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The role of hydrogen in energy systems

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University of South Wales

12th ECCRIA Conference

06/09/2018

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Outline

- Energy systems challenges
- Hydrogen role
  - Vehicle use
  - Energy storage
  - Energy in buildings
- USW Research
  - Baglan refuelling station
  - Energy storage - Cascaded electrolyser control
  - Energy in buildings - Fuel cells for combined heat and power

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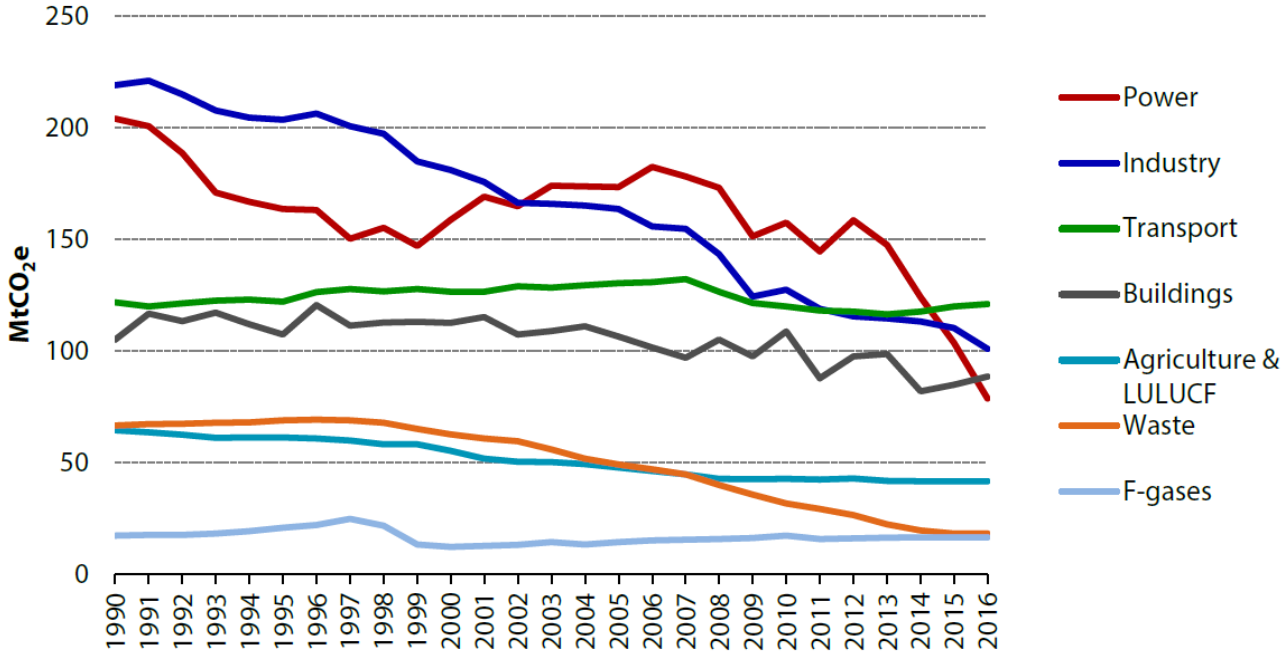
UK - GHG emissions

Budget	Carbon budget level	Reduction below 1990 levels
1st carbon budget (2008 to 2012)	3,018 MtCO2e	23%
2nd carbon budget (2013 to 2017)	2,782 MtCO2e	29%
3rd carbon budget (2018 to 2022)	2,544 MtCO2e	35% by 2020
4th carbon budget (2023 to 2027)	1,950 MtCO2e	50% by 2025
5th carbon budget (2028 to 2032)	1,765 MtCO2e	57% by 2030



UK emissions 41% below 1990 levels in 2016 – 1st and 2nd budget met, 3rd budget due to be outperformed, but not on track to meet 4th budget

www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2016

Source: Meeting Carbon Budgets: Closing the policy gap, 2017 Report to Parliament, Committee on Climate Change

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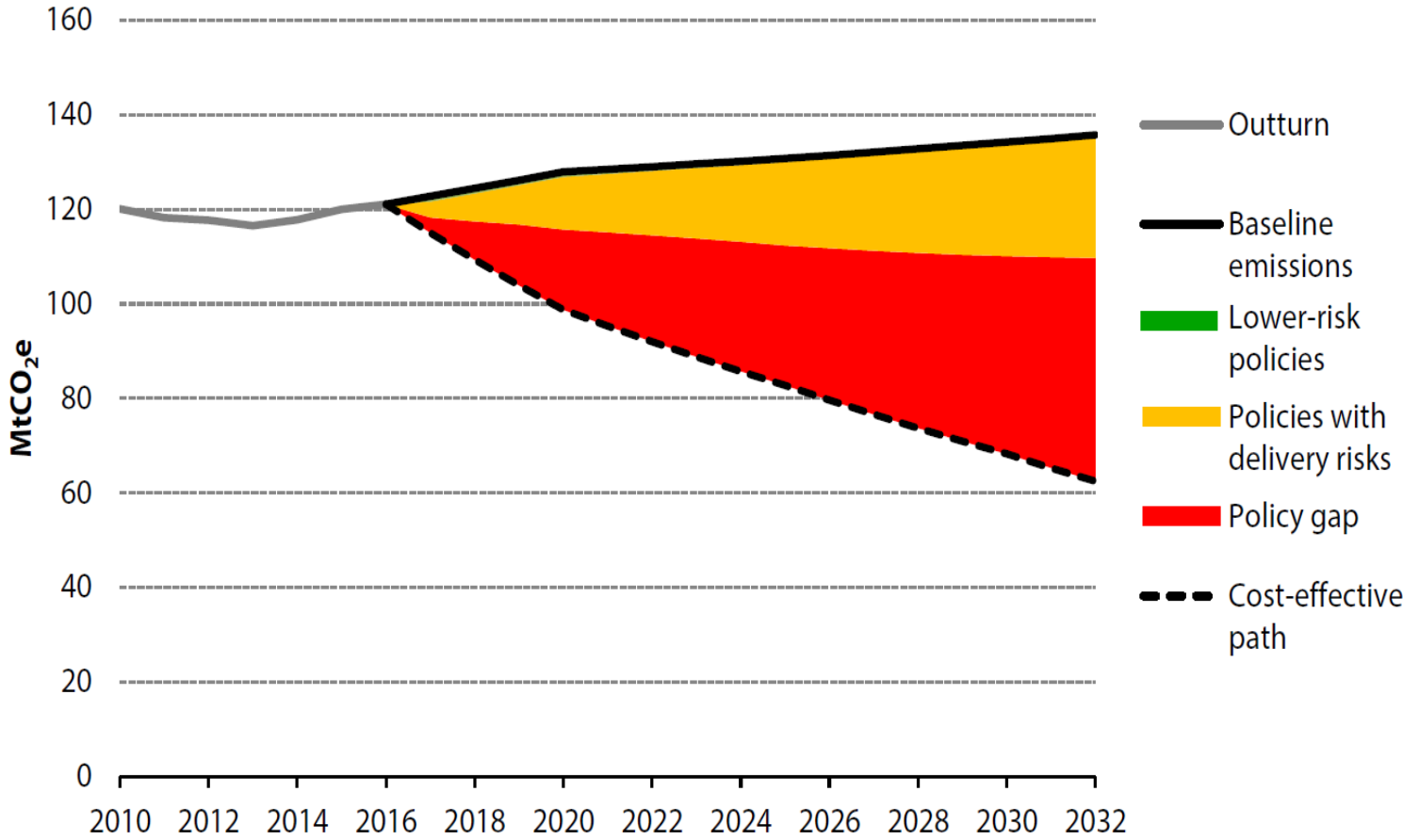
UK - GHG emission reduction: transport

- Emmisions are at their highest since 2009
- Increased travelling distance with only incremental efficiency improvements
- 1.2% of new vehicle sales were electric in 2016

Figure 5.13. The policy gap (2010-2032)



Source: Meeting Carbon Budgets: Closing the policy gap, 2017 Report to Parliament, Committee on Climate Change

