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

Chris Quarton[1], Sheila Samsatli[1]

1 Department of Chemical Engineering, University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom

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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

Chris Quarton, c.j.quarton@bath.ac.uk
PhD Student
Department of Chemical Engineering
University of Bath, UK

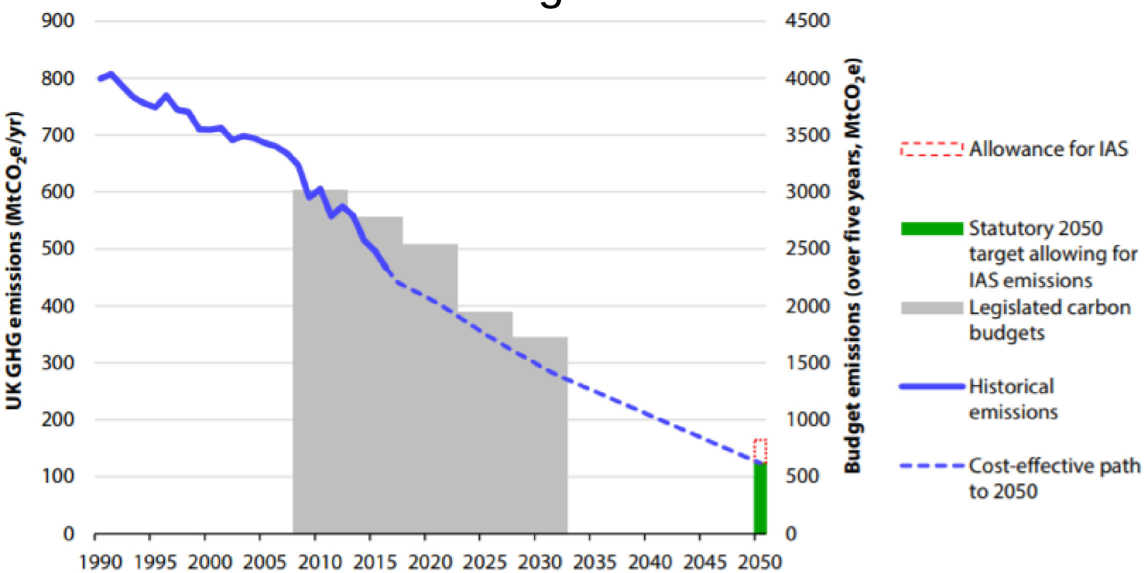
Supervisors: Dr S. Samsatli[1]; Dr I. Llewellyn[2]; Dr J. M. Bermudez[2]
[1] University of Bath; [2] Department for Business, Energy & Industrial Strategy

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

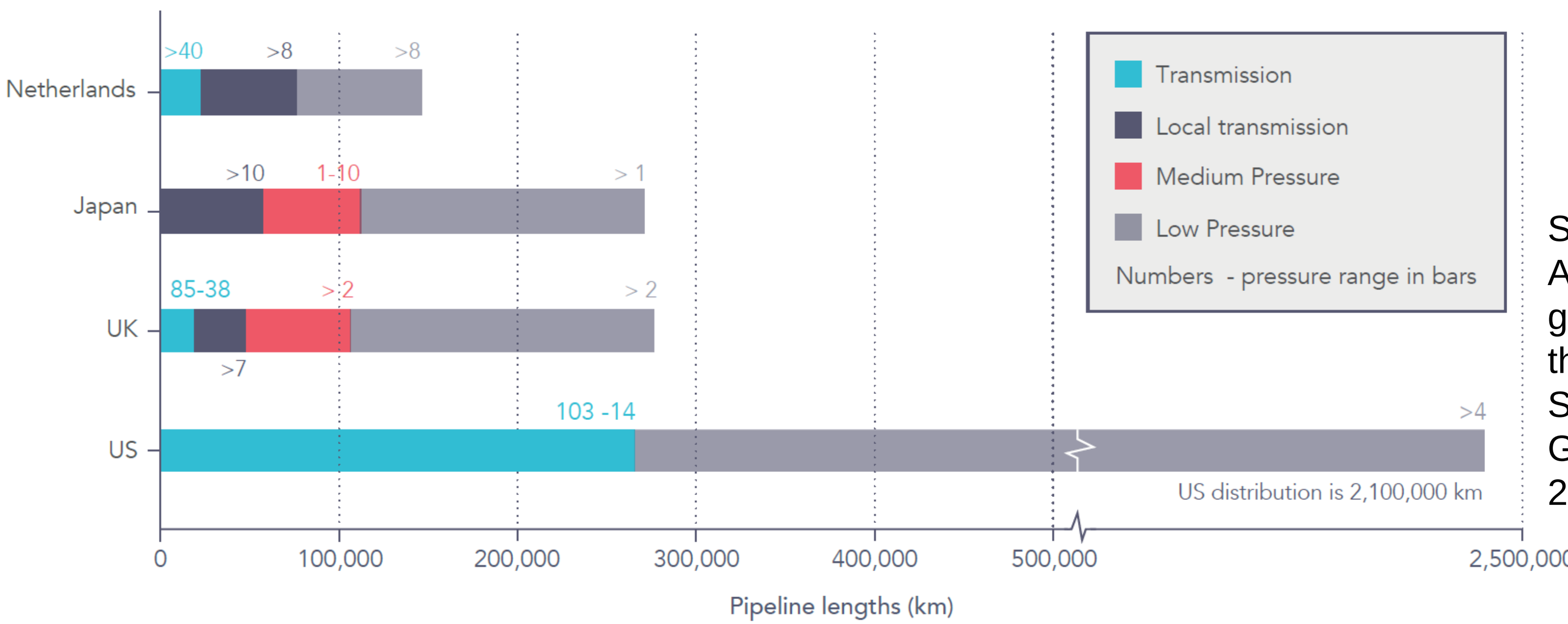


Source: Committee for Climate Change

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)

