Environmental *Change* Institute

Decarbonising Heat

Nick Eyre

BIEE, London, 16th November 2016

The challenge

"*Heating and hot water for UK buildings make up 40% of our energy consumption and 20% of our greenhouse gas emissions. It will be necessary to largely eliminate these emissions by around 2050 to meet the targets in the Climate Change Act and to maintain the UK contribution to international action under the Paris Agreement*."

UK Committee on Climate Change, October 2016

eci
UNIVERSITY OF OXFORD
OXFORD MARTIN SCHOOL

A brief history of ‘carbonisation’

First practical use in Europe of carbon based fuels for:

- electricity: 136 years ago
- transport: 212 years ago.
- heat: 176,000 years ago.

- We only live at high latitudes because early humans learnt to burn carbonaceous fuels.
- So it’s not surprising that carbon based heating is quite well-embedded in our economic and social systems.

Internationally the UK is an interesting case study?

- A cool temperate climate makes space heating the dominant use of energy in buildings.
- The building stock is old and changes slowly.
- A very high penetration of natural gas (~85%).
- Legal requirement to reduce greenhouse gas emissions by 80% by 2050.

Options for future heating infrastructure

- Electricity networks
- Gas networks
- Heat networks

Currently this is the topic of very considerable debate. The outcomes have potential huge impacts for energy security, consumer bills and carbon emissions.

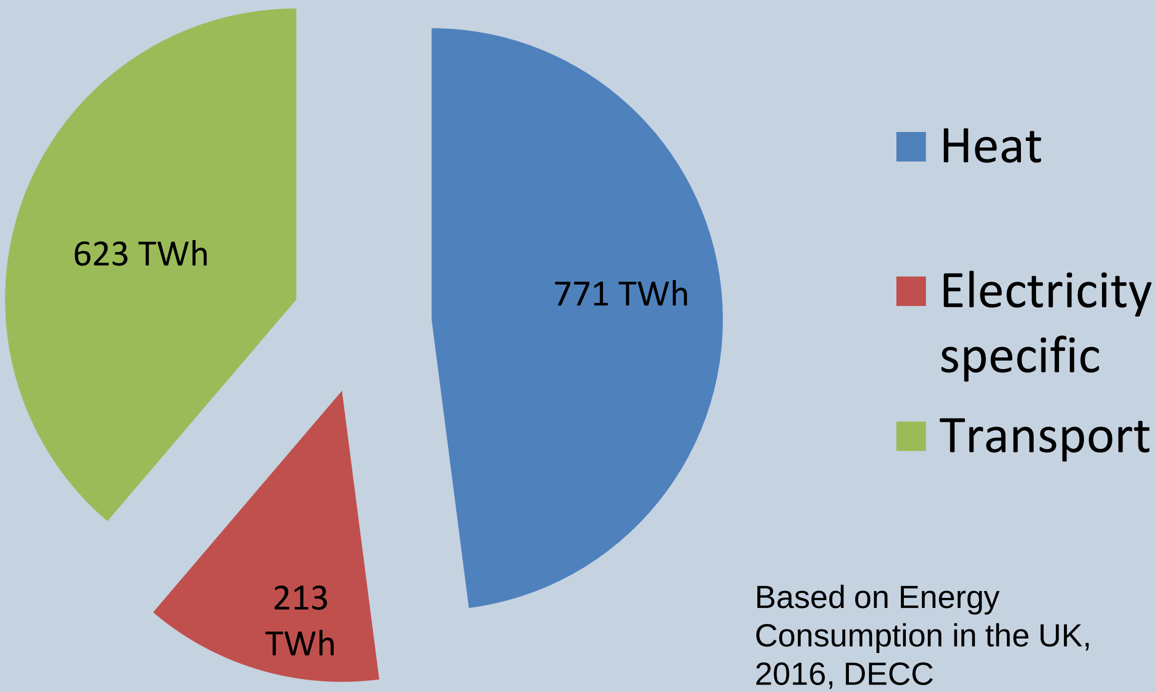
Decarbonising heat

- 4 important issues
  - Scale
  - Diversity
  - Cost
  - Time

- and 2 questions
  - Which vectors?
  - Which energy sources?

