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What is the role for hydrogen in the UK energy system? Assessment of hydrogen storage and injection into the gas grid using whole-system value chain optimisation

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Keywords: Power-to-gas, Hydrogen injection into gas grid, Linepack flexibility, Energy storage, Hydrogen, Electrolysis

With ambitions to achieve a net-zero emissions power generation sector by 2050, the UK will be increasingly reliant on intermittent energy sources such as wind and solar. This will lead to increased system variability, where energy supplies and demands do not always balance in time and space. Energy storage can be used to mitigate variability. Hydrogen, in particular, has great potential for large-scale energy storage.

In this work, we use a comprehensive MILP optimisation model for Great Britain (GB) to assess how much energy storage is optimal and how to implement it, in a system with high penetration of renewable energy.

The model accounts for time scales from hourly through to decadal, to capture all levels of variability, in addition to long-term system evolution. The GB system is represented with 16 spatial zones. The model simultaneously optimises the overall system design (e.g. what energy conversion, transport and storage technologies to install), and operating strategy on an hourly basis.

A range of hydrogen technologies are investigated, including electrolysis, fuel cells, and hydrogen storage in pressure vessels and underground. Hydrogen injection into the gas grid is also modelled, to explore the extent to which the gas grid's linepack flexibility can be exploited.

[1] Van der Geer J, Hanraads JAJ, Lupton RA. J Sci Commun 2010;163:51–9.

[2] Strunk Jr W, White EB. The elements of style. 4th ed. New York: Longman; 2000.

What is the role of hydrogen in the UK energy system?

Assessment of hydrogen storage and injection into the gas grid using whole-system value chain optimisation

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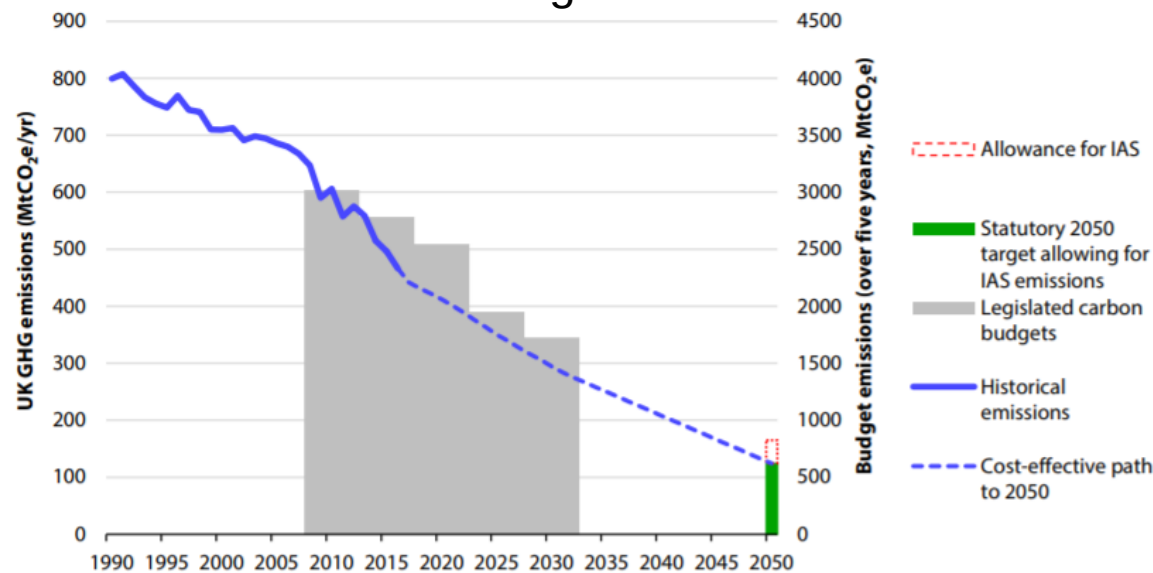
World Hydrogen Technologies Convention, Tokyo

05/06/2019

Context – UK Energy Decarbonisation

- Climate Change Act: 80% reduction from 1990 to 2050
- Net Zero by 2050?

UK Carbon Budgets



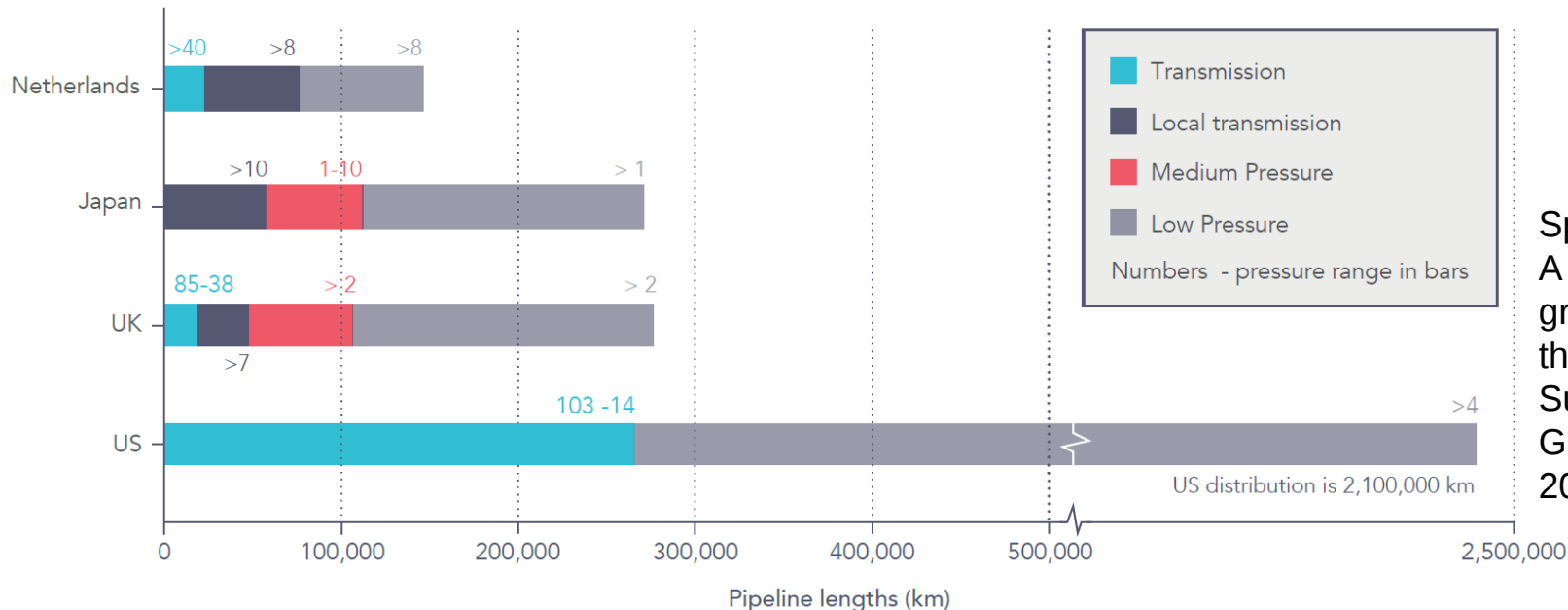
Source: Committee for Climate Change



Context – UK gas

- 86% of homes on the gas grid (560 TWh/yr, 22% of UK GHG)
- ~ 40% of electricity from gas (290 TWh/yr)
- > 50% of gas imported (> 500 TWh/yr)