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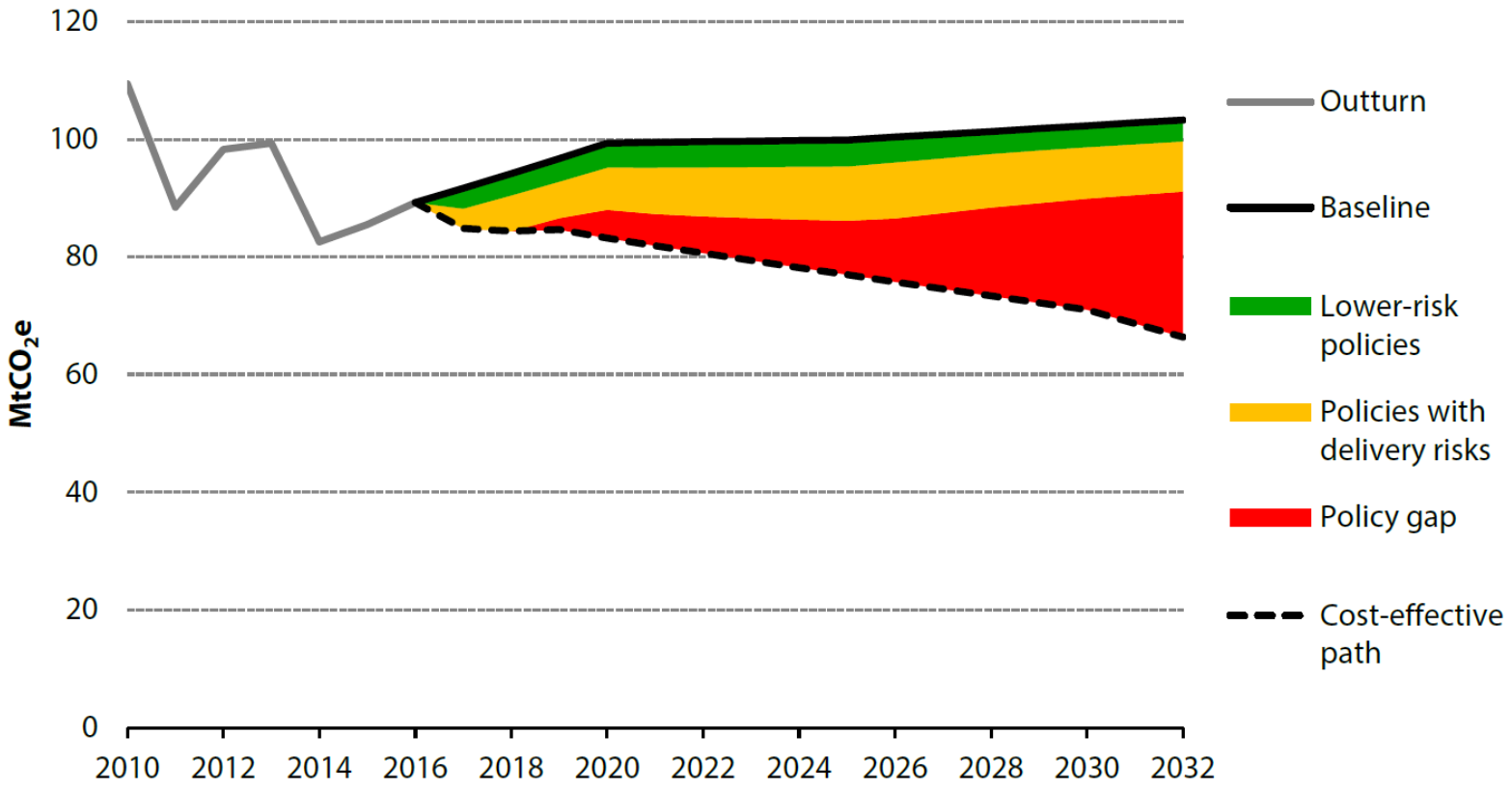
UK - GHG emission reduction - buildings

Figure 3.5. Policy Gap Chart (2010-2032)



- Emmisions from buildings have increased for the past 2 years
- Most boilers (70%) are now condensing models
- Low rates of insulation installation since 2012
- Uptake of heat pumps and district heating is minimal

Source: Meeting Carbon Budgets: Closing the policy gap, 2017 Report to Parliament, Committee on Climate Change

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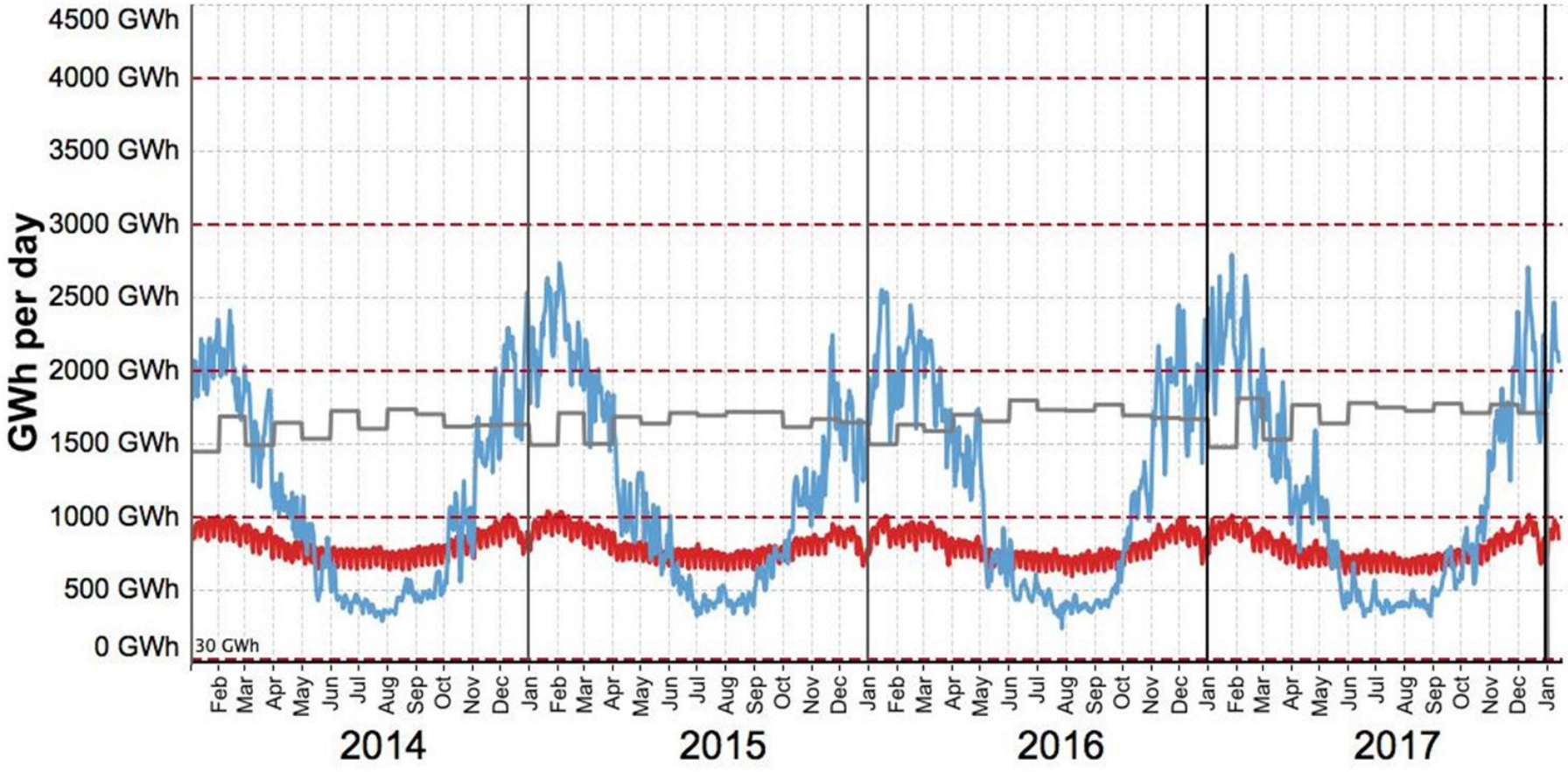
Gas, electricity and transport energy demand



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

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

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Hydrogen energy

- Hydrogen is the most abundant element in the universe (~75% of baryonic mass)
- On Earth, nearly all hydrogen is bound in other molecules: water, hydrocarbons, biomass.
- We have to create molecular hydrogen (H_2) before we can use it.
- From water:
  - $2H_2O \rightleftharpoons 2H_2 + O_2$
- From Natural Gas:
  - $CH_4 + H_2O + heat \longrightarrow CO + 3H_2$
  - $CO + H_2O \longrightarrow CO_2 + H_2 + heat$
- This involves costs and inefficiencies, so why bother making and using hydrogen?

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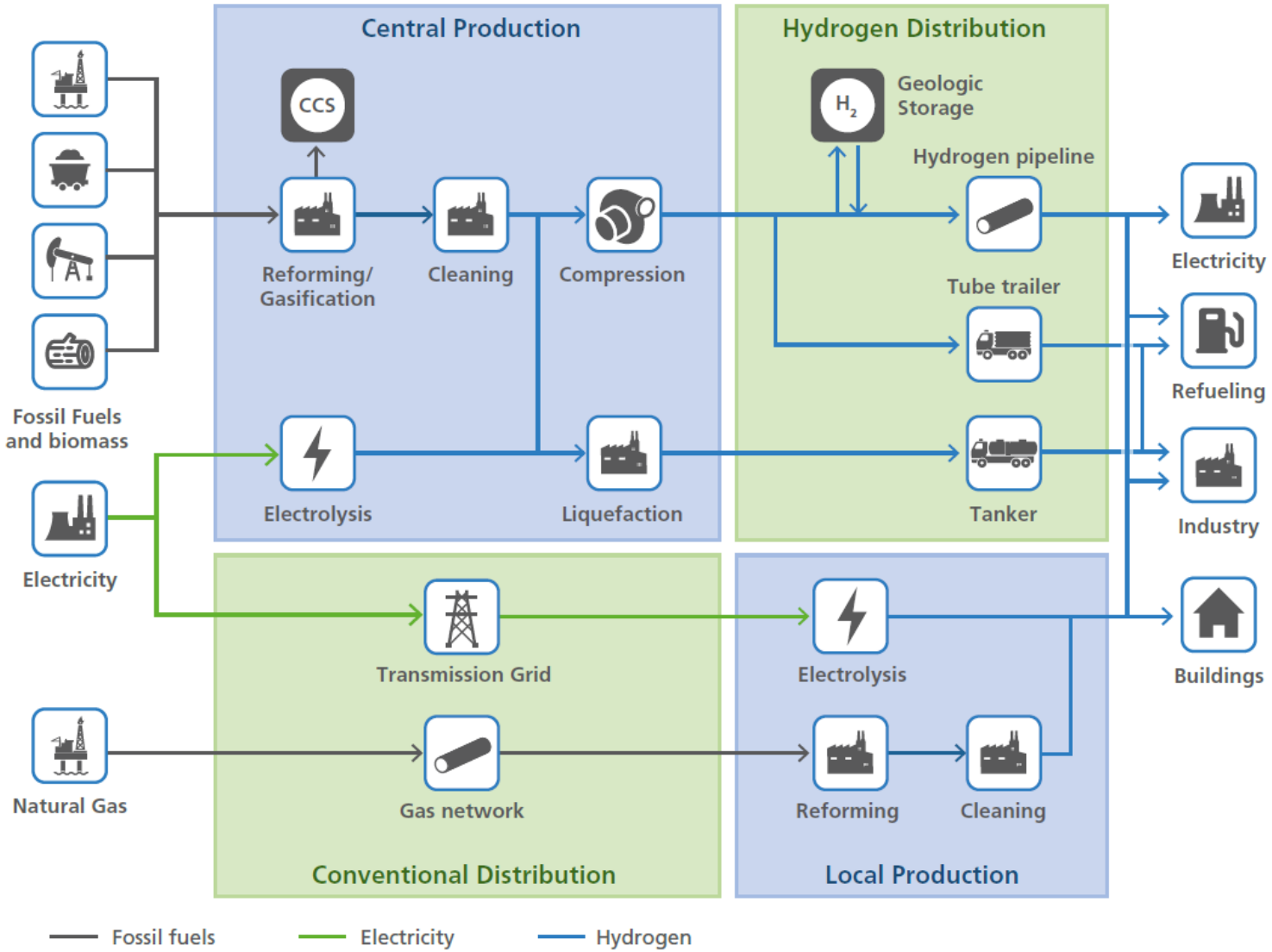
Hydrogen and energy systems challenges