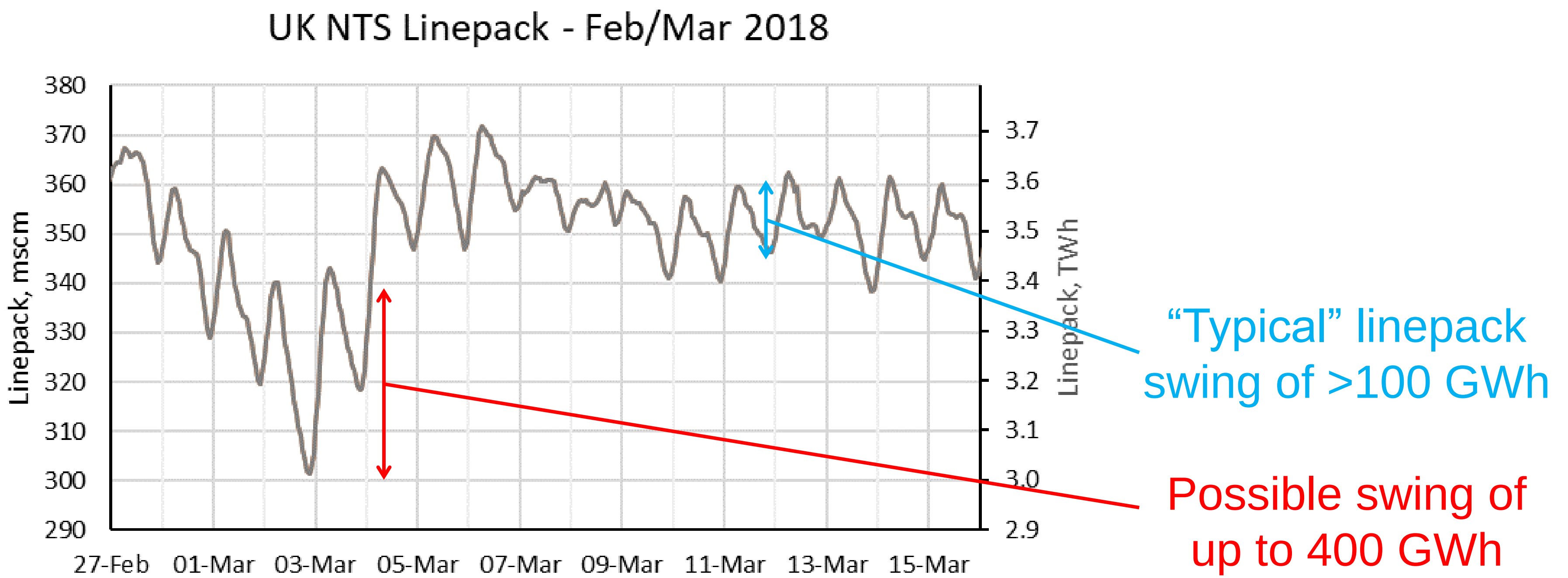
Approx. pipeline lengths of gas networks



Speirs et al. A greener gas grid: what are the options? Sustainable Gas Institute; 2017

Context – gas grid linepack

- Gas grid linepack can be used for flexibility



Hydrogen in gas grids

Distribution grids

- Partial, variable injection
  - Reduces gas CO_2 content
  - Power-to-gas?
- Complete conversion
- Opportunity to deliver low-carbon energy to homes without electricity
- Various practical issues

Transmission grids

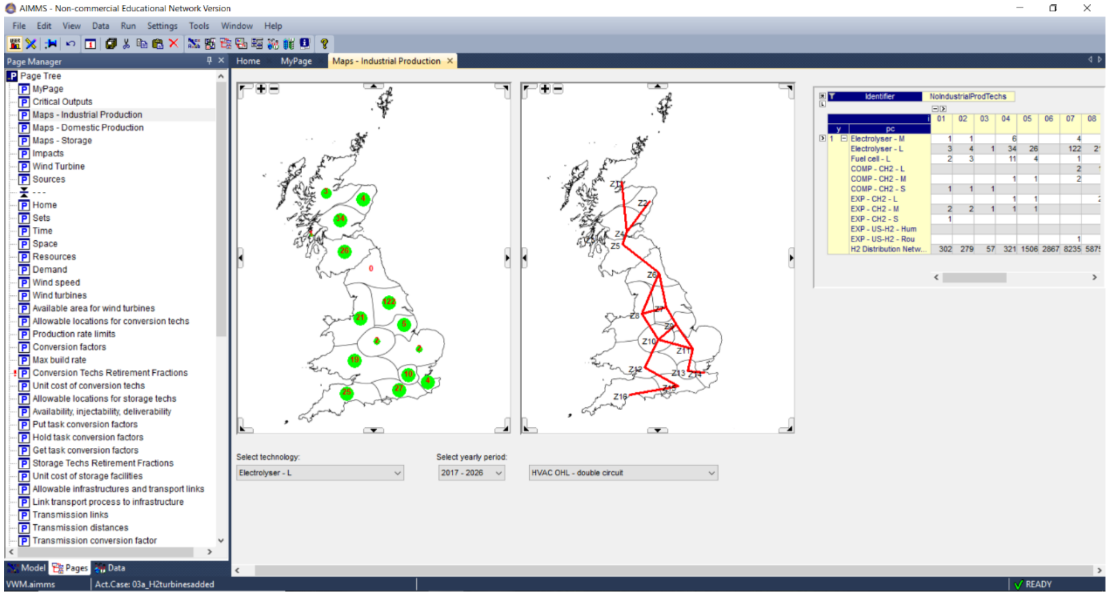
- Injection into existing natural gas transmission is questioned
  - Logistics and physical pipeline issues
- Opportunity for exploiting linepack
- Purpose-built hydrogen transmission pipelines?