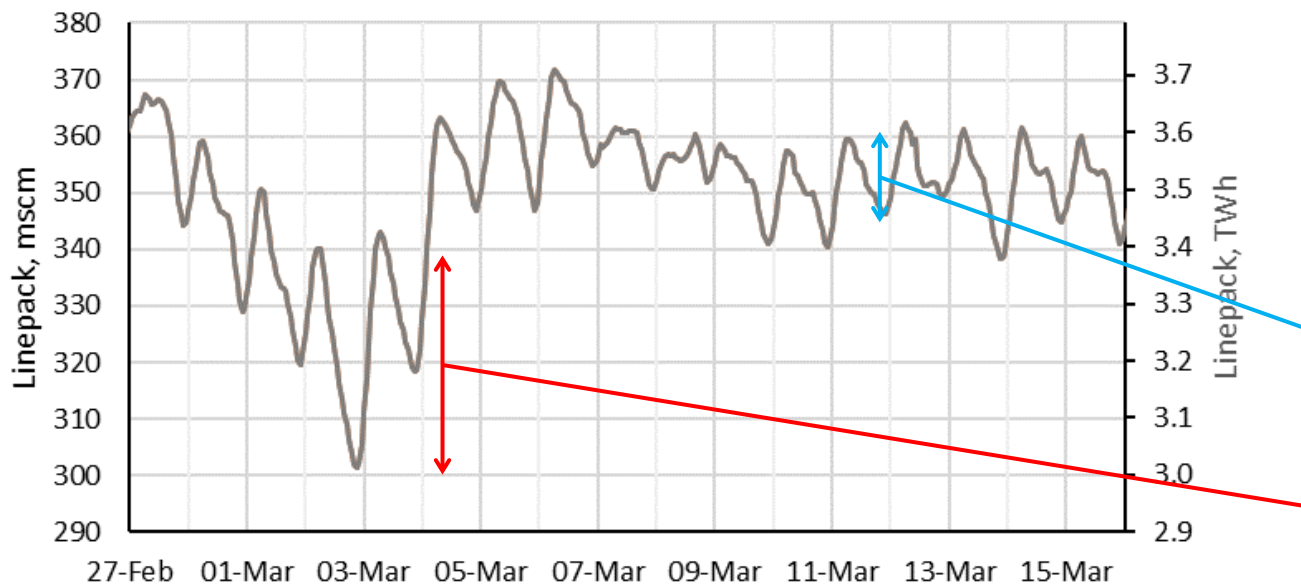
Approx. pipeline lengths of gas networks



Context – gas grid linepack

- Gas grid linepack can be used for flexibility

UK NTS Linepack - Feb/Mar 2018



“Typical” linepack swing of >100 GWh

Possible swing of up to 400 GWh

Hydrogen in gas grids

Distribution grids

- Partial, variable injection
 - Reduces gas CO₂ content
 - Power-to-gas?
- Complete conversion
- Opportunity to deliver low-carbon energy to homes without electricity
- Various practical issues

Transmission grids

- Injection into existing natural gas transmission is questioned
 - Logistics and physical pipeline issues
- Opportunity for exploiting linepack
- Purpose-built hydrogen transmission pipelines?



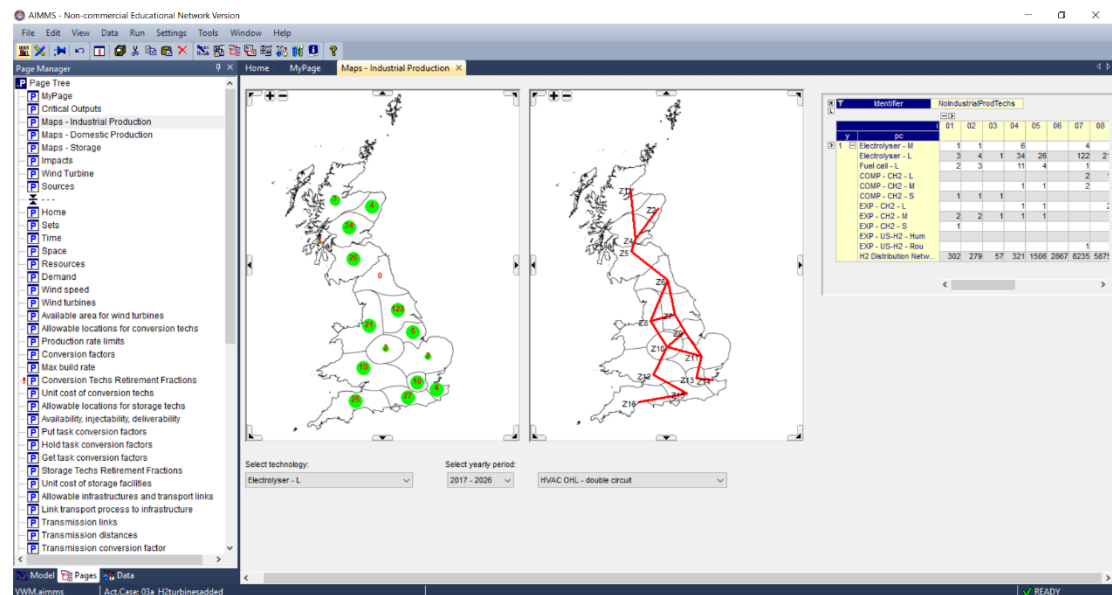
Motivation

- How can we use hydrogen in the UK energy system?
 - What is the future role of the gas grid, particularly with respect to hydrogen
 - Is there any value in partial hydrogen injection
 - What are the implications of complete hydrogen conversion
- How are these conclusions related to hydrogen in other sectors e.g. heating, industry, transport

“Value web” optimisation

- Supply chain optimisation applied to interconnected energy systems
- Design and operation of UK energy system
- Maximise system net present value
- Subject to system constraints (e.g. decarbonisation)
- Technologies for resource conversion, transport and storage
- Spatio-temporal

S. Samsatli, N.J. Samsatli (2018). A multi-objective MILP model for the design and operation of future integrated multi-vector energy networks capturing detailed spatio-temporal dependencies, Applied Energy, 220, 893-920.