- Hydrogen can provide:
  - An energy storage mechanism for integrating renewables
  - A link between the electricity, heat and transport system
  - An alternative route to carbon free heat and transport through electrolysis and SMR of methane with CCS



Source: H2FC SuperGEN: THE ROLE OF HYDROGEN AND FUEL CELLS IN FUTURE ENERGY SYSTEMS 2017

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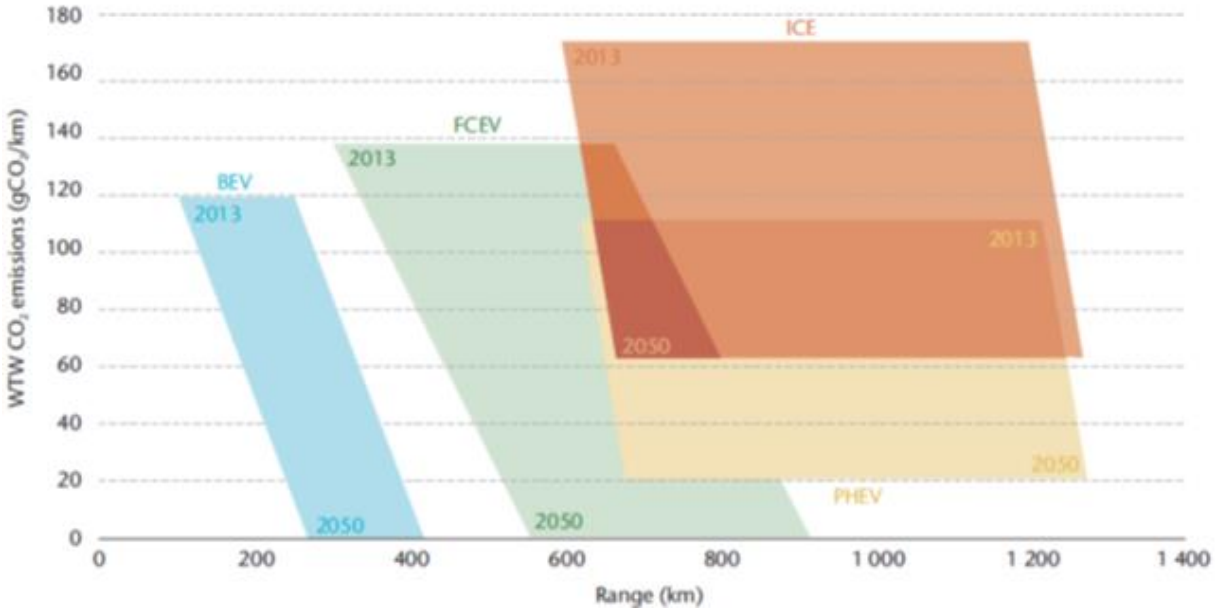
Hydrogen end use - vehicle fuel

- Future vehicles likely to include battery electric vehicle (BEV) and fuel cell electric vehicles (FCEV)
- FCEV are currently
  - less commercially advanced
  - less established infrastructure
  - have more inefficiencies
- But
  - have the potential for a greater range
  - faster refuelling
  - more system integration possibilities



Well-to-wheel (WTW) emissions vs. vehicle range for several vehicle technologies

Source: IEA Technology Roadmap – Hydrogen and Fuel Cells 2015

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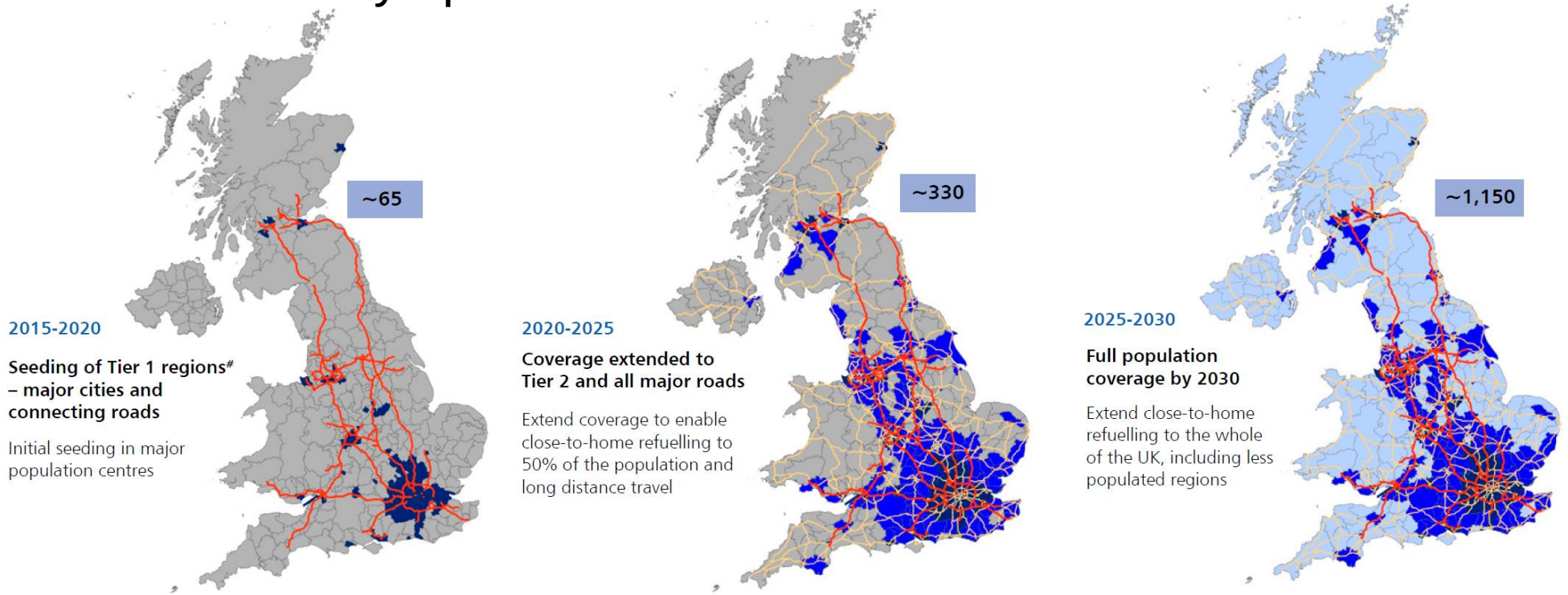
Hydrogen station build-up: UK H2 mobility

- Collaboration between UK Government and industry to evaluate and plan the development of hydrogen refuelling stations in the UK
- Aiming for full coverage of the country in 2030s
- ~15 stations currently operational