Decarbonising heat: Issue 1 - Scale

Decarbonising heat: Issue 1 – Scale
Heat is the biggest use of energy in the UK

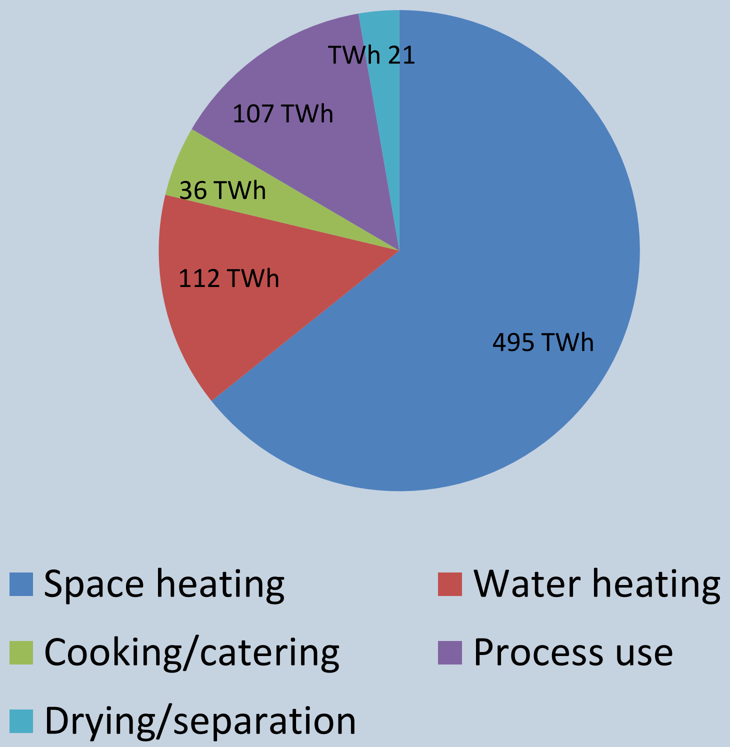


Based on Energy Consumption in the UK, 2016, DECC

Reducing the amount of heat used makes the decarbonisation challenge easier, so demand reduction is a high priority

Decarbonising heat: Issue 2 - Diversity

Heat is diverse



Diverse in

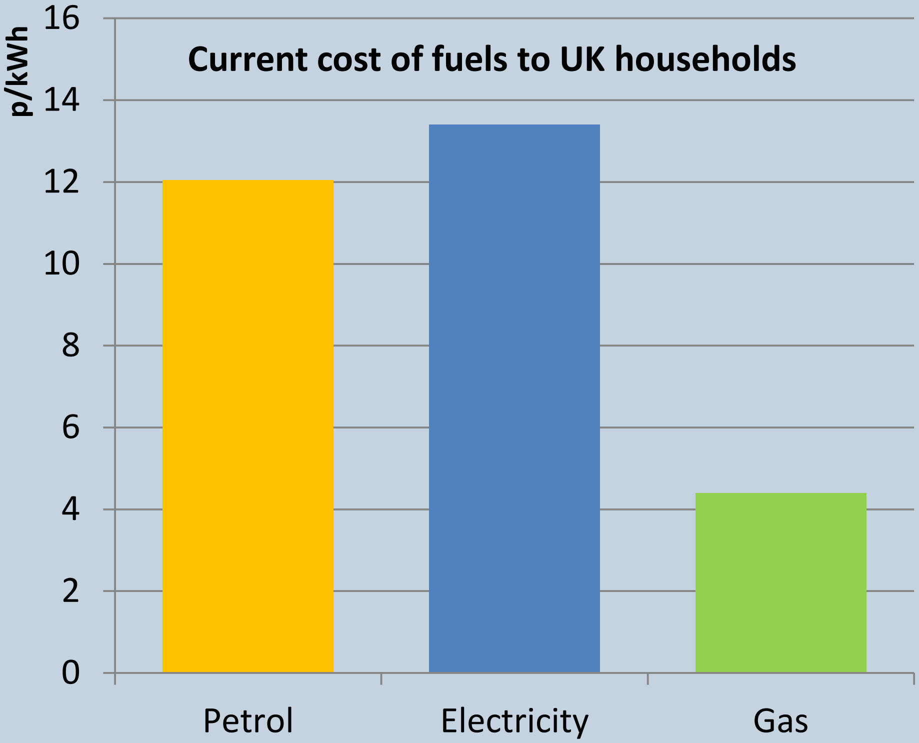
- End use: although space heating is dominant
- Temperature: room temp to ~1500C
- Geography, building type and size, location and existing fuel

A 'one size fits all' solution is unlikely

ECI · University of Oxford · Oxford Martin School

Decarbonising heat: Issue 3 - Cost

Decarbonising heat: Issue 3 – Cost
Heat needs to be affordable



- Heating fuels are currently relatively cheap
- Heat is the biggest energy cost for most households
- Heat costs are proportionately higher for low income households
- Most energy intensive industries are 'heat intensive'