Technologies & processes modelled

Electrolysis

Steam methane reforming

Natural gas CCGTs

Natural gas OCGTs

Hydrogen fuel cells

Natural gas CHP

Hydrogen CHP

Nuclear Power

CO₂ capture

CO₂ storage

Natural gas boilers (Domestic/Commercial)

Natural gas heating (Industrial)

Electric heat pumps (Domestic/Commercial)

Electric heating (Industrial)

Hydrogen boilers (Domestic/Commercial)

Hydrogen heating (Industrial)

Natural Gas distribution grid

Hydrogen distribution grid

Electricity distribution grid

Heat networks

Hydrogen injection into natural gas grids (partial)

Conversion of natural gas grids to pure hydrogen

Hydrogen compression & expansion

Underground hydrogen storage

Hydrogen pressure vessel storage

Natural gas compression & expansion

Underground natural gas storage

Natural gas pressure vessel storage

Electricity transmission

CO₂ transmission pipelines

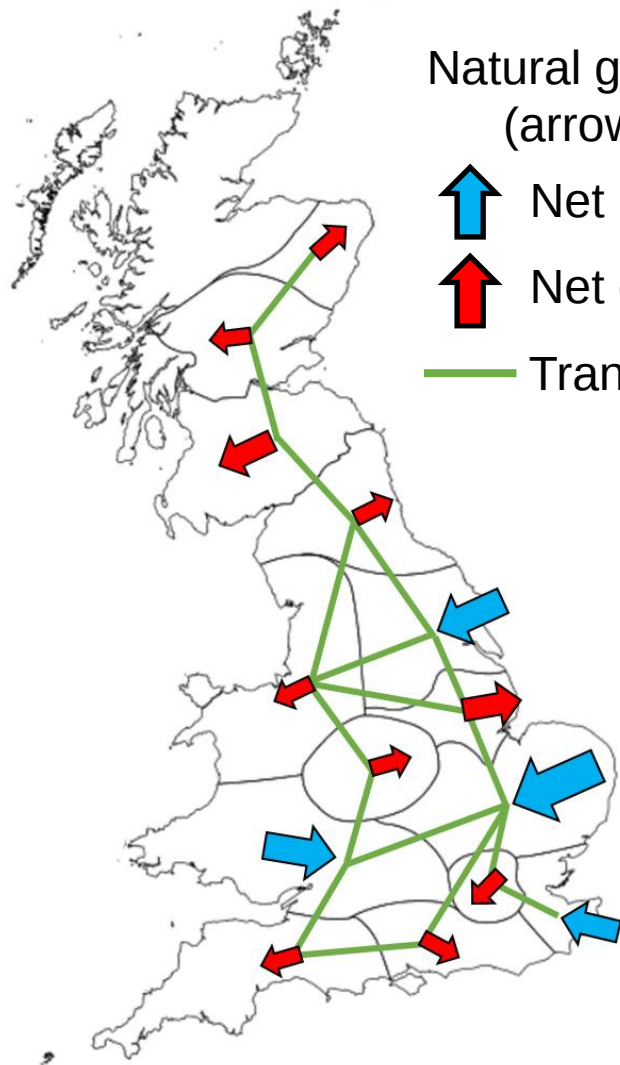
Natural gas transmission pipelines

Hydrogen transmission pipelines

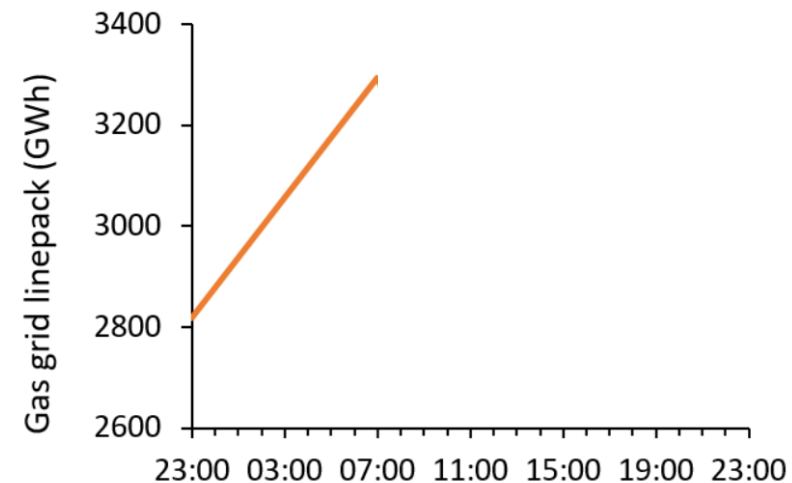
Gas grid modelling

- Transmission linepack
- Distribution hydrogen injection
 - Partial injection
 - Up to 20 vol.% variable injection
 - Costs for grid upgrades & injection equipment (£3500 per MW of grid)
 - Complete conversion
 - Conversion to 100% hydrogen
 - Costs for conversion (£1700 per MW of grid)
 - Irreversible
- Effects on energy delivery rate included

