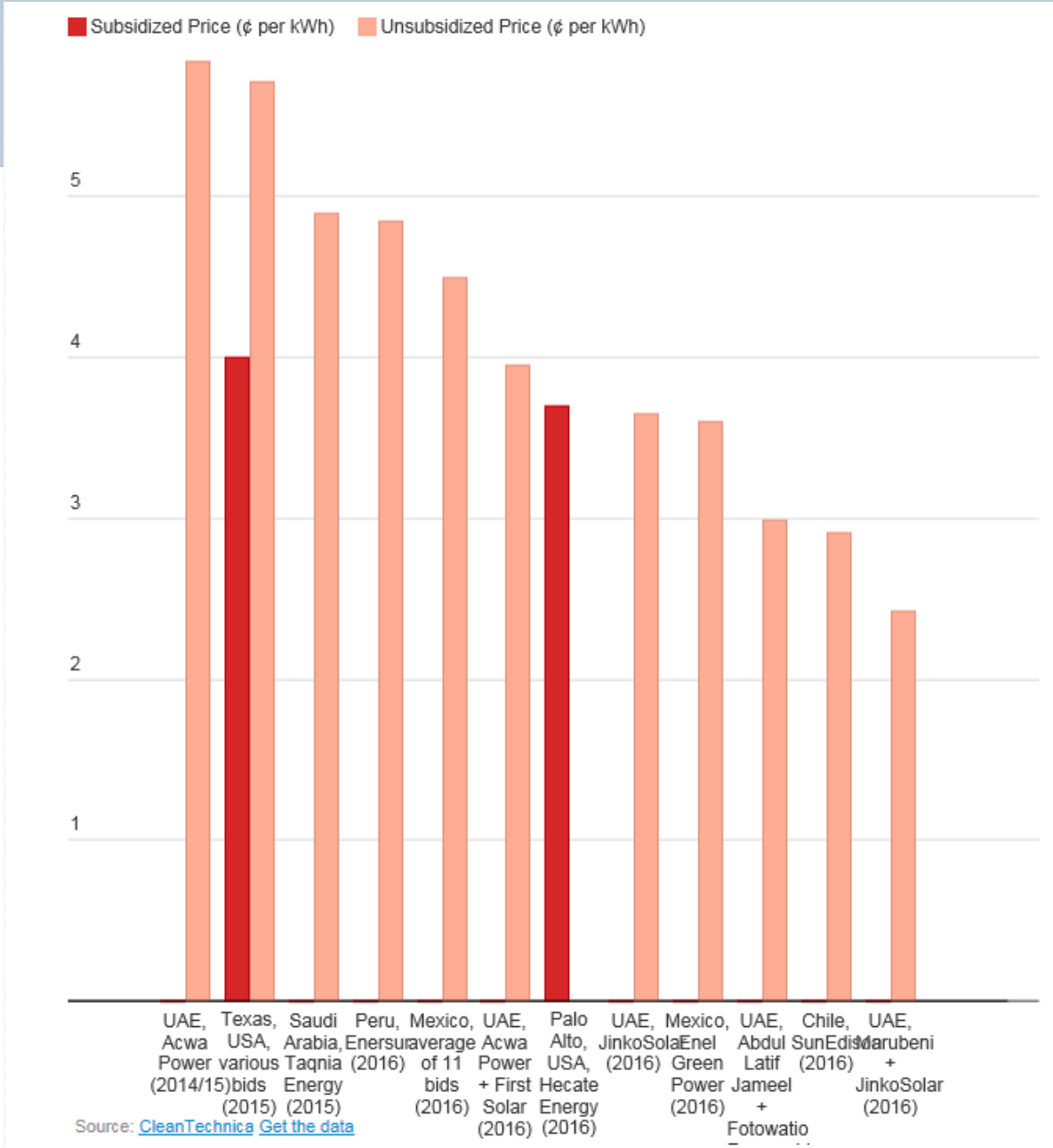
System cost [1]			Today	2015	2020	2025	2030
EUR/kW	Alkaline	Central	**1,100**	**930**	**630**	**610**	**580**
		Range	1,000 - 1,200	760 - 1,100	370 - 900	370 - 850	370 - 800
	PEM	Central	**2,090**	**1,570**	**1,000**	**870**	**760**
		Range	1,860 - 2,320	1,200 - 1,940	700 - 1,300	480 - 1,270	250 - 1,270

[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

With acknowledgements to Thomas Wasser, Siemens AG.