Source: UK H2 mobility

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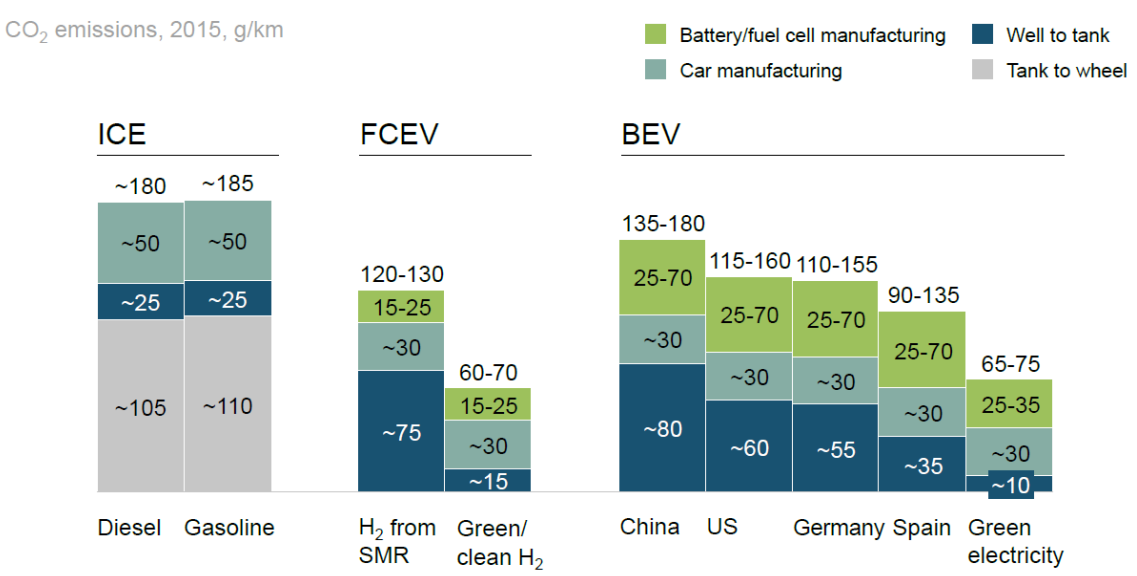
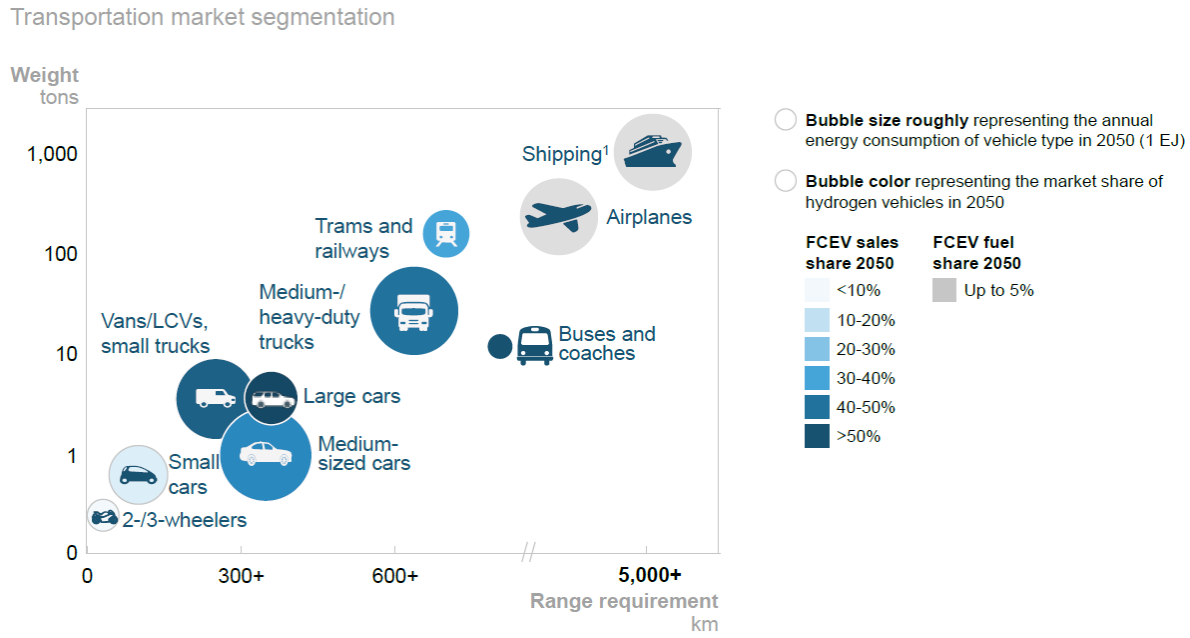
Hydrogen for transportation

- Hydrogen Council vision for 2050
  - 400 million cars
  - 20 million trucks
  - 5 million busses
- As well as road use hydrogen has potential in
  - Rail transport,
  - Aviation
  - Shipping



Assumption: compact car (C-segment) as reference vehicle (4.1 l/100 km diesel; 4.8 l/100 km gasoline; 35.6 kWh battery), 120,000 km lifetime average grid emissions in China, Germany, Spain in 2015; EV manufacturing (excl. fuel cell and battery) 40% less energy-intensive than ICE manufacturing; 10 kg CO_2/kg H_2 from SMR; 0.76 kg H_2/100 km; 13 kWh/100 km

SOURCE: EPA; A Portfolio of Powertrains for Europe (2010); Toyota Mirai LCA; IVL; Enerdata; expert interviews



1 Hydrogen-based fuels or fuel cells

SOURCE: IEA ETP; IHS; A Portfolio of Powertrains for Europe (2010); Thiel (2014); Hydrogen Council

Hydrogen scaling up: A sustainable pathway for the global energy transition. Hydrogen Council November 2017

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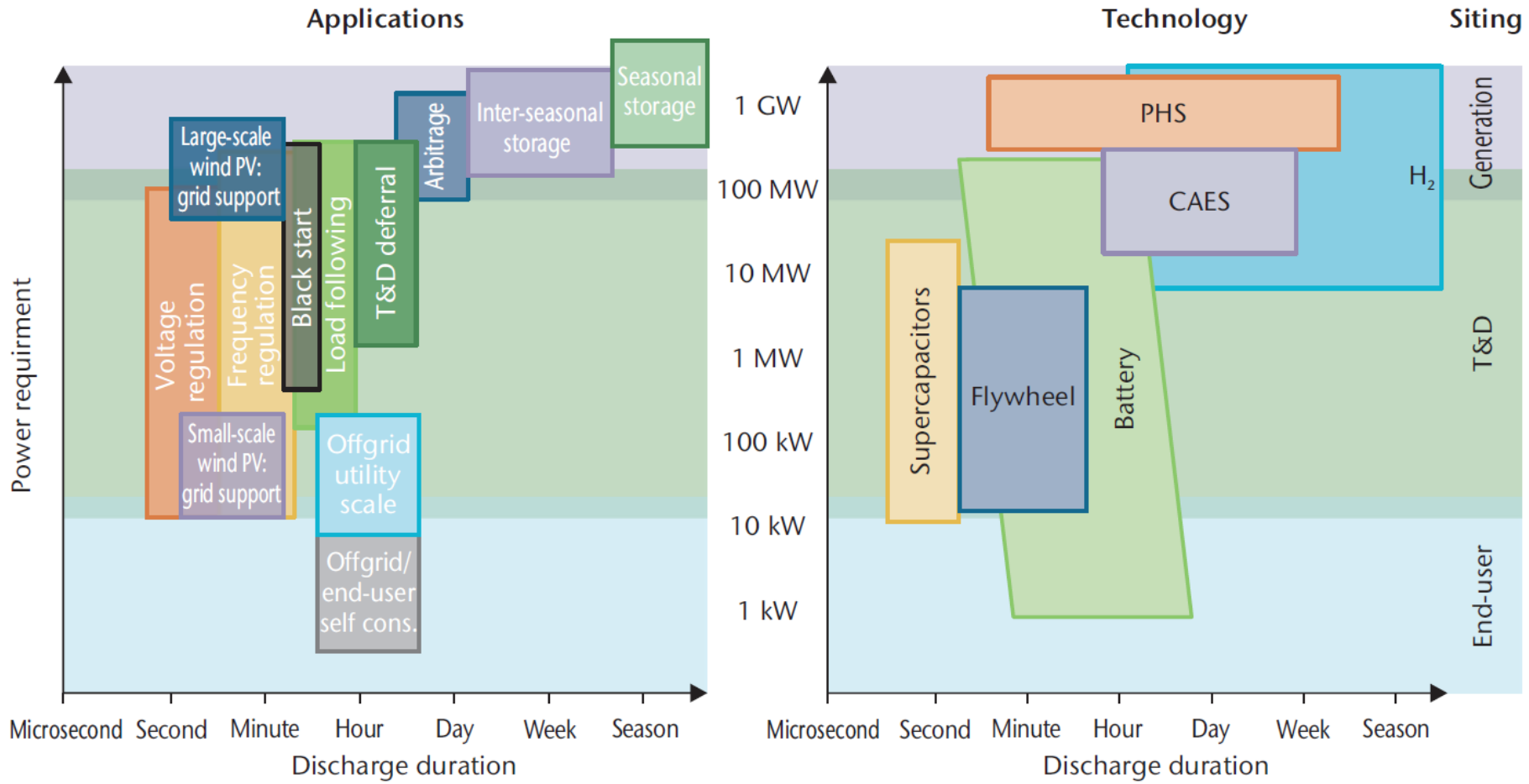
Hydrogen end use - energy storage