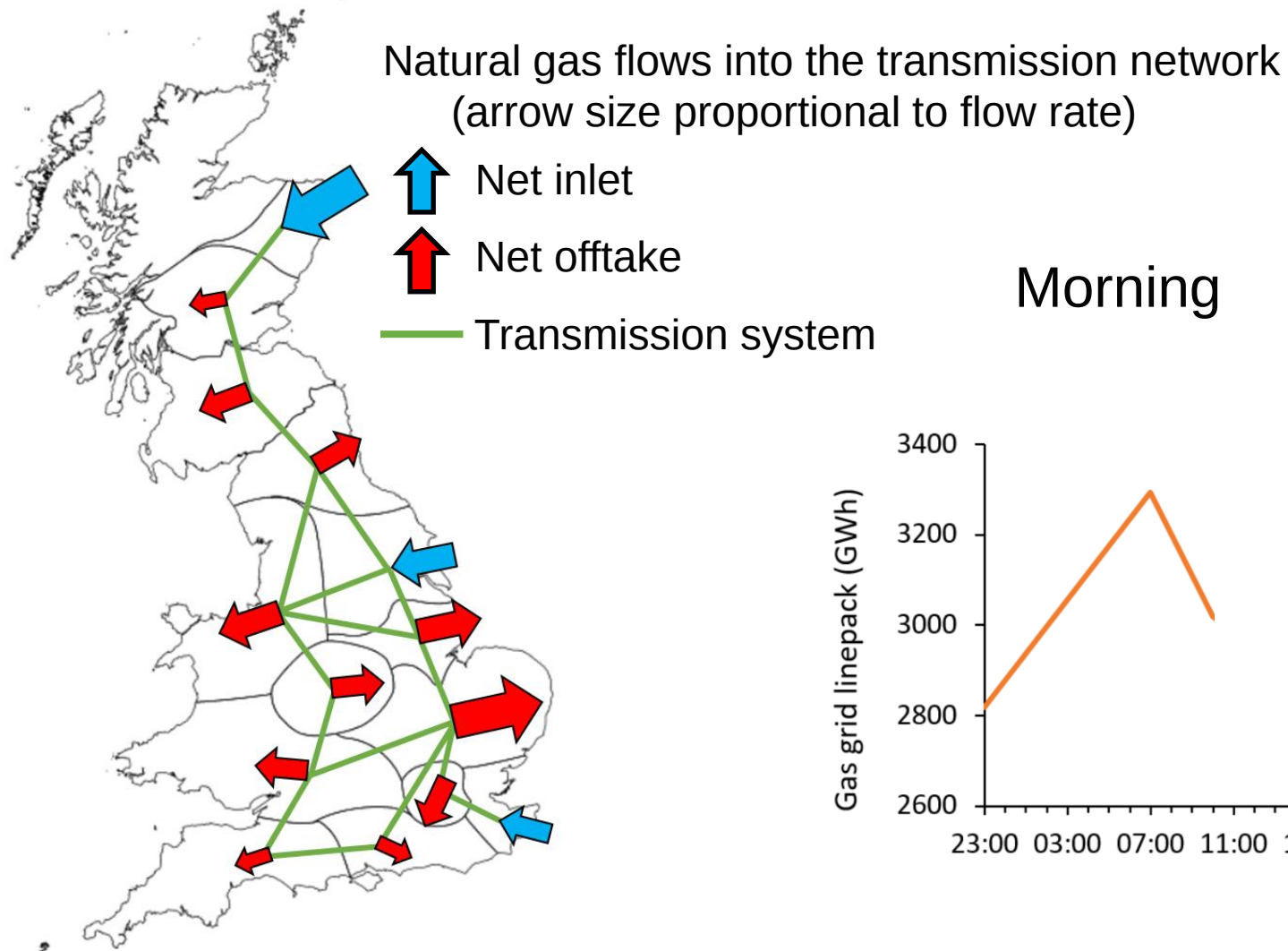
Results – natural gas linepack



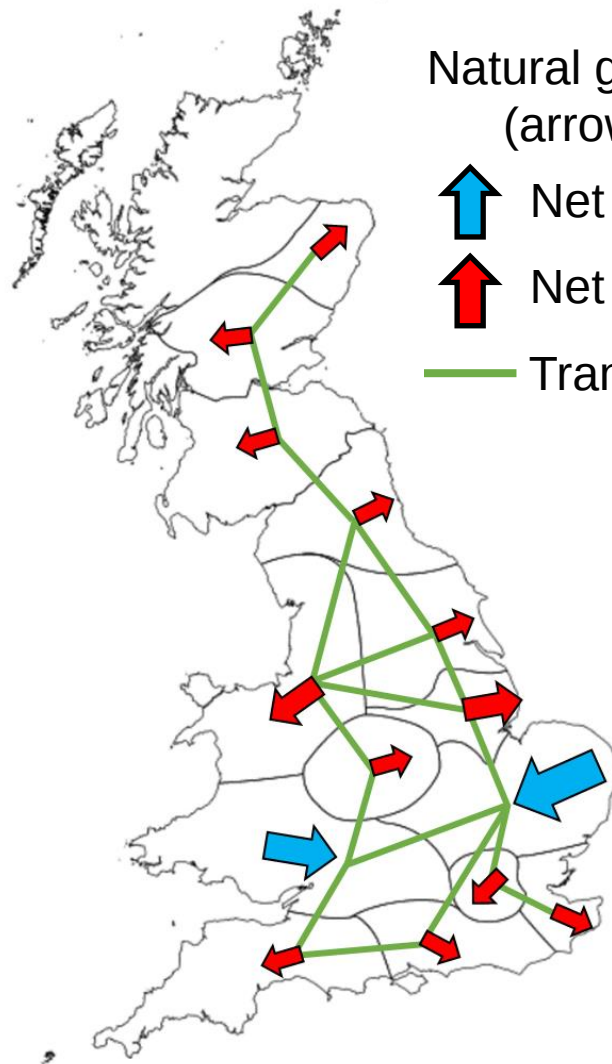
Overnight



Results – natural gas linepack



Results – natural gas linepack



Natural gas flows into the transmission network
(arrow size proportional to flow rate)