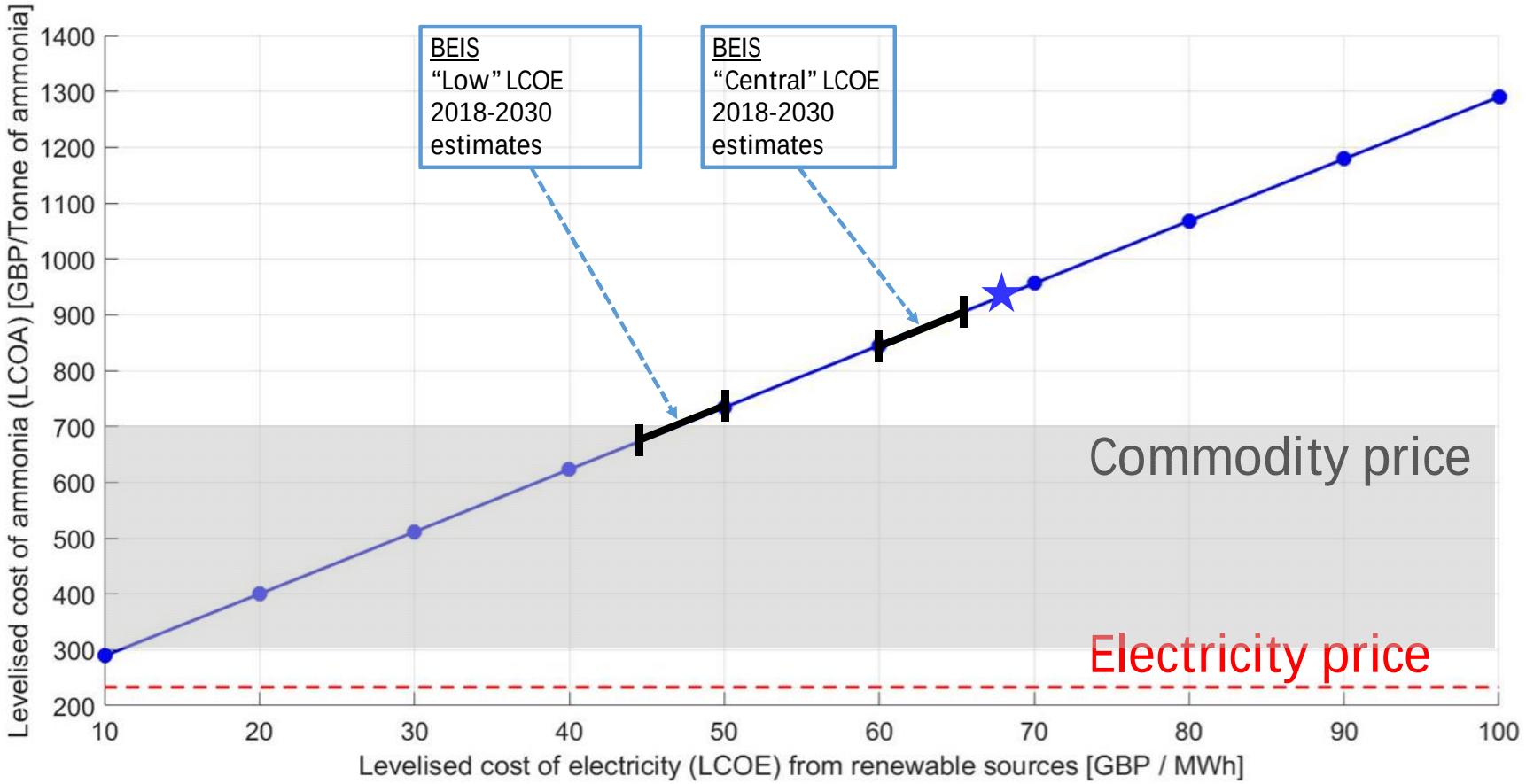
Low Bids for Solar PV



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

With acknowledgements to Thomas Wasser, Siemens AG.