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

CO_2 capture
CO_2 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

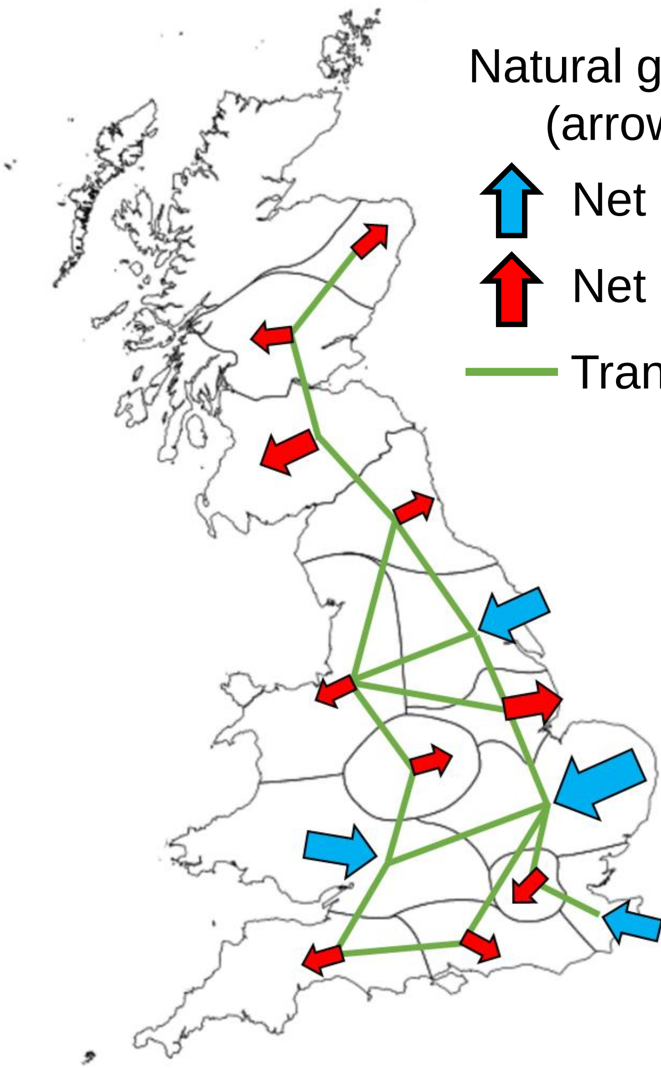
Electricity transmission
CO_2 transmission pipelines
Natural gas transmission pipelines
Hydrogen transmission pipelines

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



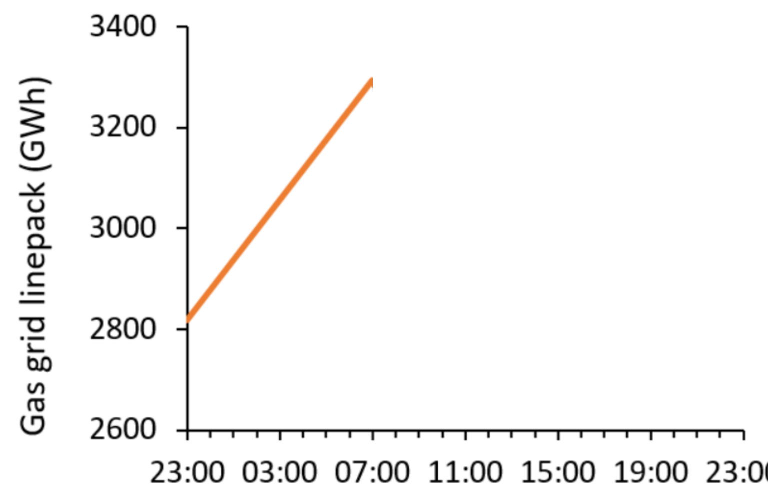
Natural gas flows into the transmission network
(arrow size proportional to flow rate)

Net inlet

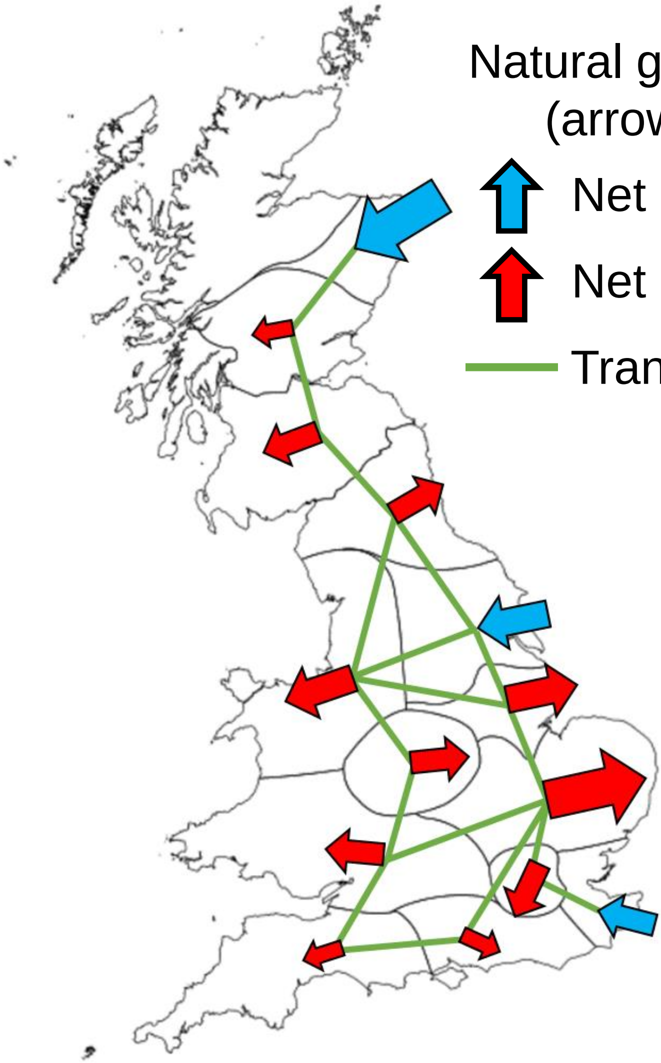
Net offtake

Transmission system

Overnight



Results – natural gas linepack



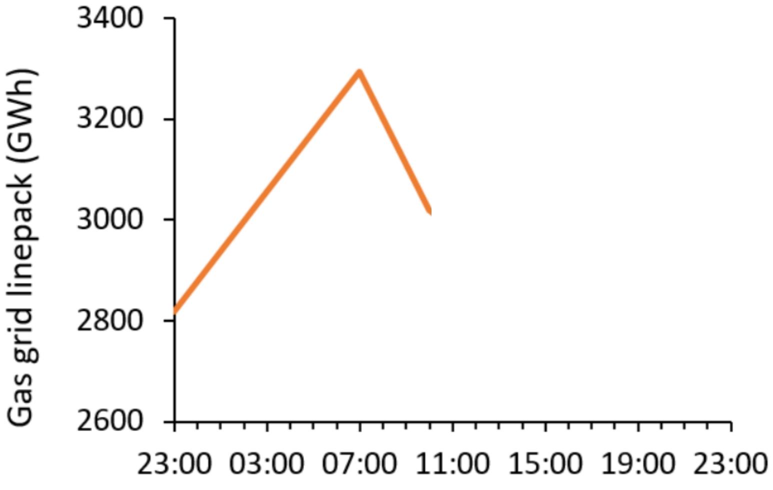
Natural gas flows into the transmission network (arrow size proportional to flow rate)