Net inlet

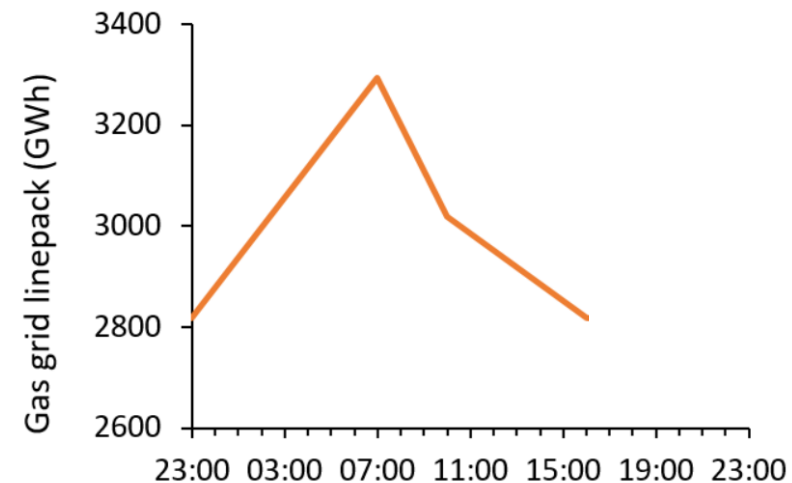


Net offtake

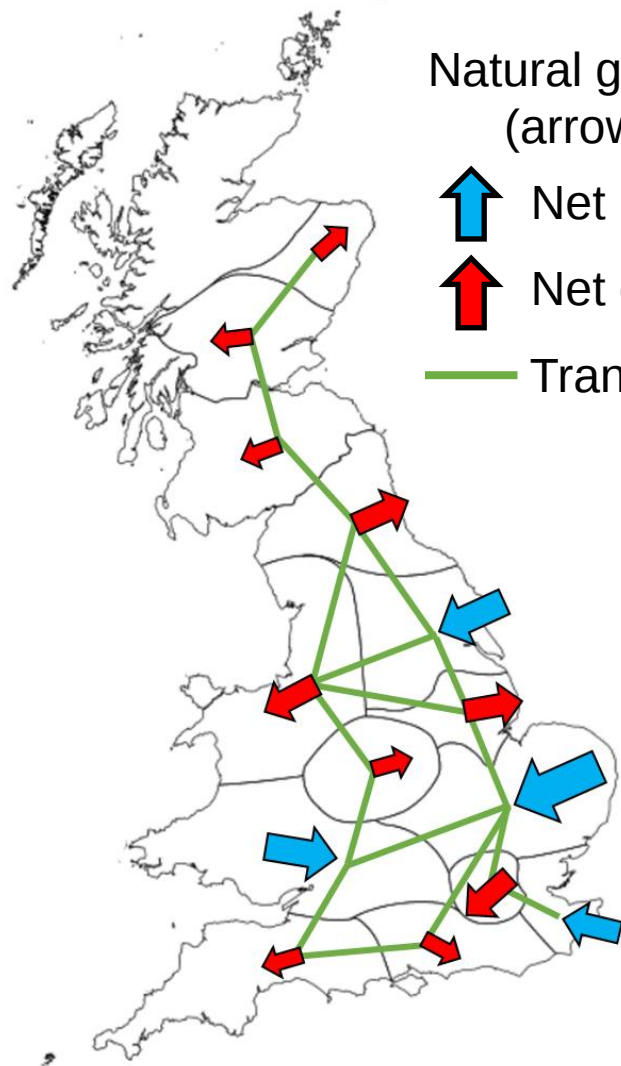


Transmission system

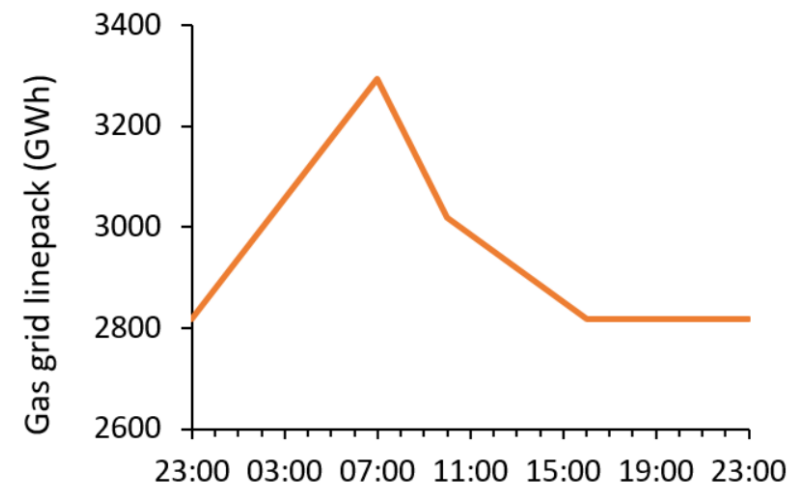
Midday



Results – natural gas linepack

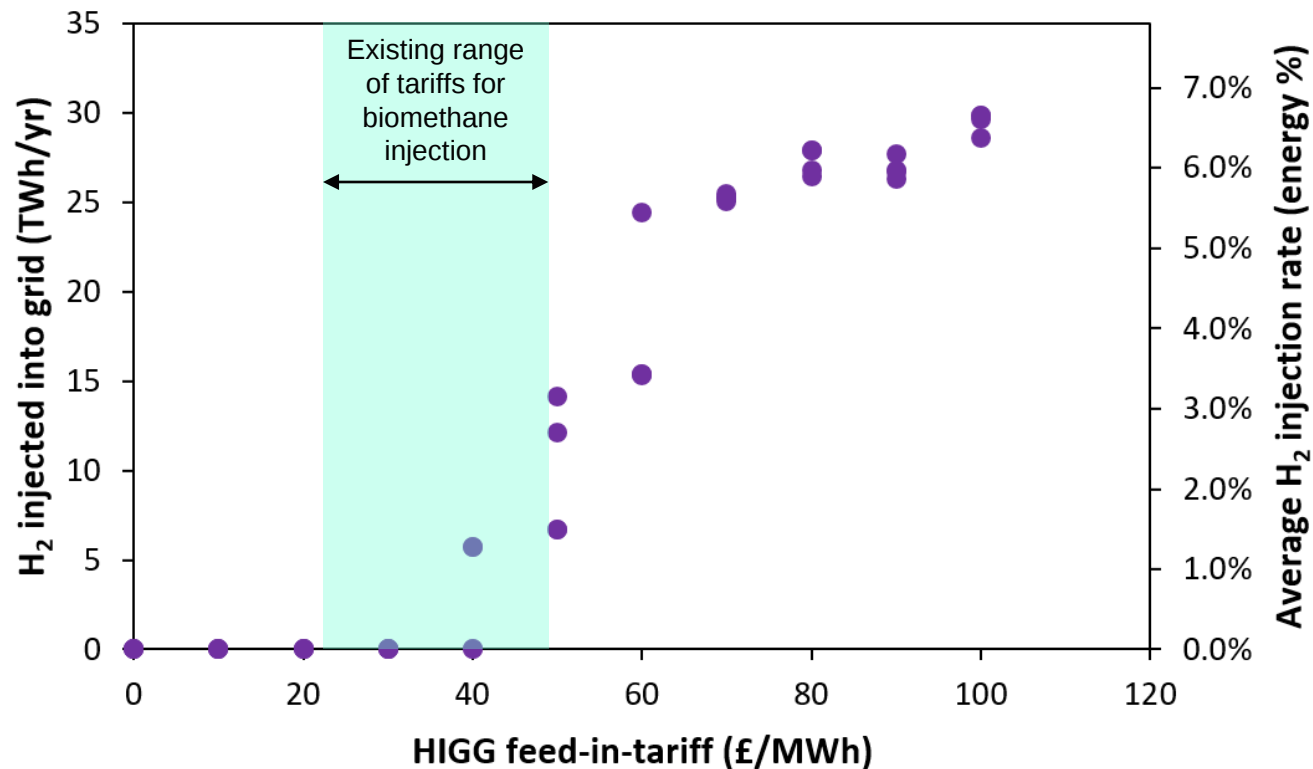


Evening



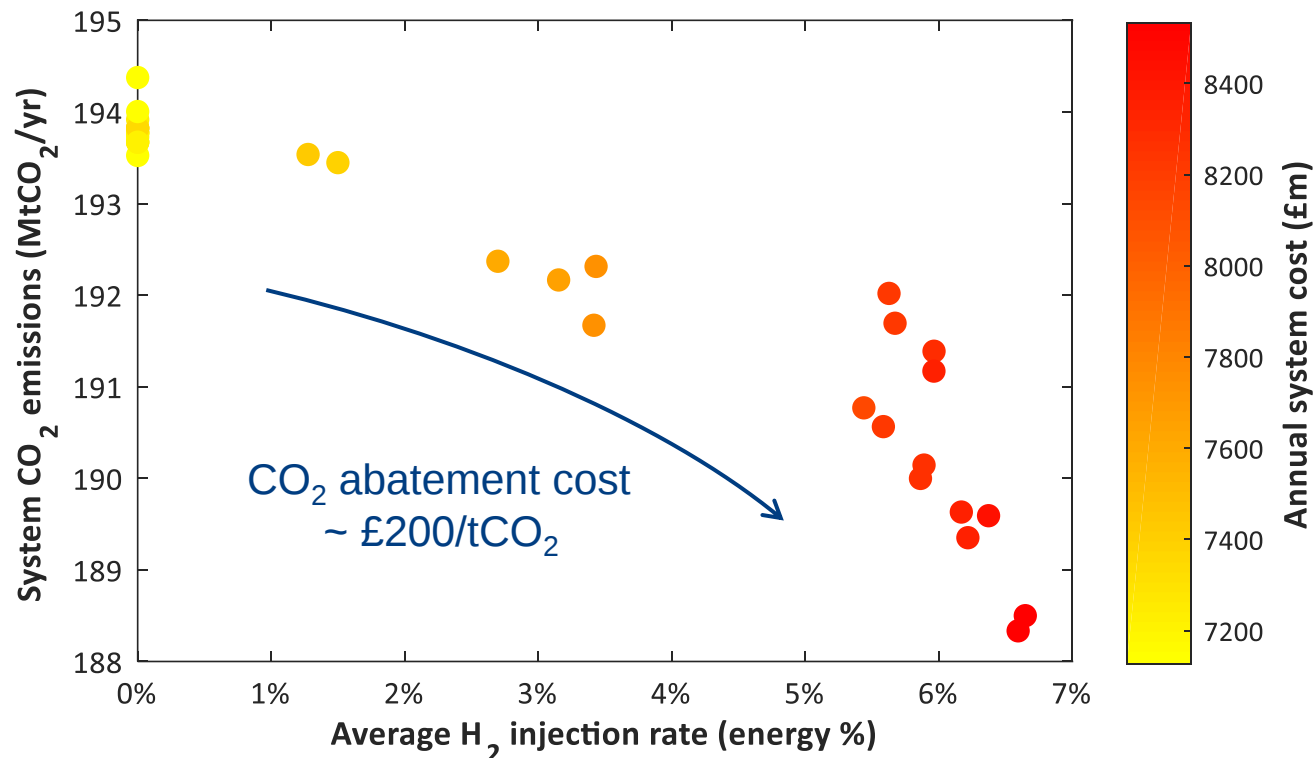
What if we injected hydrogen today?