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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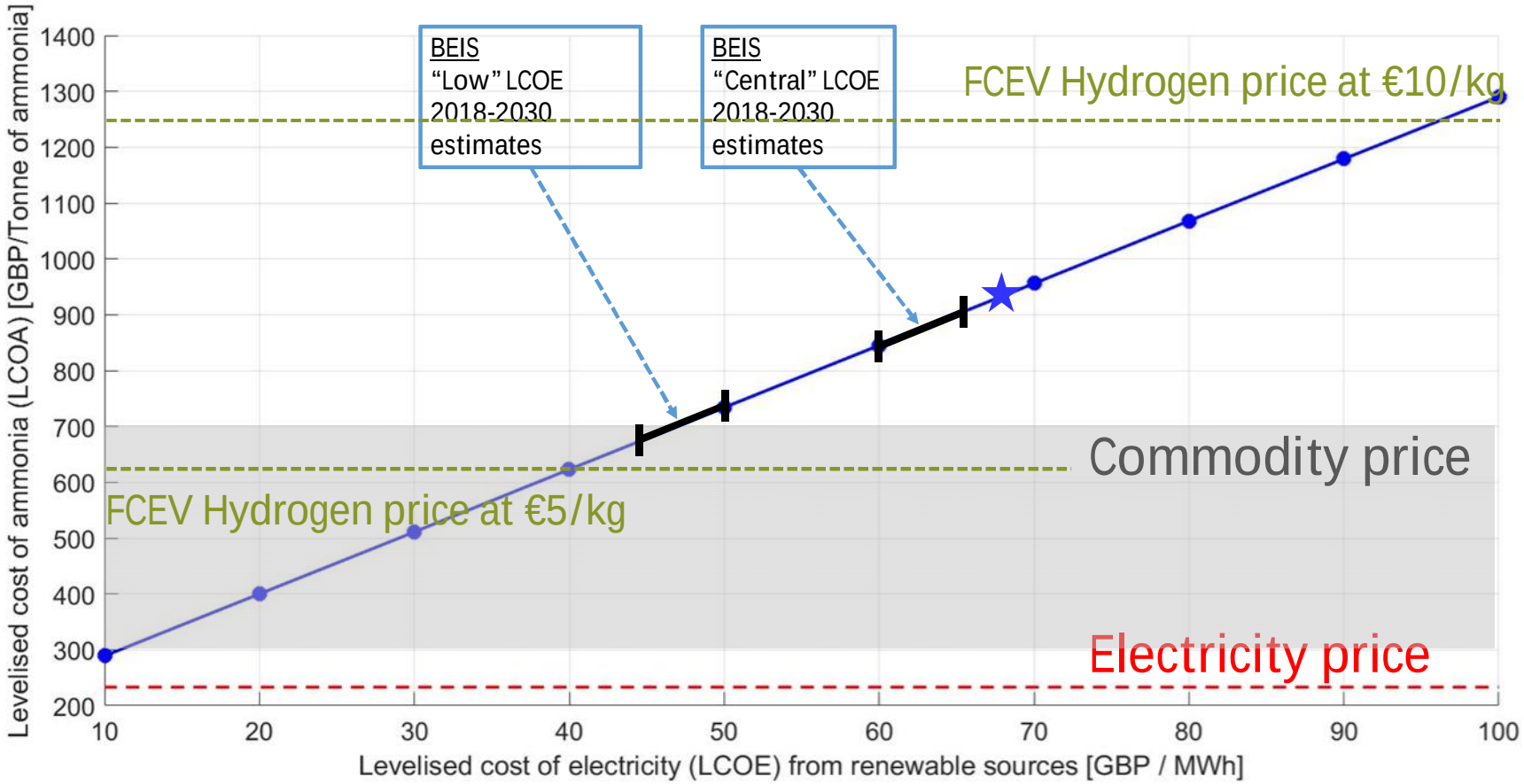