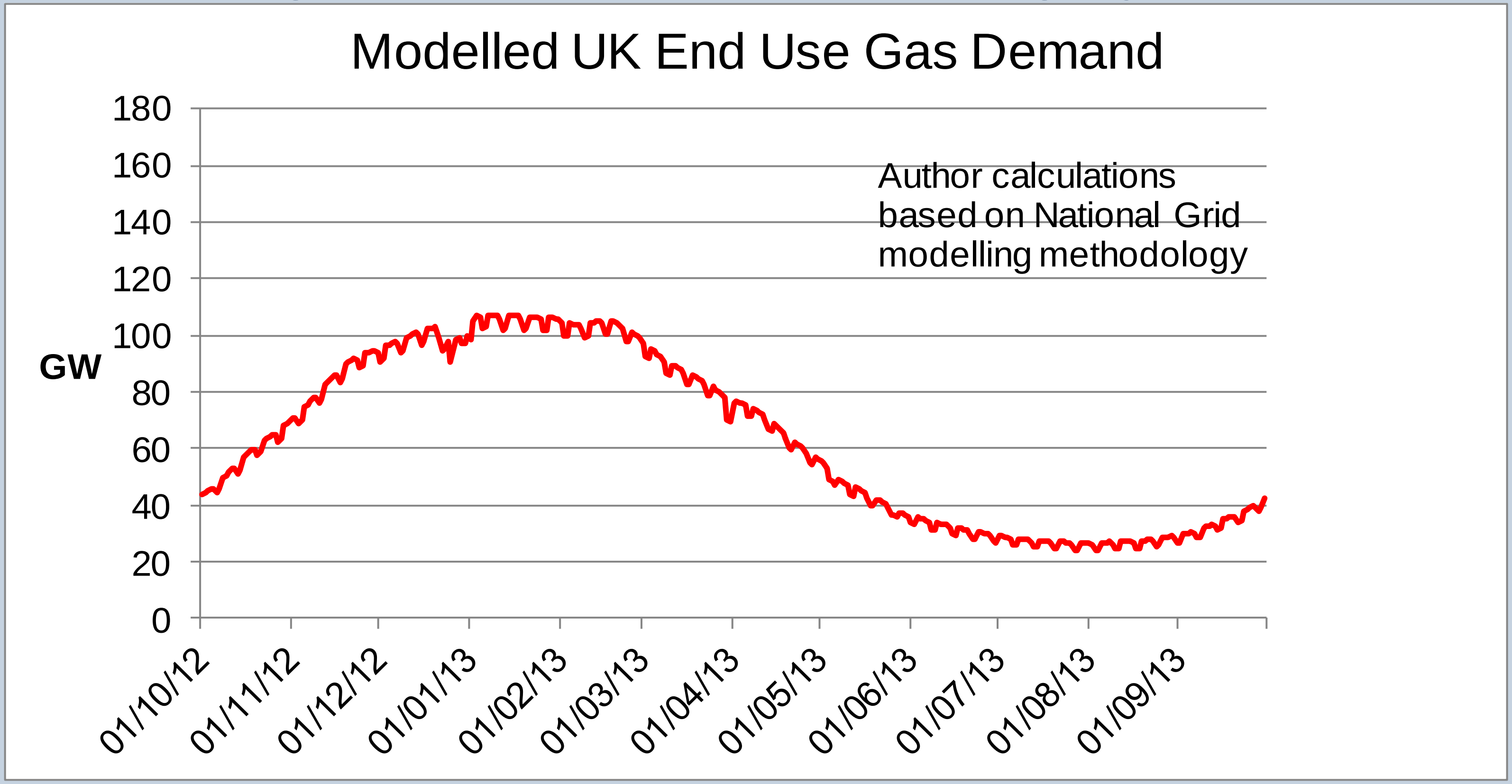
kWh price increases translate into much bigger percentage changes for heating fuels than other fuels