Hydrogen “feed-in tariff” for up to 20 vol.% injection



What if we injected hydrogen today?

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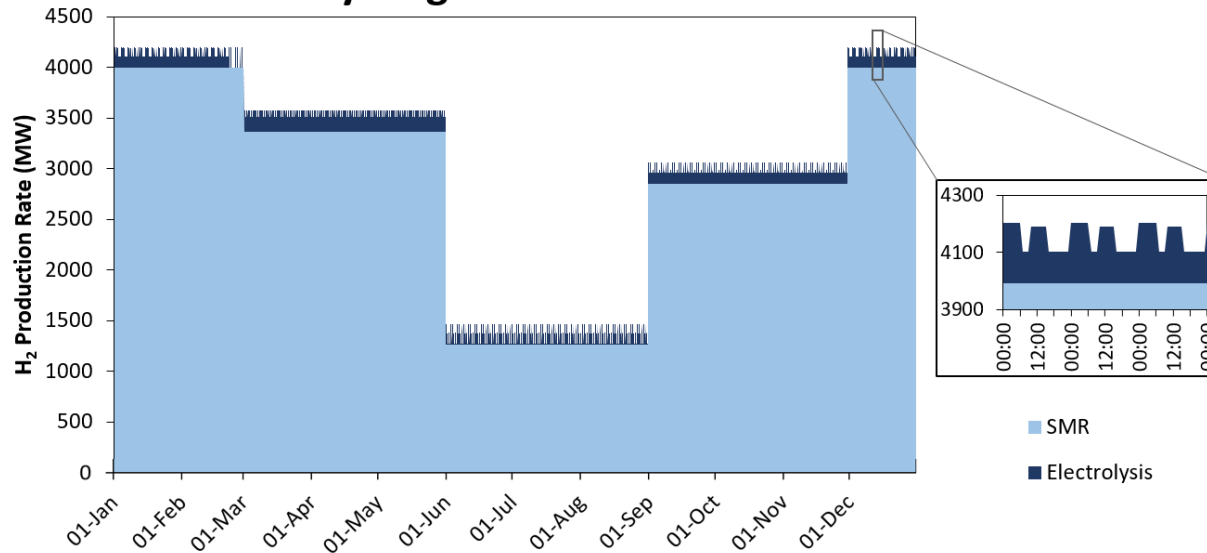


What if we injected hydrogen today?

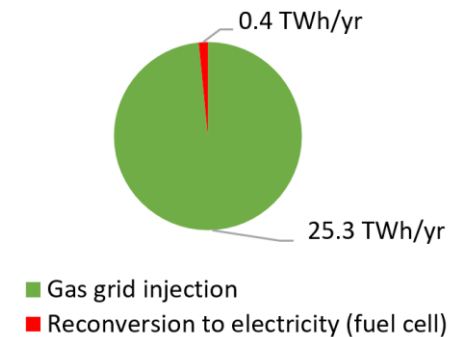
Snapshot of system with up to 20 vol.% injection