Net inlet

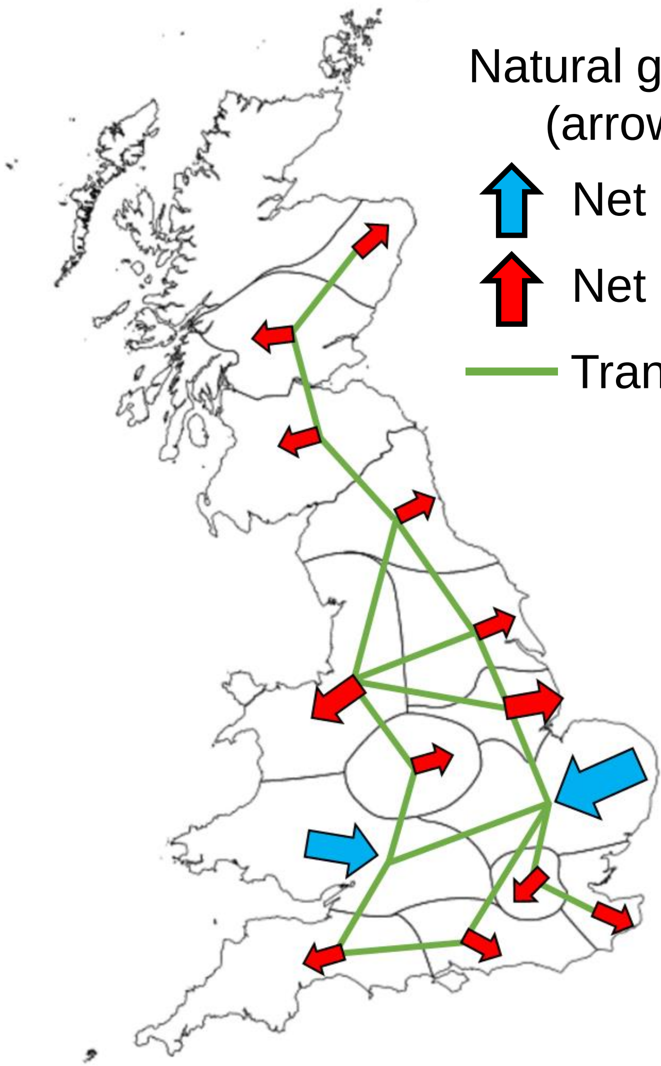
Net offtake

Transmission system

Morning



Results – natural gas linepack



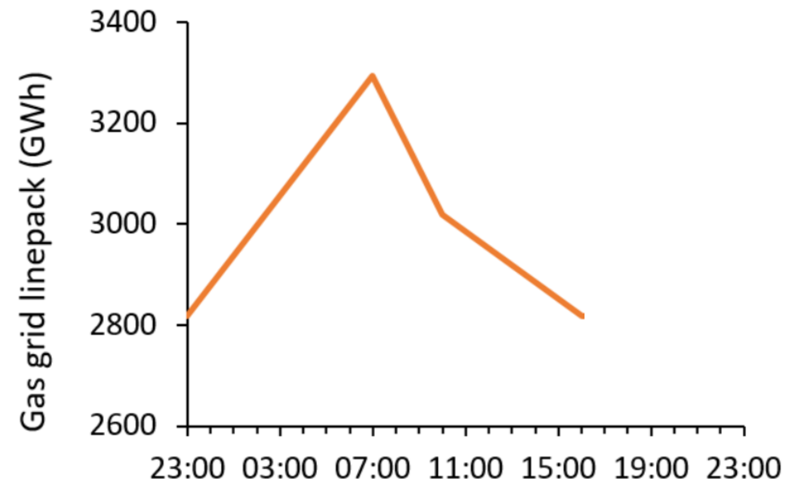
Natural gas flows into the transmission network (arrow size proportional to flow rate)

Net inlet

Net offtake

Transmission system

Midday



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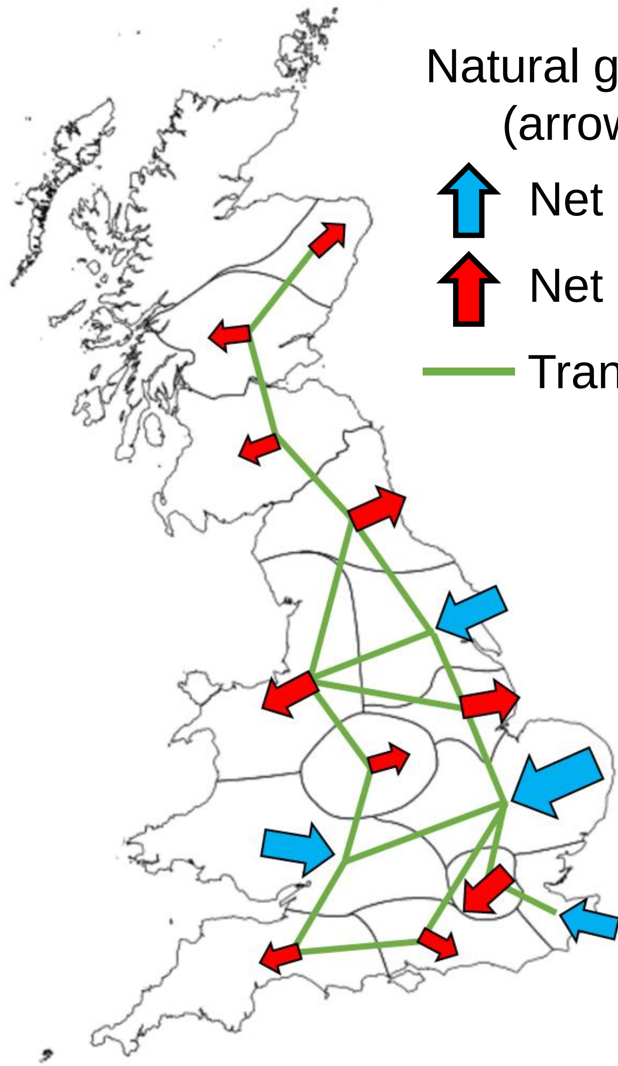
Results – natural gas linepack