Cost increases are less politically acceptable

Decarbonising heat: Issue 4 - Time

Decarbonising heat: Issue 4 – Time

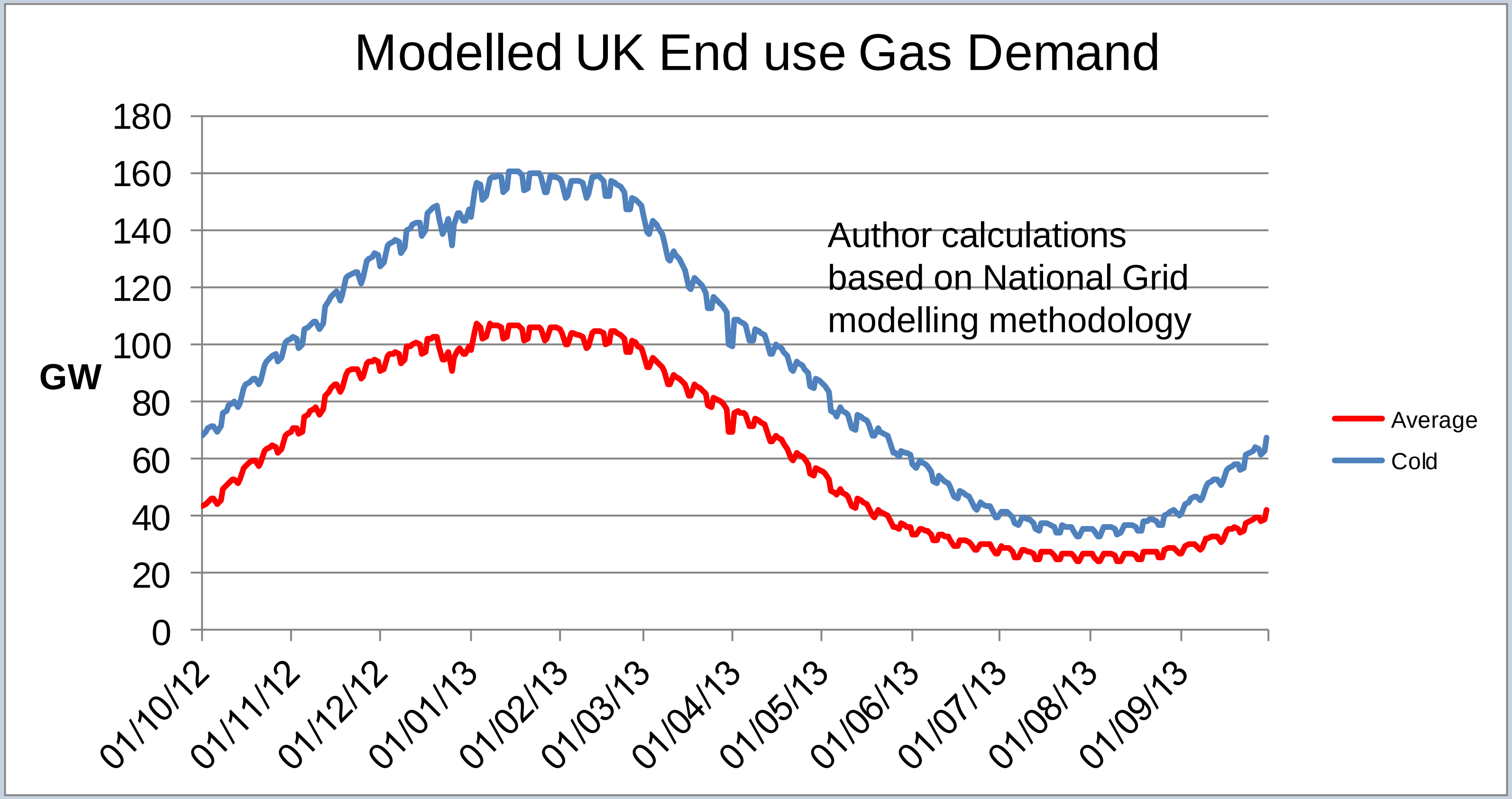
Heating demand is variable: highly seasonal



UNIVERSITY OF OXFORD

OXFORD MARTIN SCHOOL

…and is very weather dependent



Total electrification with resistance heating would more than triple peak electricity demand. Even using heat pumps it nearly double peak demand.