Source: IEA Technology Roadmap – Hydrogen and Fuel Cells 2015

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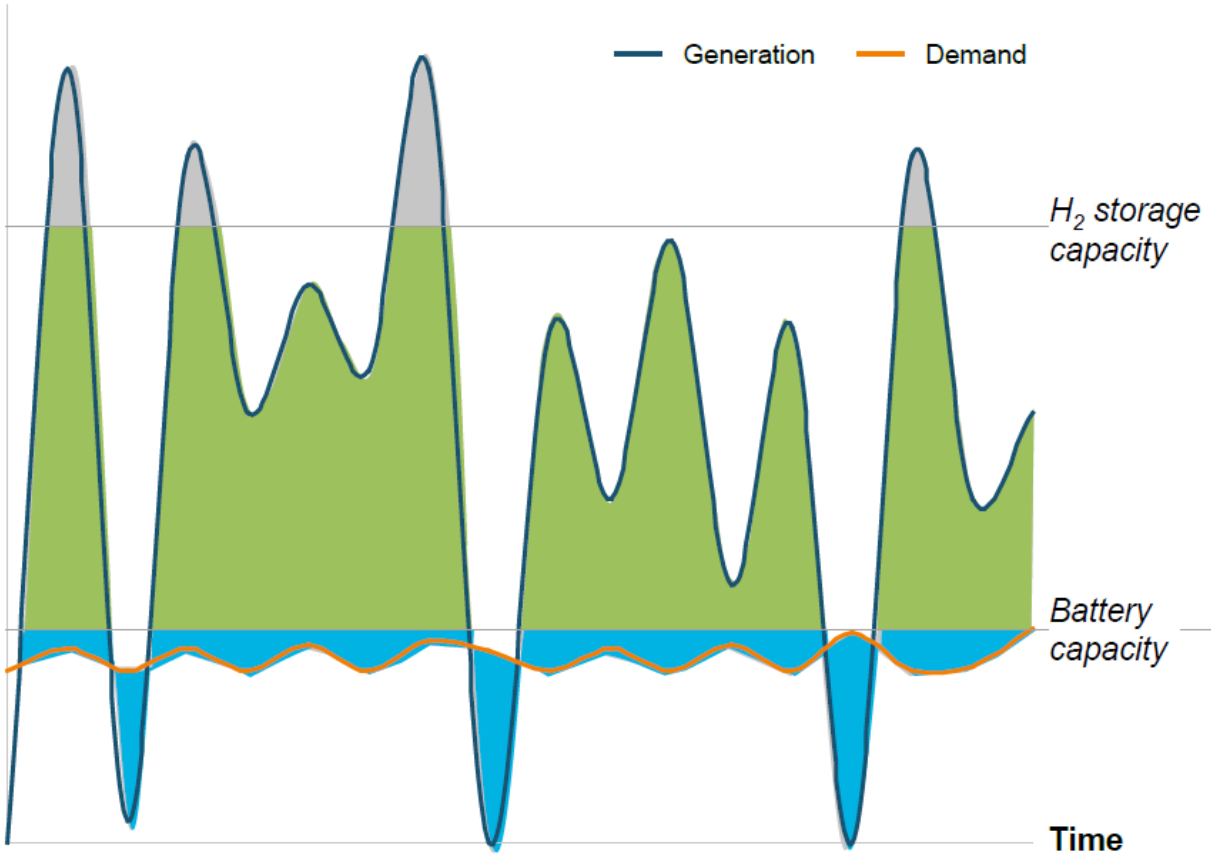
Hydrogen end use - energy storage

Electricity supply and demand, TWh

ILLUSTRATIVE



Means of balancing

Curtailment of extreme peaks

Hydrogen used for

- **Long-term storage** to balance across weeks and seasons
- **Transfer** of renewable energy to other sectors
- Transfer to other **regions** where electricity transmission is not sufficient/ not cost efficient

Batteries and power balancing[1]: short-term storage to balance within hour/day

1 Demand-side load balancing, etc.

Hydrogen scaling up: A sustainable pathway for the global energy transition. Hydrogen Council November 2017

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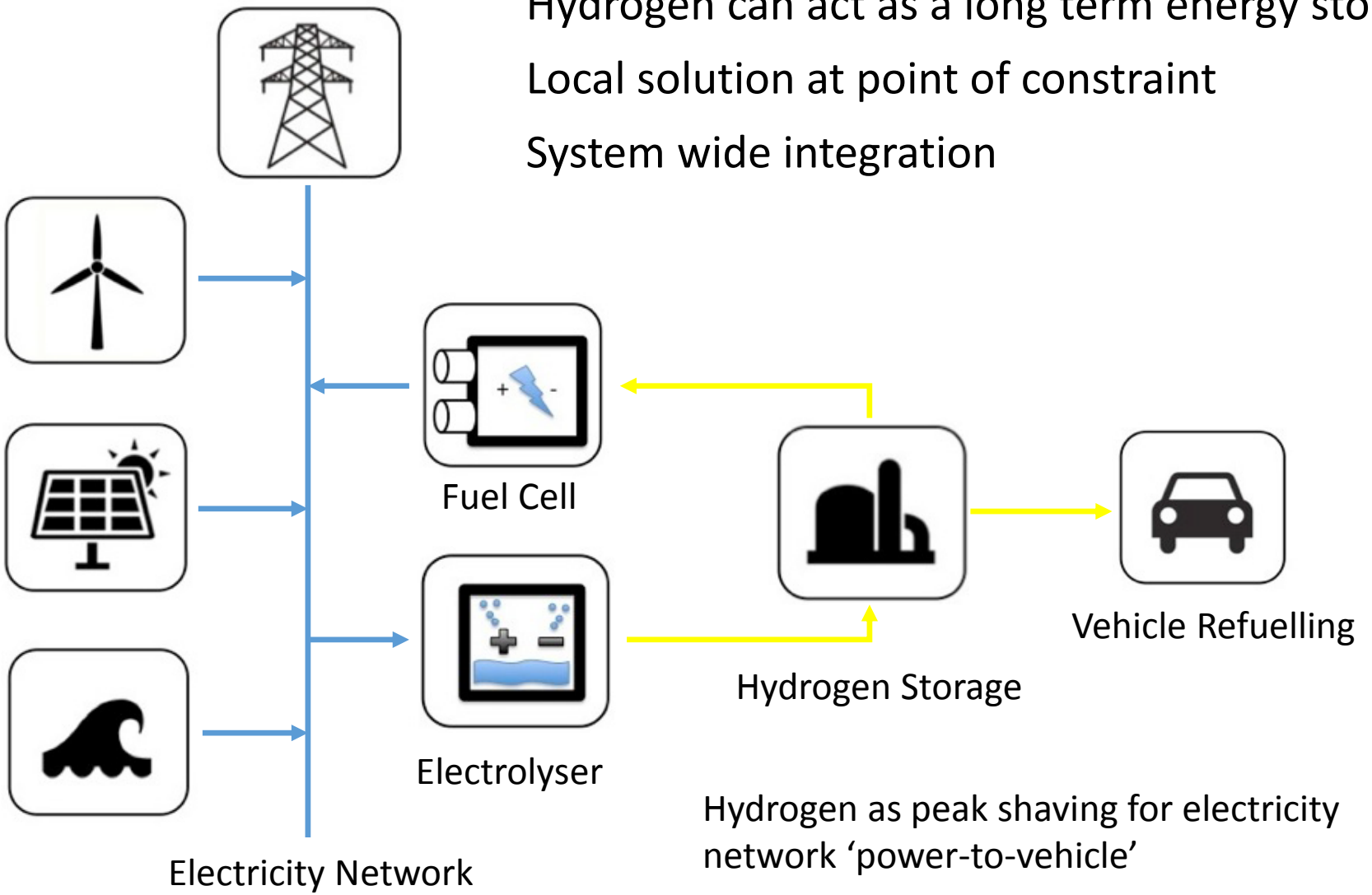
Hydrogen in energy systems: Storage

Hydrogen can act as a long term energy store

Local solution at point of constraint

System wide integration



Hydrogen as peak shaving for electricity network ‘power-to-vehicle’

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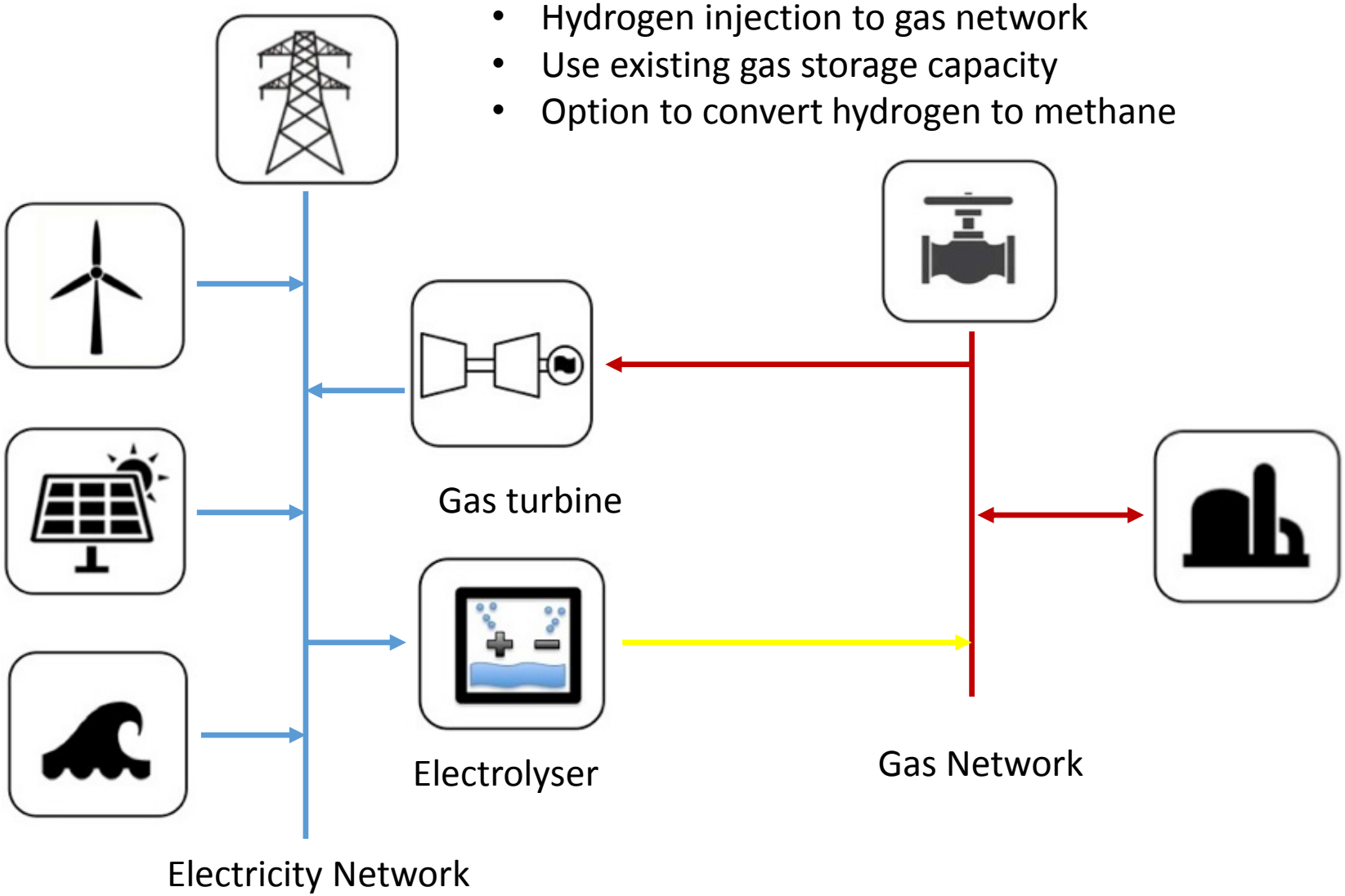
Hydrogen in energy systems: Power-to-gas