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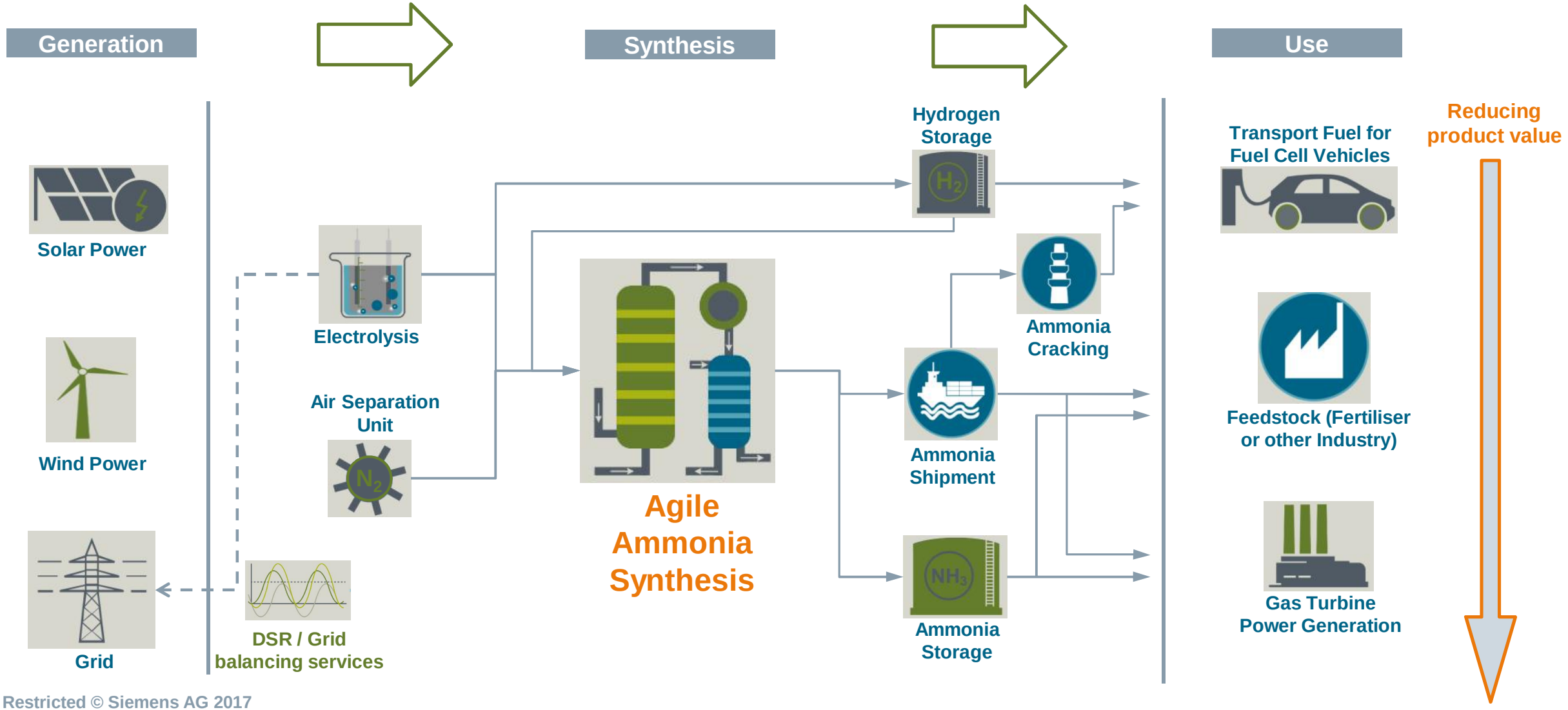
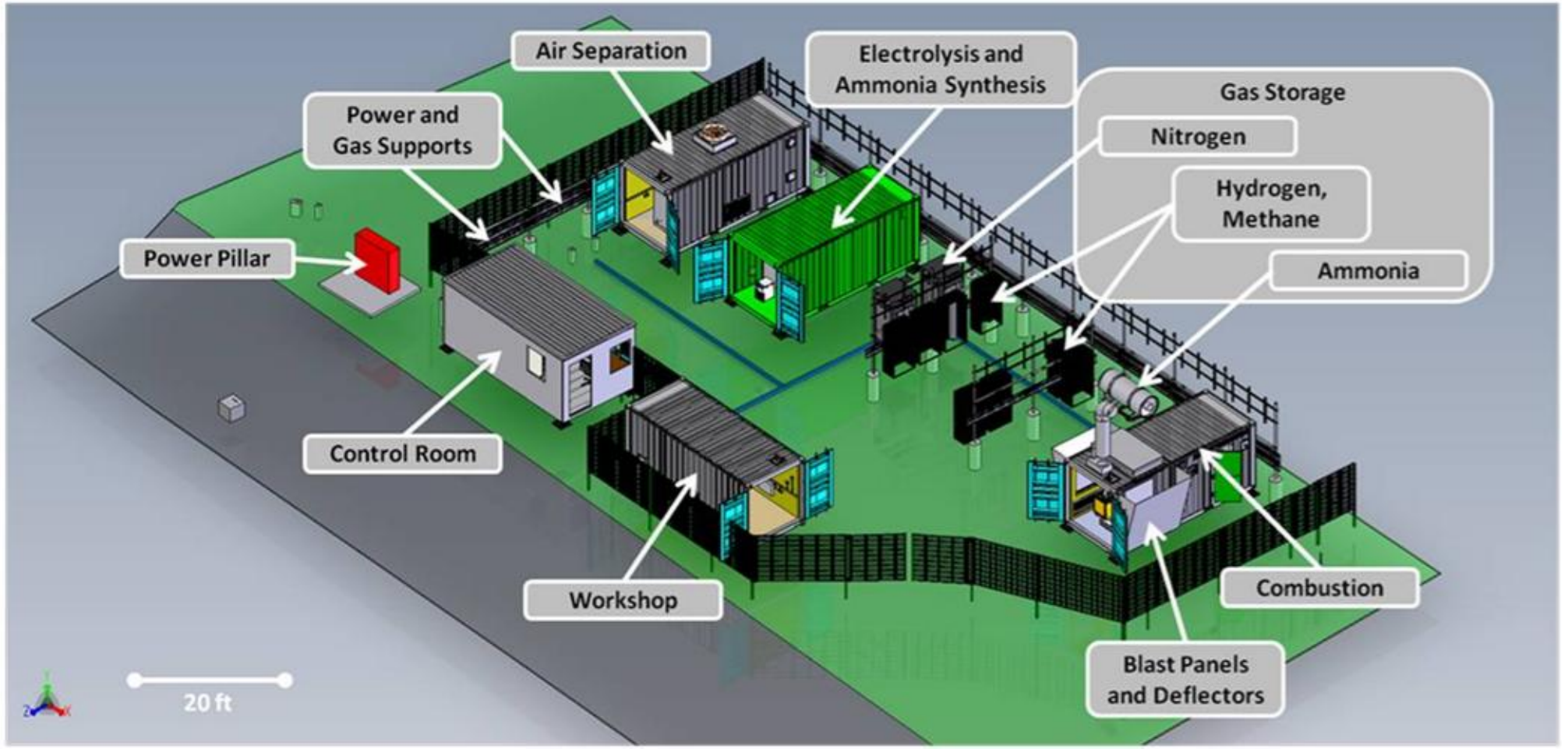