eci UNIVERSITY OF OXFORD OXFORD MARTIN SCHOOL

Decarbonising heat: Question 1

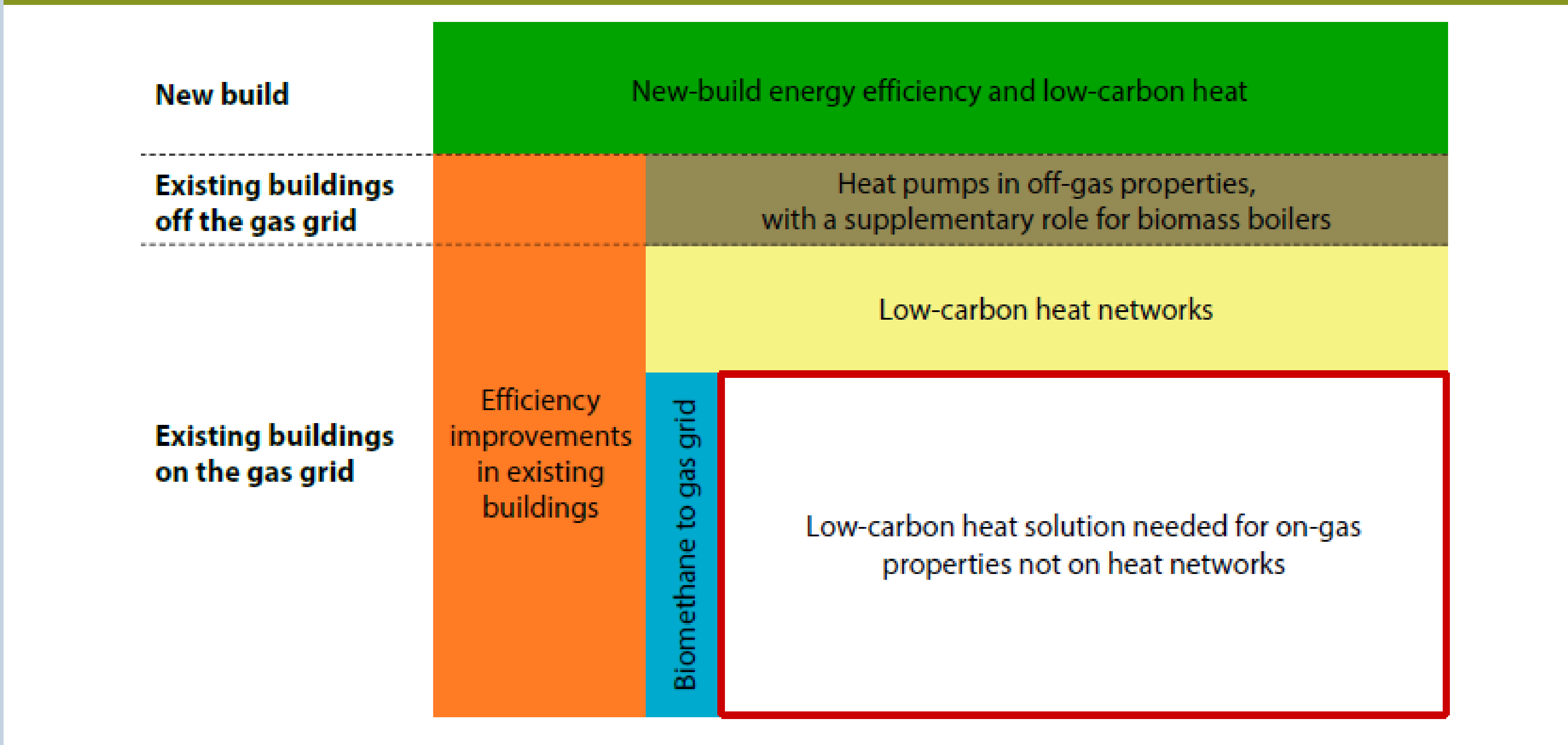
Which vectors are we going to use?

Options for future heating infrastructure

- Electricity networks
  - Key advantage is existing ~100% coverage
  - Would require some strengthening of low voltage networks
  - And adapting some buildings and consumer practices for heat pumps
- Heat networks
  - Can use a range of fuel inputs, with high efficiency
  - Currently very limited deployment in the UK
  - Only likely to be economic is areas of high heat density
- Gas networks
  - Generally the lowest cost way of moving energy
  - Currently ~85% network coverage
  - Would require 'repurposing' for hydrogen or other zero carbon vector
  - Without this the gas network becomes a stranded asset

Current thinking on UK heat infrastructure options

Figure 2.2. Low-regrets measures and the remaining challenge for existing buildings on the gas grid



Committee on Climate Change. Next Steps for Heat Policy, 2016

Decarbonising heat: Question 2

Which energy sources are we going to use?