- H₂ Feed-in-tariff of £70 /MWh

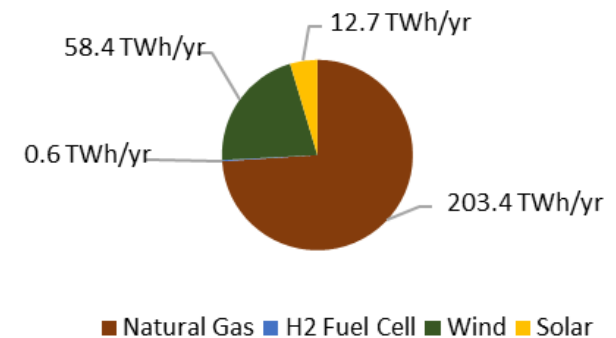
Hydrogen Production

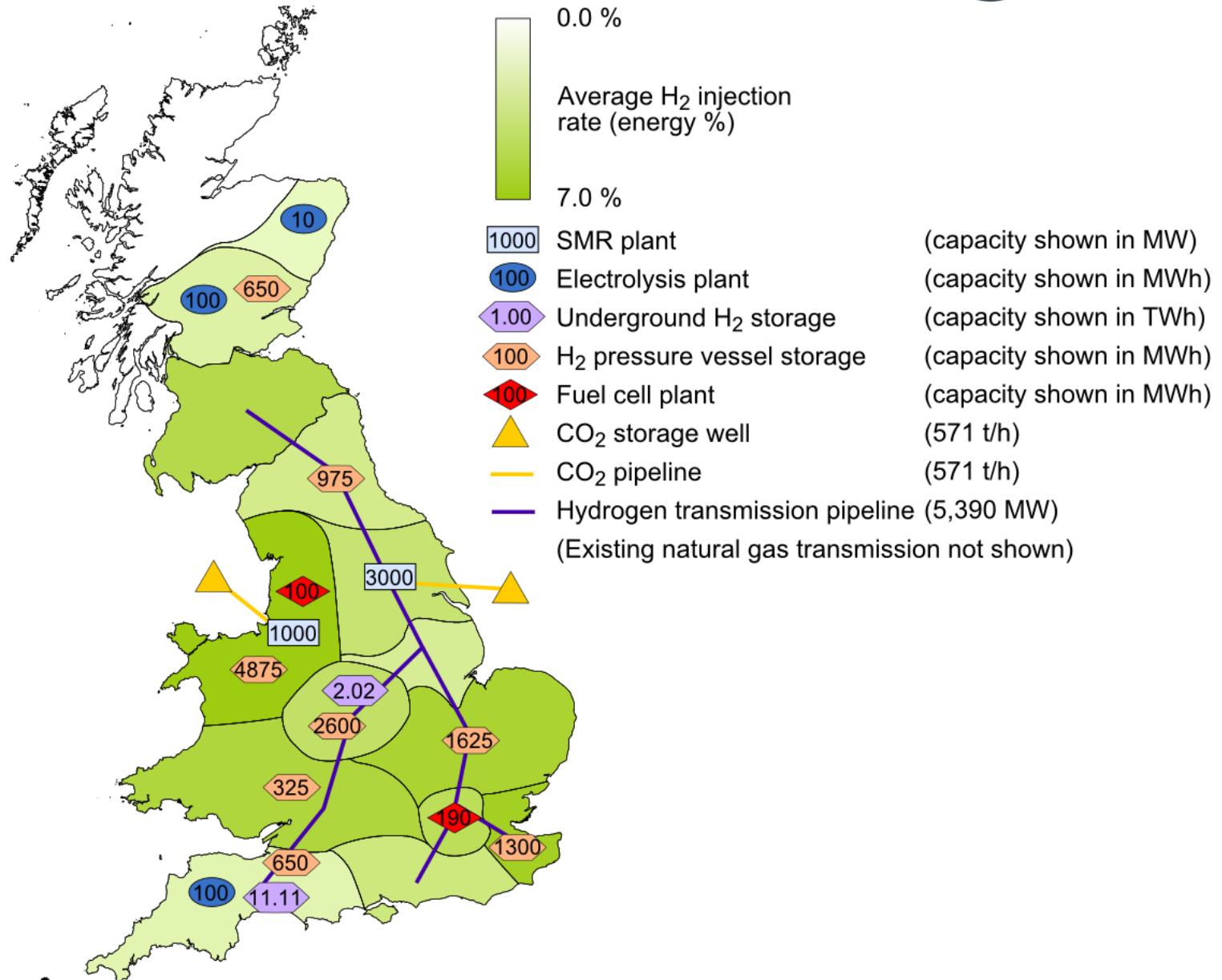


Hydrogen end use



Electricity supply



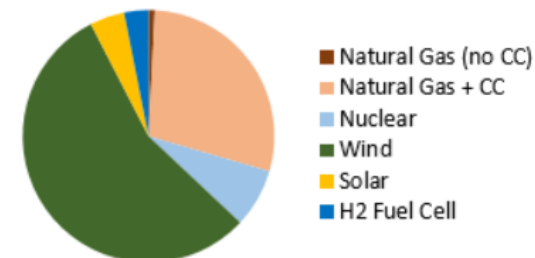


Long run decarbonisation

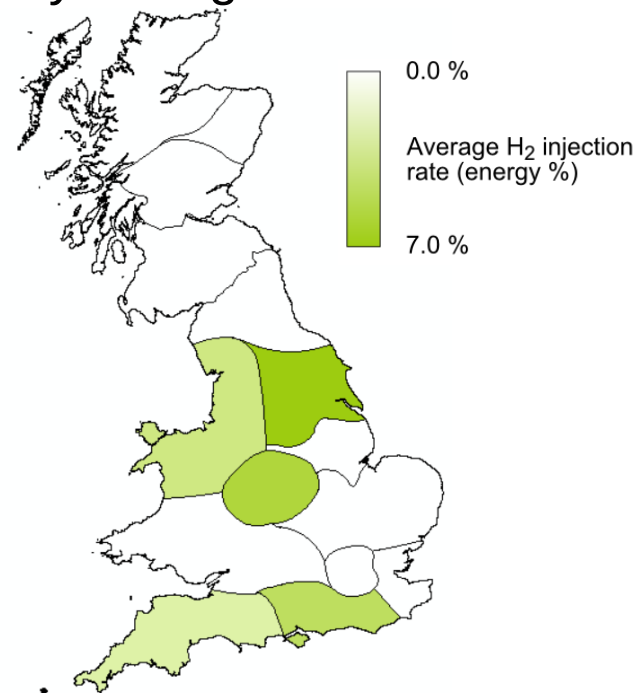
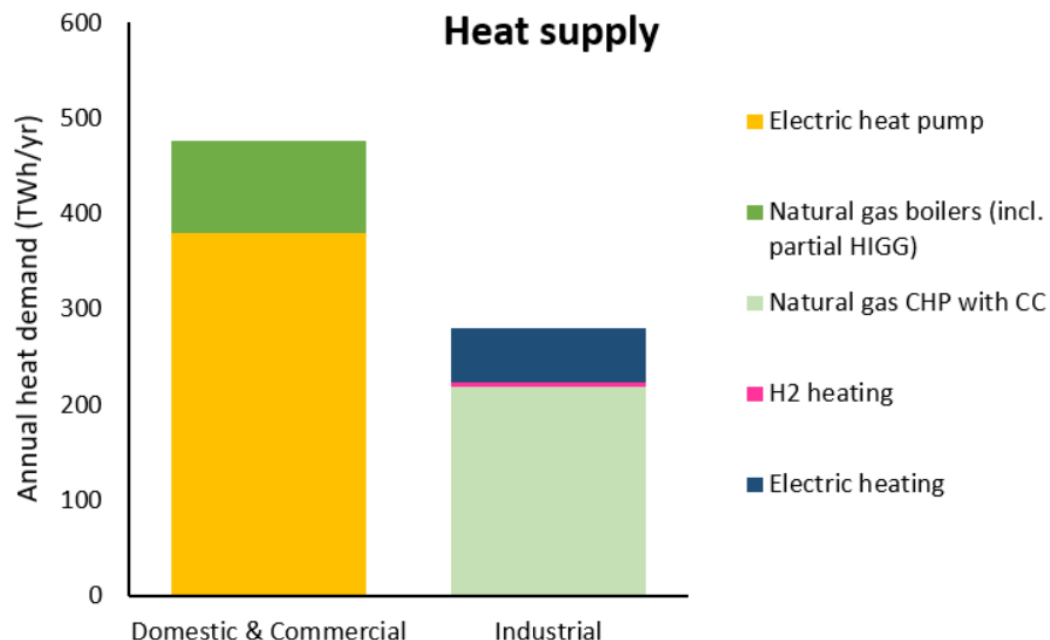
“Optimal” system in 2050