The Green Ammonia Demonstrator will show the complete cycle of renewable power, storage as ammonia, and conversion back to electricity



The main components of the Green Ammonia energy storage system demonstrator are: wind turbine, N_2 generator, H_2 electrolyser, ammonia reactor, and an internal combustion engine

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NH_3 H-B Reactor (Bespoke)

Test site, Combustion and Synthesis Containers

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

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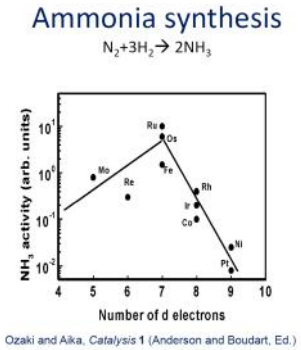
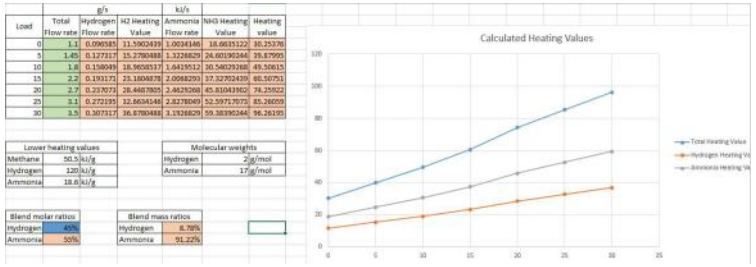
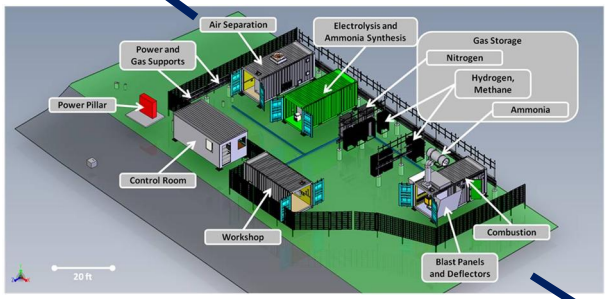
Haber-Bosch synthesis catalyst