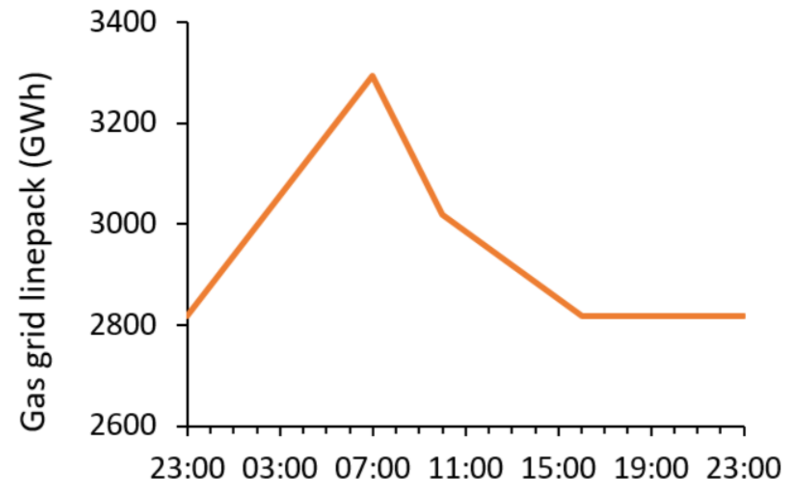
Natural gas flows into the transmission network (arrow size proportional to flow rate)

Net inlet

Net offtake

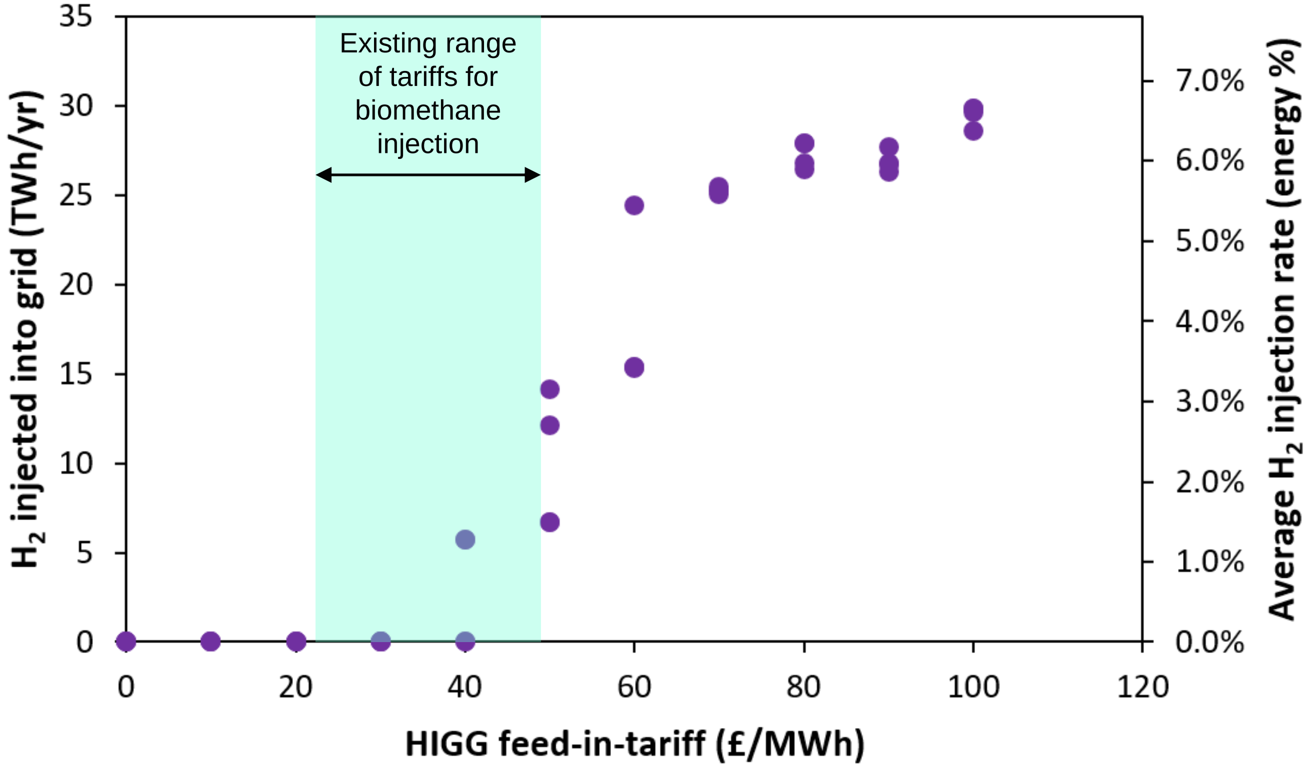
Transmission system

Evening



What if we injected hydrogen today?