- Hydrogen injection to gas network
- Use existing gas storage capacity
- Option to convert hydrogen to methane



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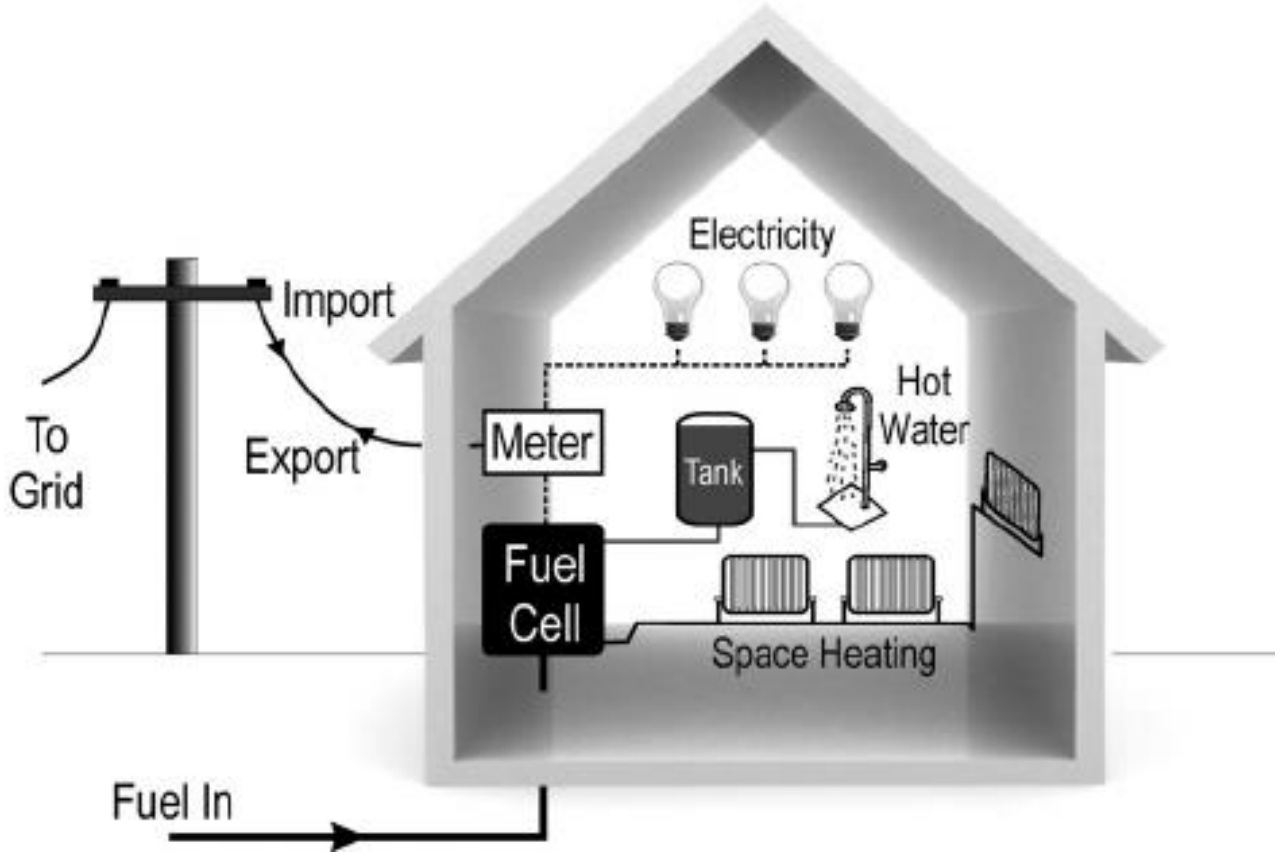
Hydrogen in buildings

- Fuel cells can provide combined heat and power for buildings
- Input fuels are hydrogen or natural gas
- Heating used in building
- Electricity can be used in building or exported
- CHP combined electrical and thermal efficiencies up to 90%



Source: Hawkes, A., Staffell, I., Brett, D. and Brandon, N., 2009. Fuel cells for micro-combined heat and power generation. *Energy & Environmental Science*, *2*(7), pp.729-744.

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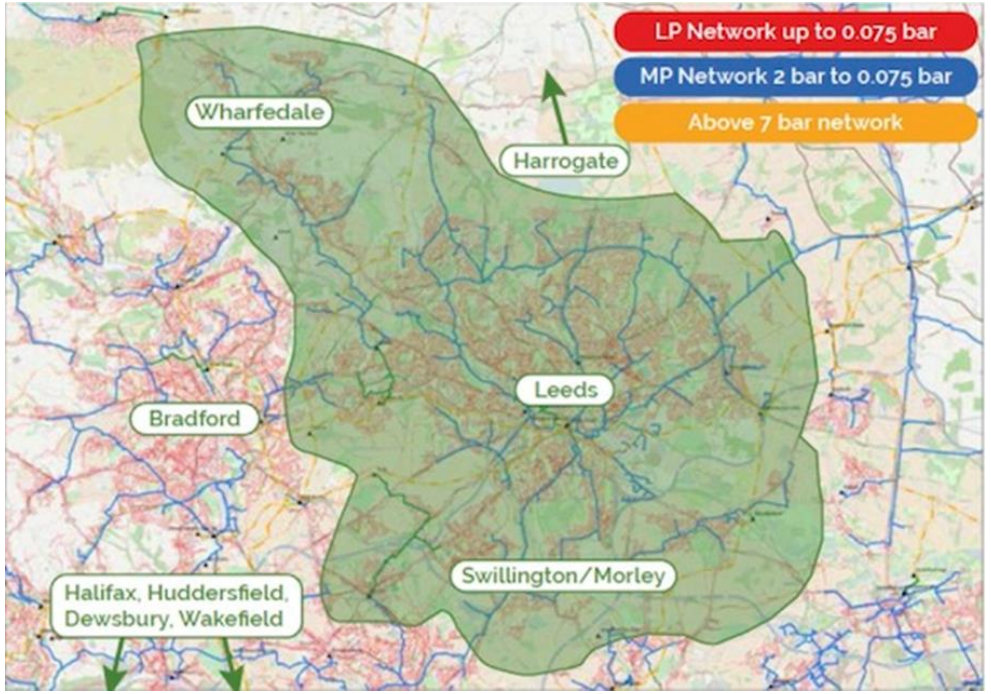
Hydrogen gas schemes

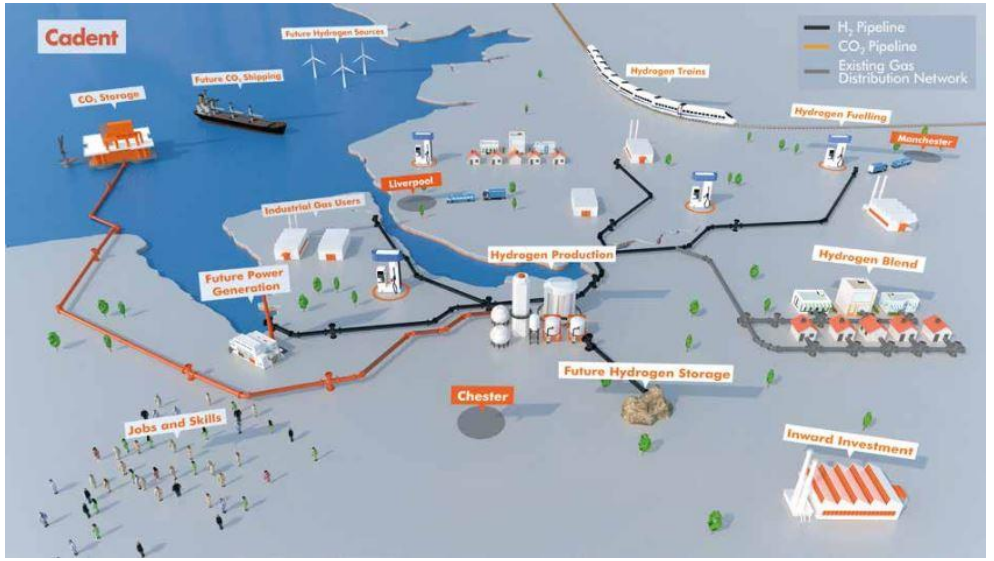
Northern Gas Networks - Leeds City Gate

- convert the low and medium pressure networks in Leeds and suburbs.
- Appliances will need to be converted to hydrogen use



Cadent - HyNet

- Low carbon hydrogen to heat 2m homes
- Hydrogen produced from natural gas with CCS
- Due to become operational in 2025