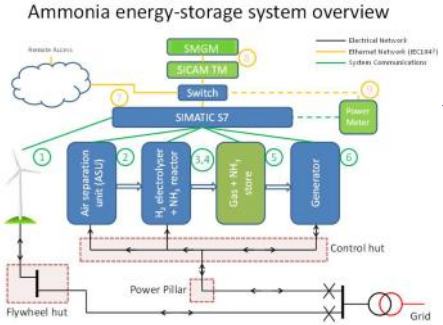


Ammonia combustion studies

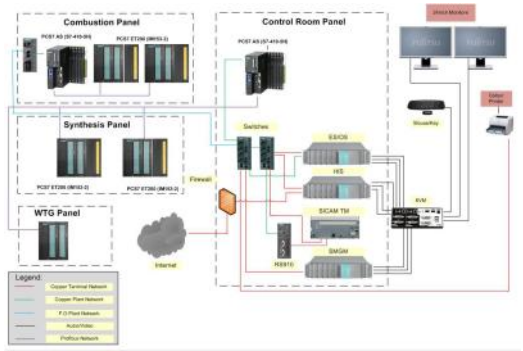




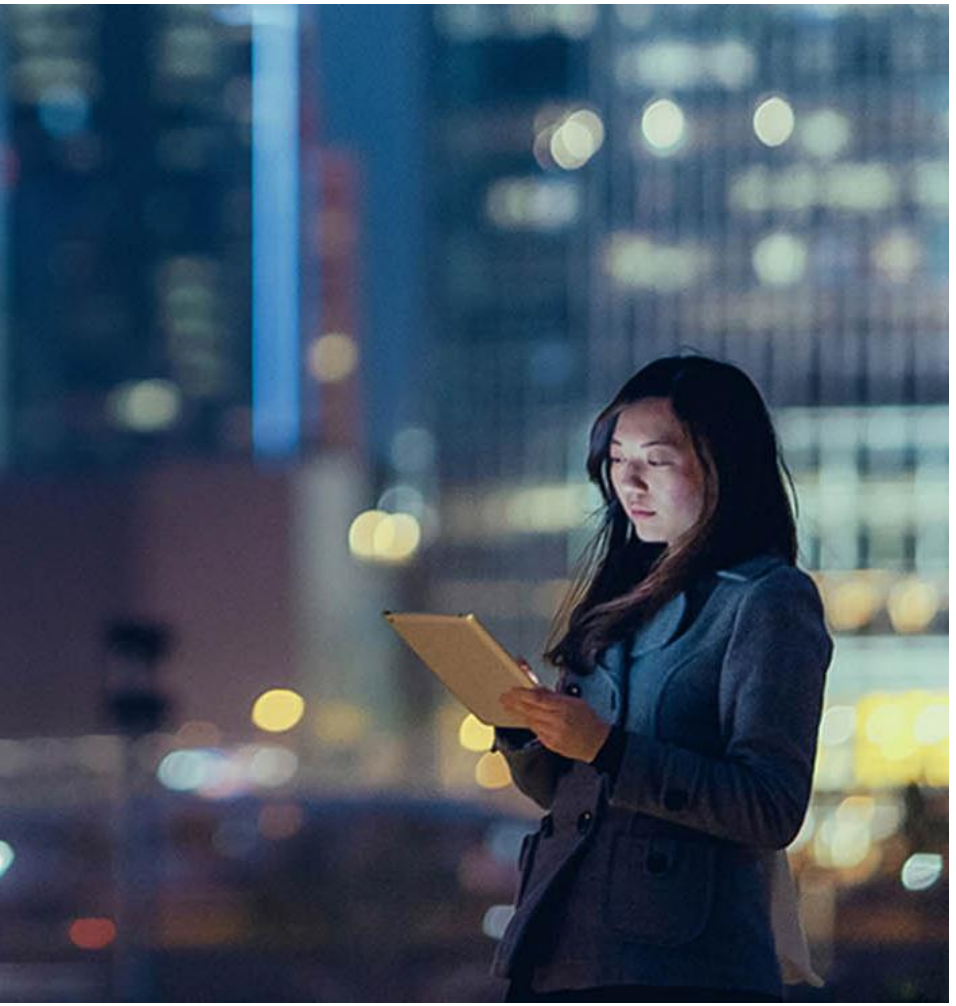
Energy management system



Control system



Thank you for your attention!



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For further information, see

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