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



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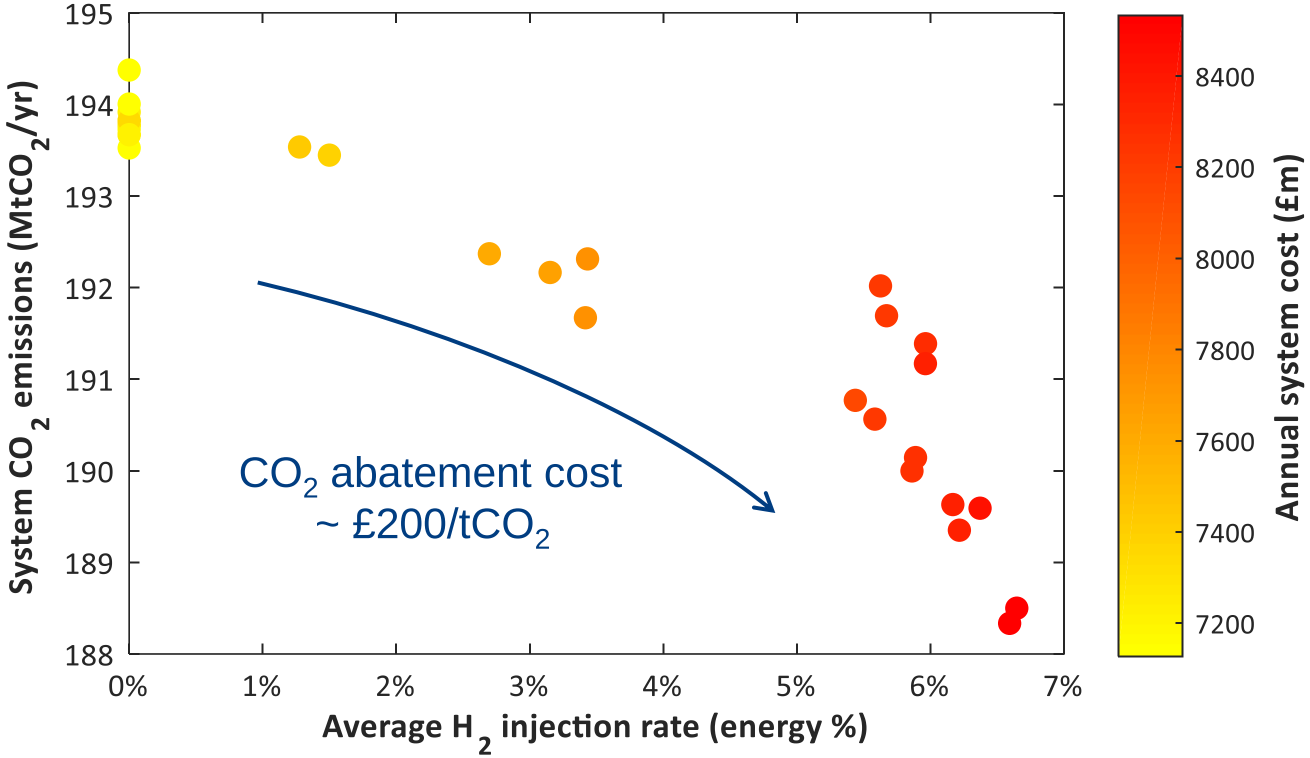
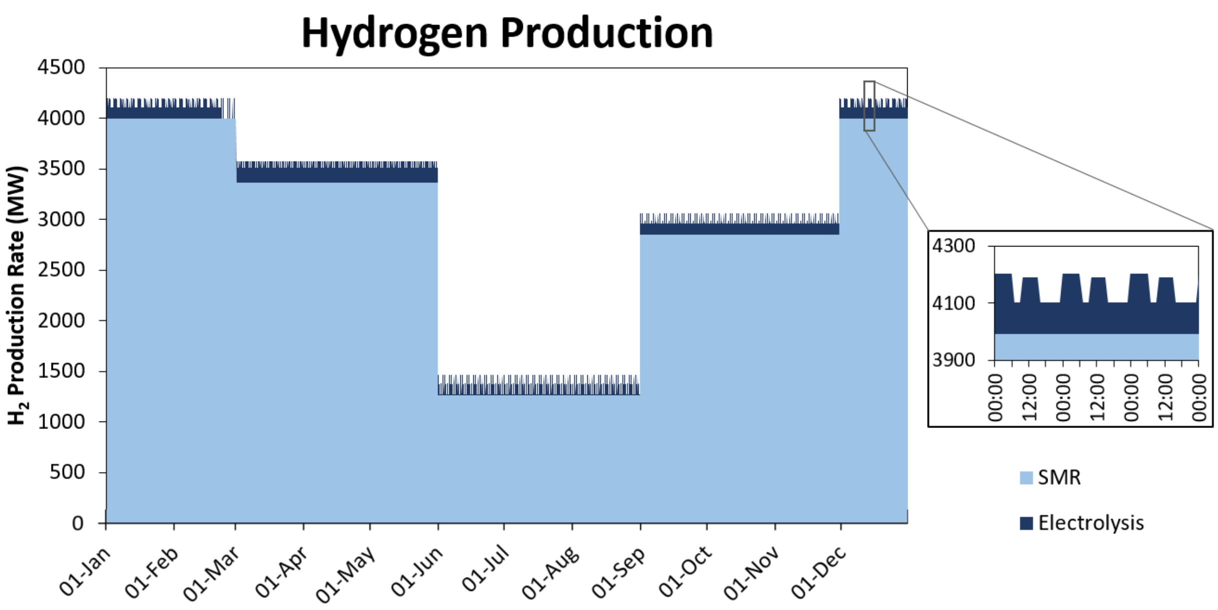
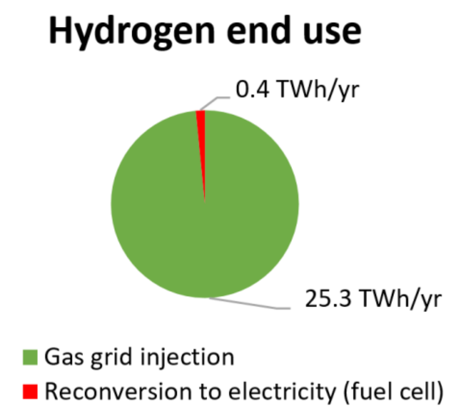


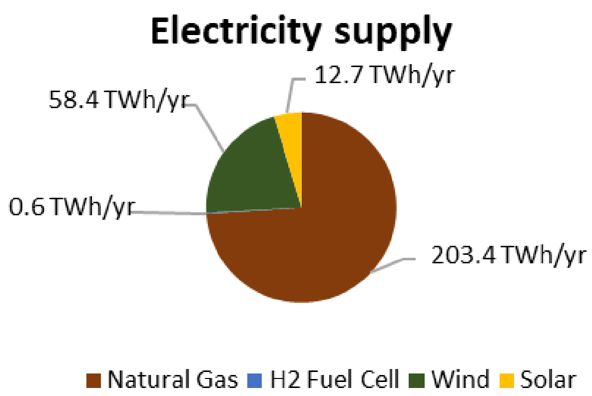
What if we injected hydrogen today?