Kiwa/Arup - Hy4Heat

- Developing hydrogen quality standard
- Developing and testing appliances

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Hydrogen Research and Demonstration Centre

SERC
SUSTAINABLE ENVIRONMENT RESEARCH CENTRE

- Located at Baglan Bay, near Port Talbot
- Hydrogen technology demonstration
- Hydrogen vehicles and fuelling infrastructure
- Renewables integration
- Recovery of hydrogen from industrial streams
- Bio-hydrogen
- Solid oxide fuel cell testing

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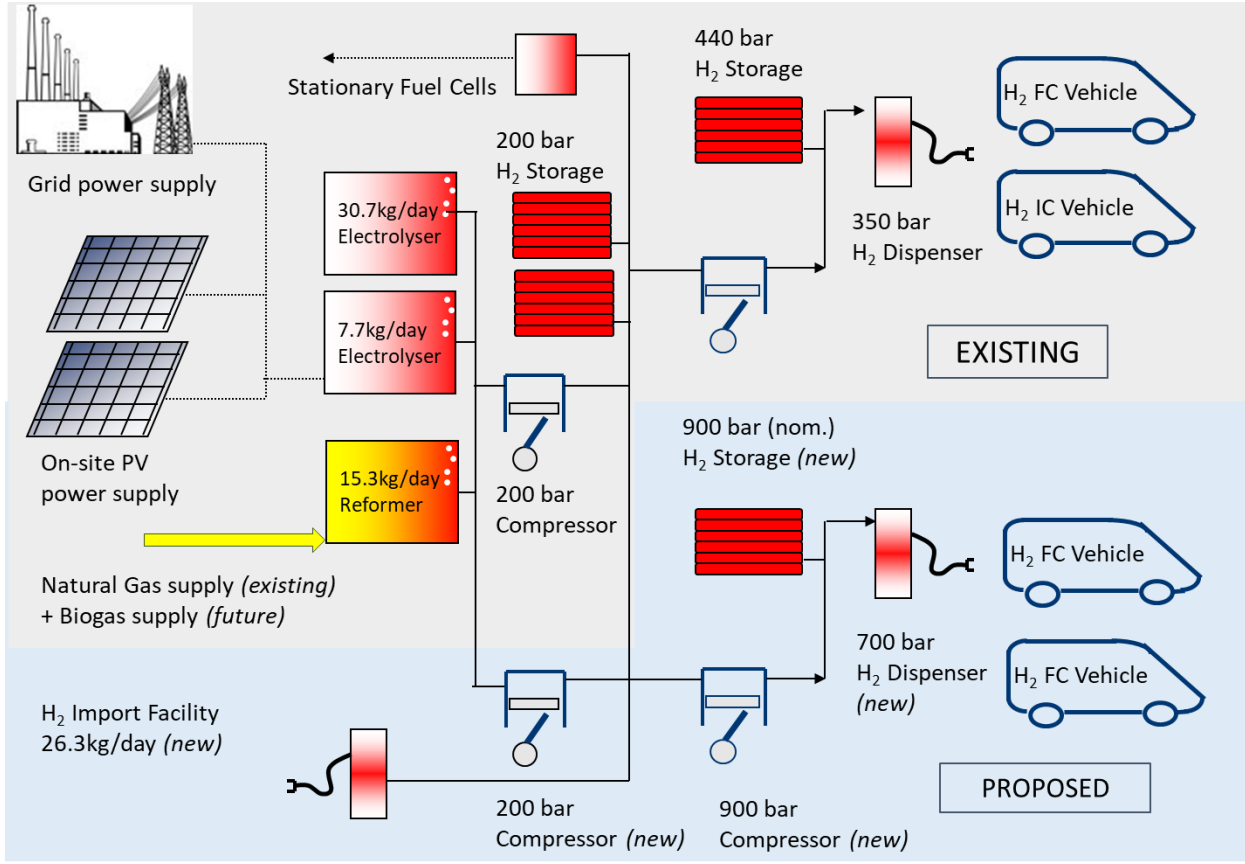
Hydrogen Refuelling

- Existing 350 bar refuelling system being upgraded to 700 bar.
- Facilitating local hydrogen vehicle fleet
  - Mid and West wales fire brigade
  - Riversimple
  - Swansea university ESRI vehicle



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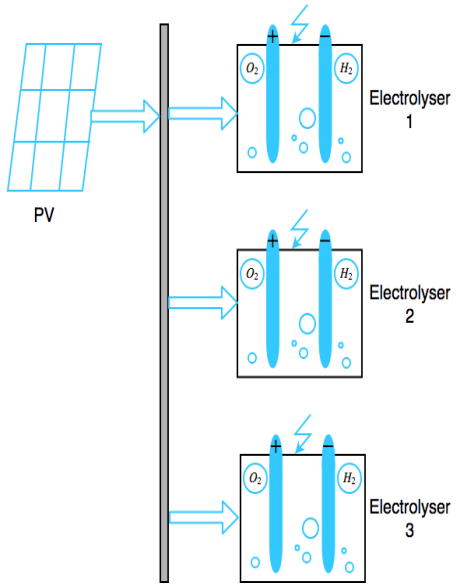
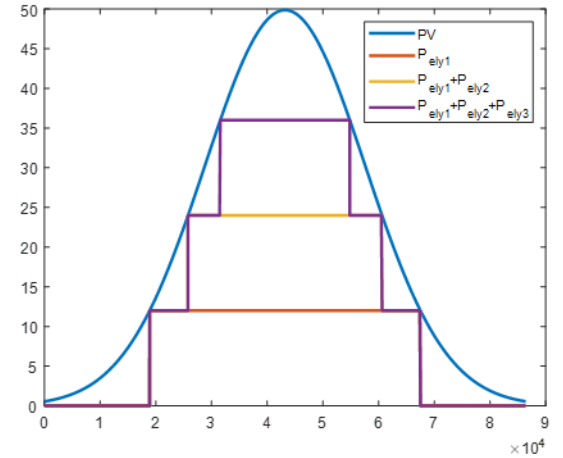
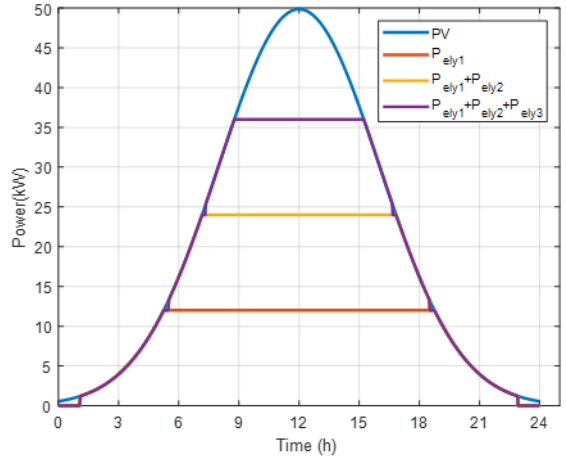
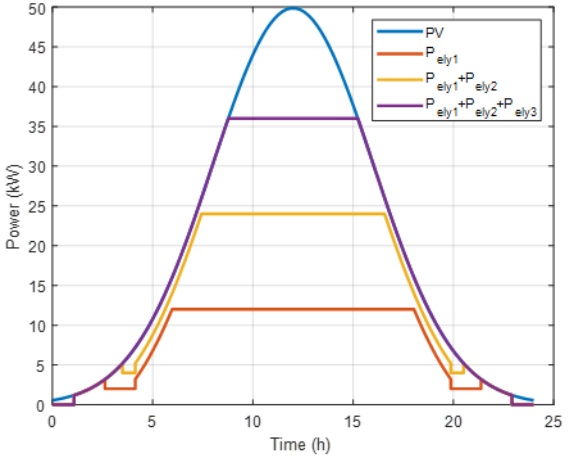
Cascaded Electrolyser operation

- Operation of multiple electrolysers can be more efficient than a single electrolyser
- Modelling included validated PEM electrolyser including thermal performance and minimum turn down ratio
- Different rules for electrolyser switching investigated to maximise efficiency whilst minimizing switch on switch off events
  - On/Off Operation
  - Full Ramping
  - Cascaded
- Work funded by Chinese State Grid Research Project and FLEXIS









Two Stage Operation Strategy for Multiple Electrolysers Coupled with Renewable Power Supply, Fan Zhang, Stephen Carr, Pengcheng Zhao, Bo Zhao, Jon Maddy - paper submitted to IJHE