- Limited to 40 MtCO₂/yr (90% reduction from 1990)
- Heat decarbonisation from heat pumps (domestic & commercial); natural gas CHP with CO₂ capture (industrial)
- Small contribution of H₂ for heat and electricity storage

Electricity supply



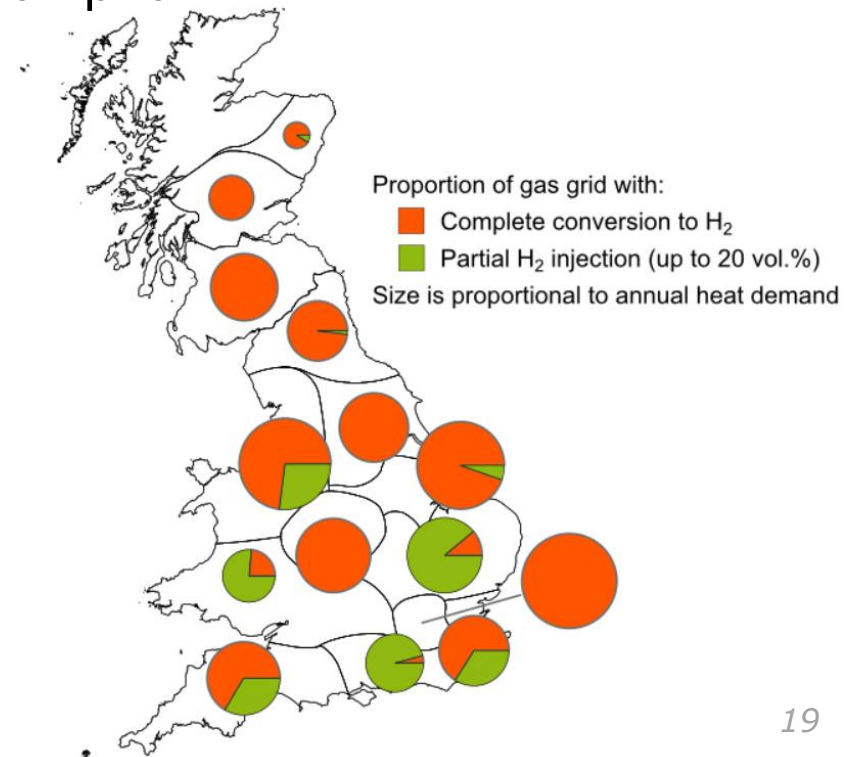
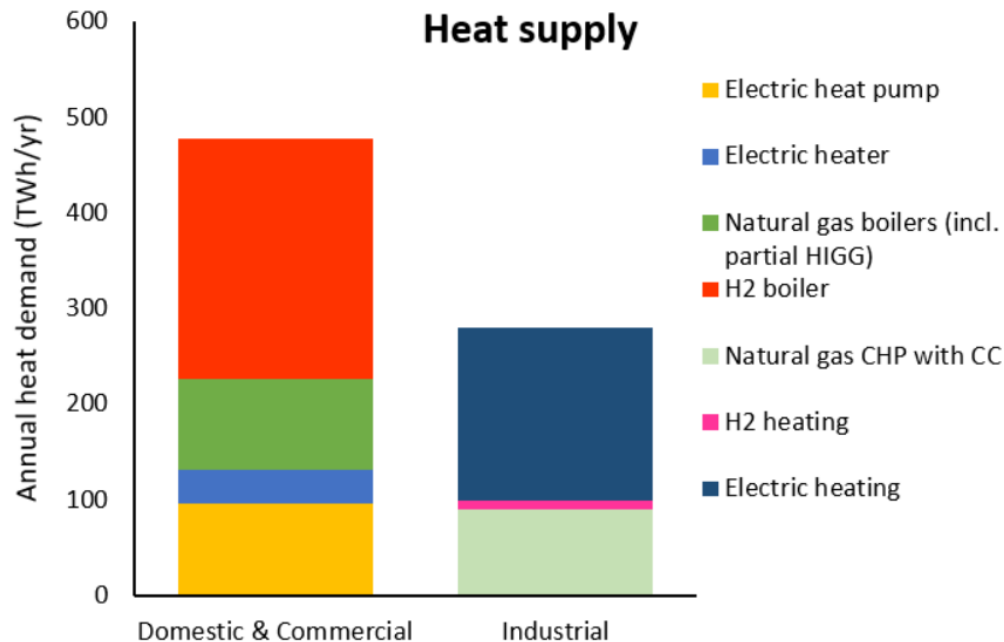
Heat supply



Long run decarbonisation

Heat pumps $\leq 20\%$ of heat (domestic & commercial)

- Limited to 40 MtCO₂/yr (90% reduction from 1990)
- What if heat pumps aren't available? Conversion of gas grids to H₂
- System costs 54% higher than heat pump run



Conclusions

- Energy systems ready for low levels of HIGG now
- Partial HIGG can support wider transition towards H₂
 - H₂ production (both SMR & electrolysis)
 - H₂ storage and conversion to electricity (fuel cells)
 - H₂ in industry
- However decarbonisation potential of partial HIGG is low (costs of ~£200/tCO₂)
- Long term role for H₂ depends on decarbonisation of heat
 - High electricity pathway still sees H₂ in supplementary role
 - Conversion of distribution grids to H₂ can support a H₂ for heat pathway

Thank you for listening

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