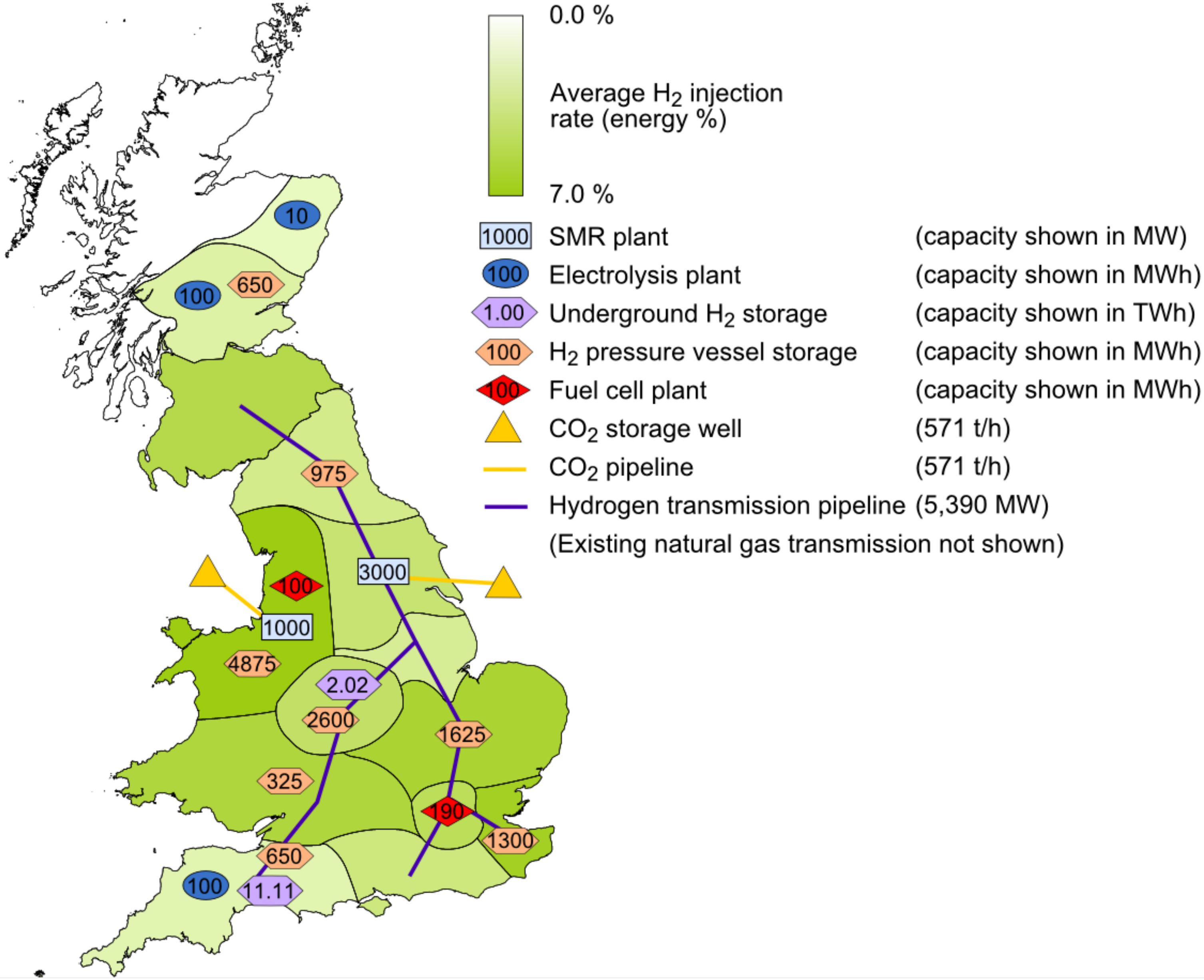
Snapshot of system with up to 20 vol.% injection

- H_2 Feed-in-tariff of £70 /MWh



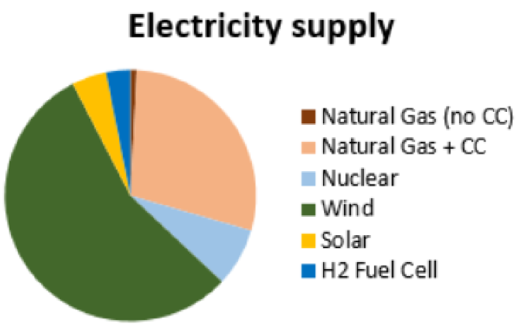




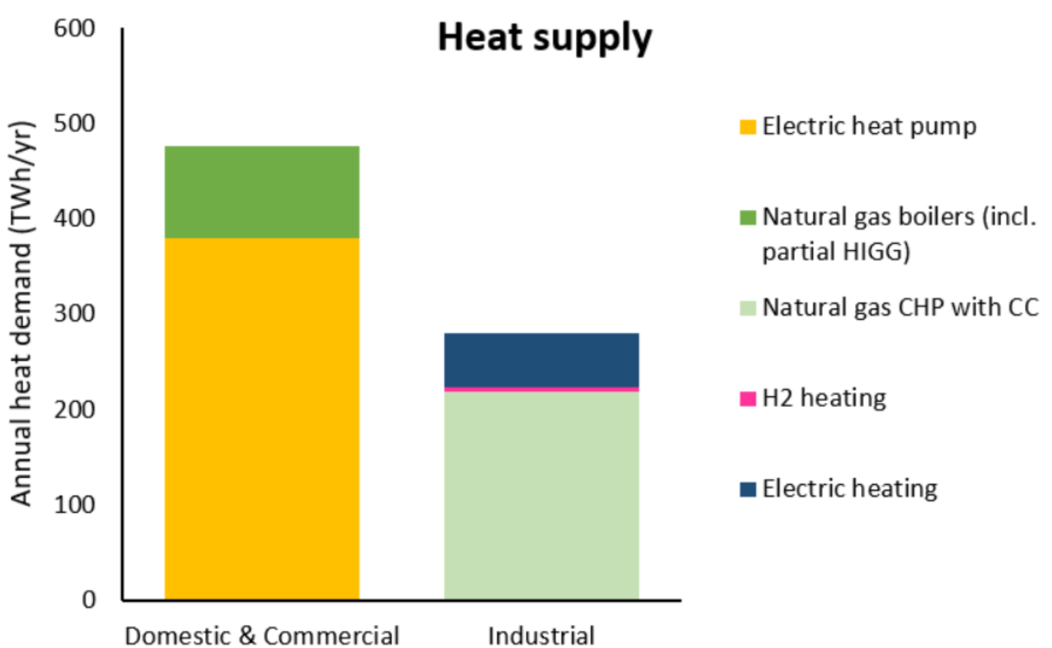

0.0 %
Average H2 injection rate (energy %)
7.0 %
1000 SMR plant (capacity shown in MW)
100 Electrolysis plant (capacity shown in MWh)
1.00 Underground H2 storage (capacity shown in TWh)
100 H2 pressure vessel storage (capacity shown in MWh)
100 Fuel cell plant (capacity shown in MWh)
CO2 storage well (571 t/h)
CO2 pipeline (571 t/h)
Hydrogen transmission pipeline (5,390 MW)
(Existing natural gas transmission not shown)
10
100
650
975
3000
100
1000
4875
2.02
2600
1625
325
190
1300
650
100
11.11