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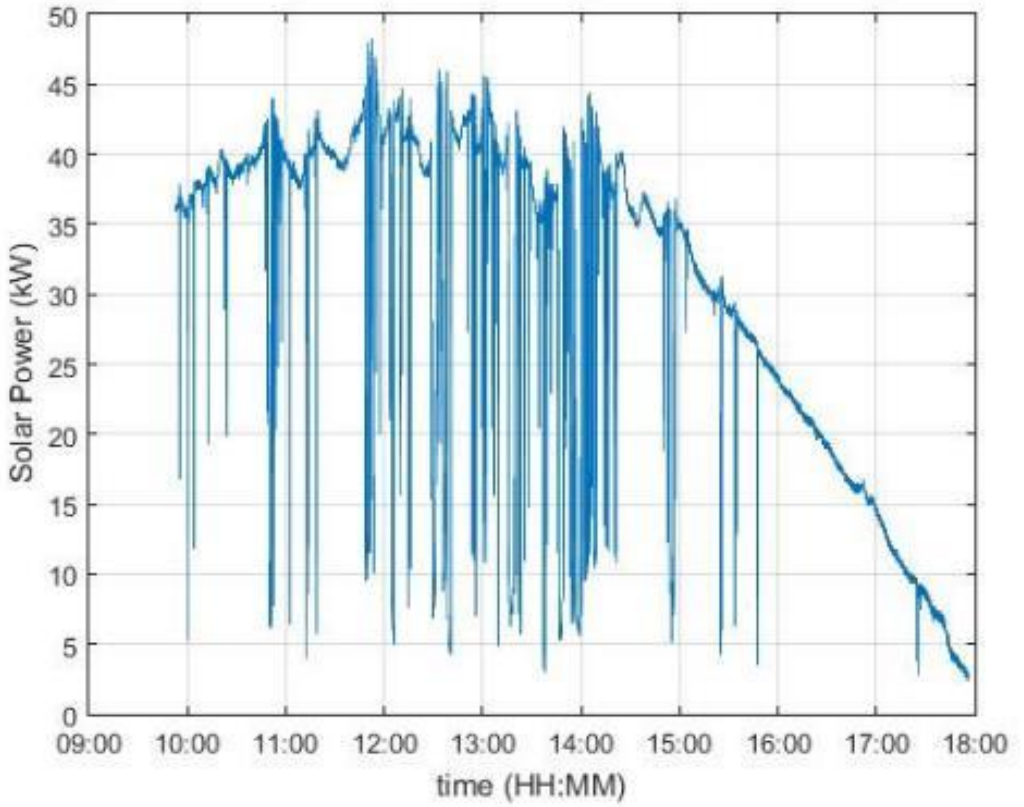
Cascaded Electrolyser Operation

- Under idealised conditions (no cloud) minimal on-off switching required for any strategy
- With cloud cover cascaded switching strategy could
  - Provide similar performance to full ramping
  - Greatly reduce number of switching events
  - Increase overall hydrogen production



On 7th June 2014 – minimum load requirement 1.2kW				
Case No.	Total H2 Production (kg)	Electrolyser 1 switch times	Electrolyser 2 switch times	Electrolyser 3 switch times
On-Off	3.2733	67	104	157
Full ramping	3.8346	0	66	114
Cascade 2kW	3.8565	0	13	17
Cascade 4 kW	3.8600	0	17	37
Cascade 6 kW	3.8578	0	50	66
Cascade 8 kW	3.8530	0	37	76
Cascade 10 kW	3.8460	0	55	104

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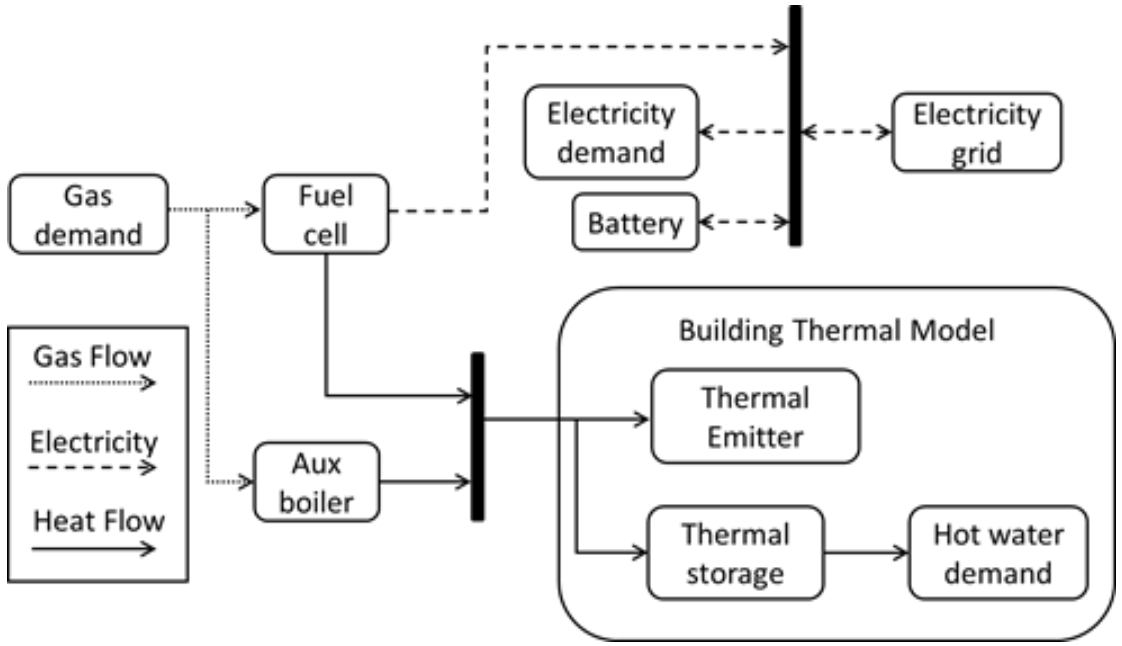
Hydrogen fuel cell for heating

- Use of hydrogen in gas grid allows fuel cell use in buildings
- Fuel cell scheduled to ensure building temperature remains within comfort limits whilst minimising costs
- MILP model optimises over 24 hour horizon with 1 minute resolution



$$OF = \sum_{t=1}^{t=1440} C_e(t) \times P_g(t) + C_g \times \left(Gas_{FC}(t) + Gas_{Br}(t)\right) + C_{susd}|u_{FC}(t) - u_{FC}(t-1)|$$

Optimal Scheduling of a Fuel Cell for Domestic Combined Heat and Power, Stephen Carr, James Reed, Fan Zhang, Jon Maddy, paper in preparation

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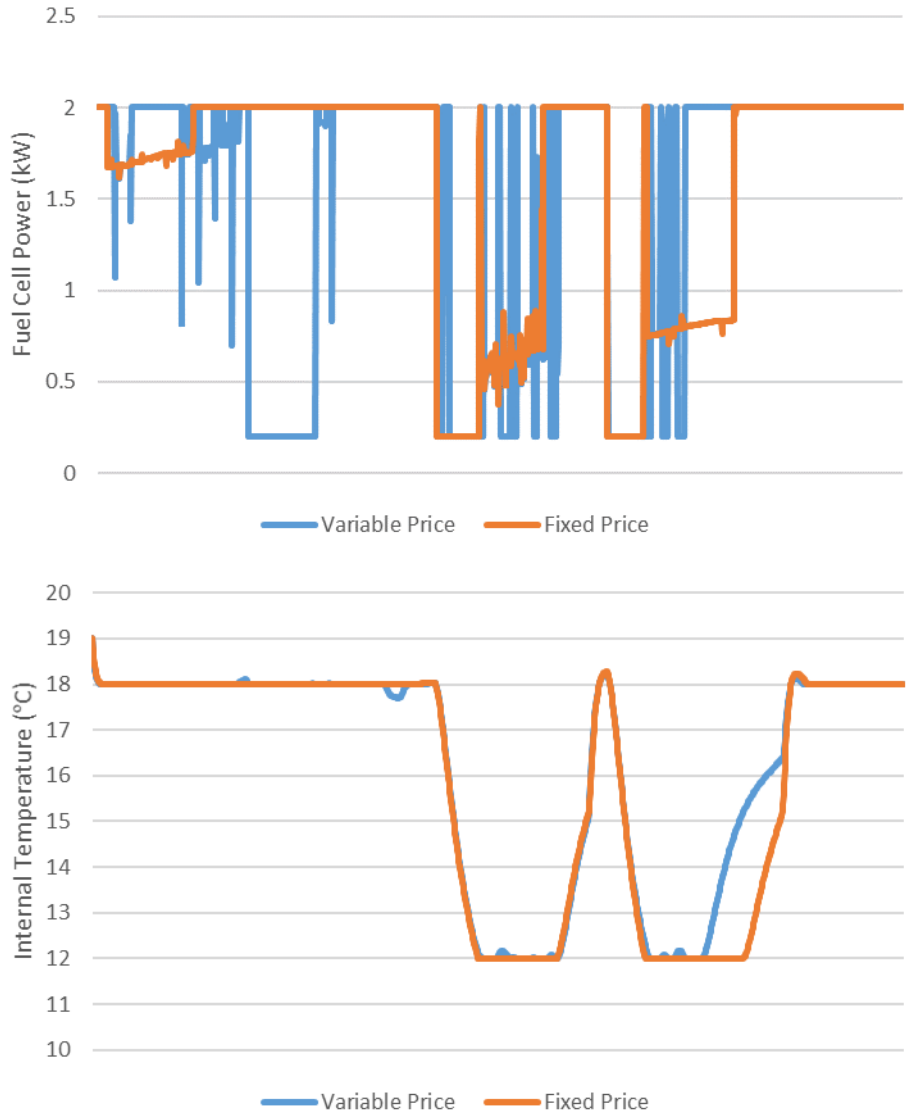
Hydrogen fuel cell for heating

- Variable and fixed electricity price compared to determine potential of fuel cell scheduling
- With variable pricing electrolyser more likely to operate at times of high electricity price
- Can help support electricity grid by generating at times of high demand



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University of South Wales - Current Hydrogen Research

- Currently funded through FLEXIS (Flexible Integrated Energy Systems)
- £24 million project designed to develop energy research capability in Wales
- Led by Cardiff University, Swansea University and University of South Wales
- Hydrogen related work packages
  - WP5: Hydrogen Energy Storage
  - WP6: Sustainable Production and Purification of Hydrogen, Syngas, BioH_2 and Bio CH_4
  - WP7: Hydrogen and Syngas: Efficient Use
  - WP15: Energy Vectoring through Hydrogen

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FLEXIS

DEMONSTRATION AREA