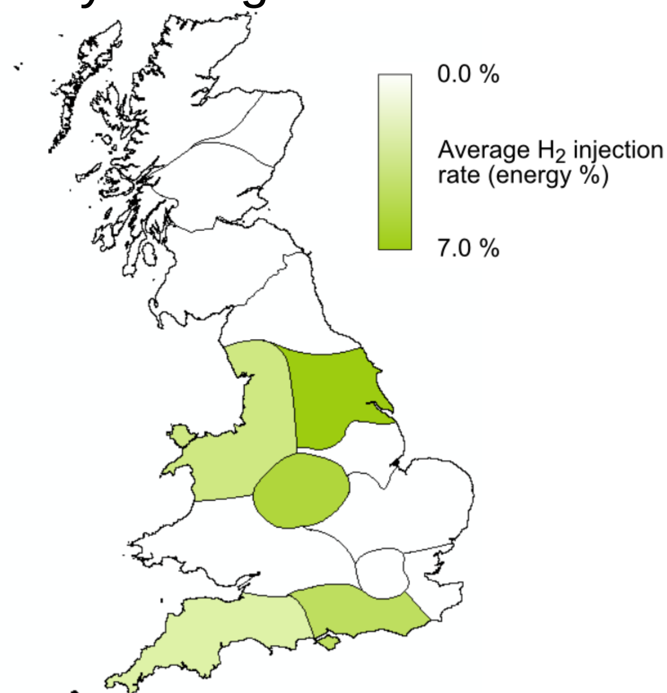
Long run decarbonisation

“Optimal” system in 2050



- Limited to 40 $MtCO_2$/yr (90% reduction from 1990)
- Heat decarbonisation from heat pumps (domestic & commercial); natural gas CHP with CO_2 capture (industrial)
- Small contribution of H_2 for heat and electricity storage

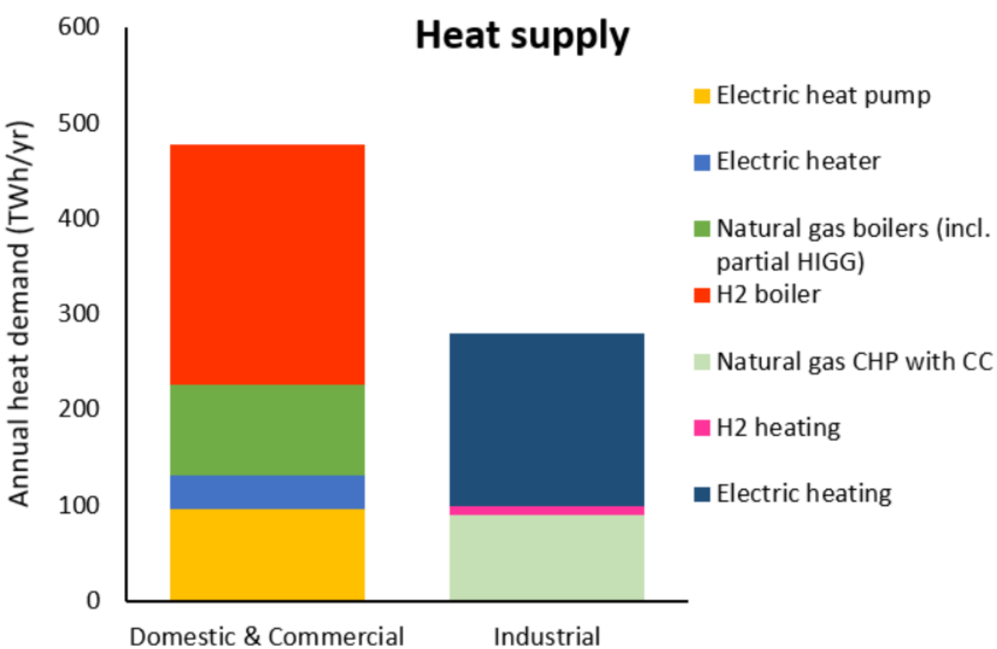


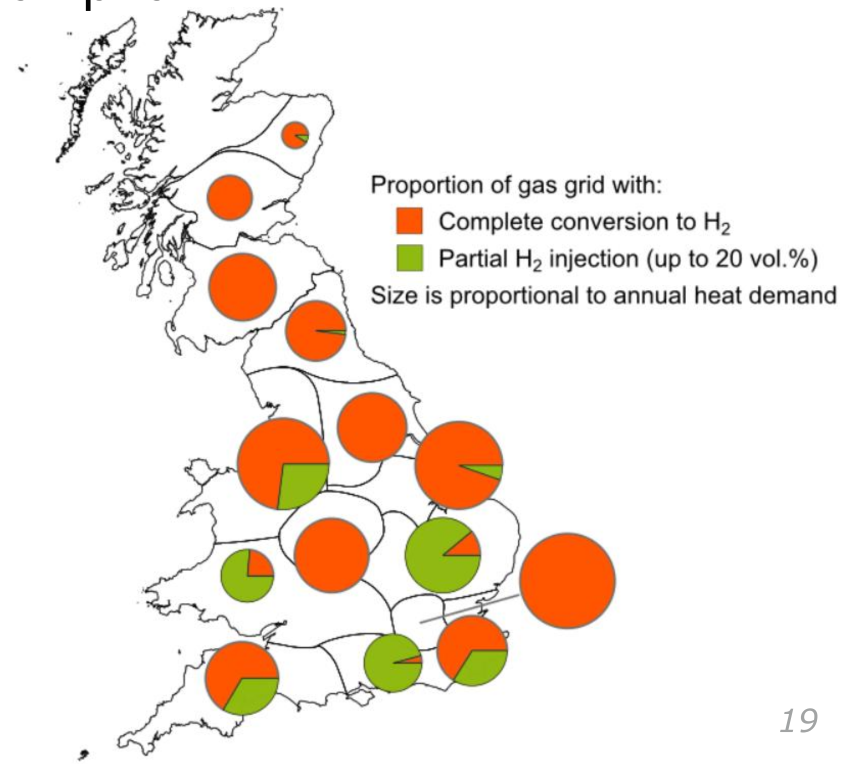


Long run decarbonisation

Heat pumps ≤ 20% of heat (domestic & commercial)

- Limited to 40 $MtCO_2$/yr (90% reduction from 1990)
- What if heat pumps aren't available? Conversion of gas grids to H_2
- 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 H_2
  - H_2 production (both SMR & electrolysis)
  - H_2 storage and conversion to electricity (fuel cells)
  - H_2 in industry
- However decarbonisation potential of partial HIGG is low (costs of ~£200/tCO_2)
- Long term role for H_2 depends on decarbonisation of heat
  - High electricity pathway still sees H_2 in supplementary role
  - Conversion of distribution grids to H_2 can support a H_2 for heat pathway

Thank you for listening

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