Low carbon heating options are relatively limited

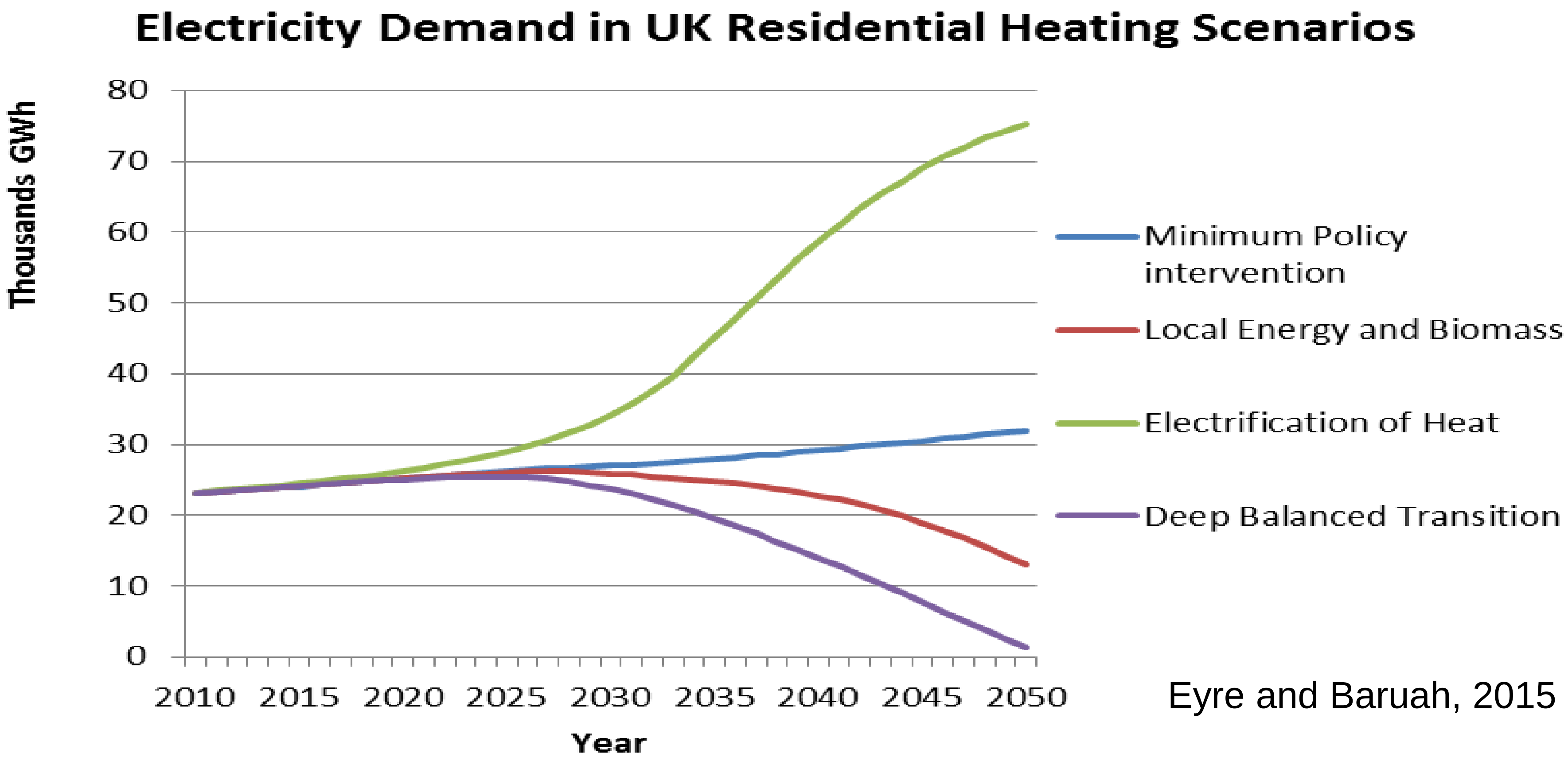
Fuel	Likely Scale
Solar heat	Limited. Critical to ‘passive design’, but not sufficient for winter heating.
Geothermal	Limited. Good resource in some areas, but not generally economic.
Waste heat	Limited. Mainly from thermal power generation, so declining availability.
Biofuels	Constrained availability in the UK. Some options, e.g. wastes and biogas, but relatively small compared to total heat demand.
Nuclear	i.e. the same potential sources as low carbon electricity. Potentially they are all very large resource if widely deployed.
Fossil fuels with CCS	
Intermittent renewables	
Energy efficiency	Very significant. Likely to provide a major contribution to low carbon heating, but not 100%.

eci
UNIVERSITY OF OXFORD
OXFORD MARTIN SCHOOL

The energy sources for low carbon heat
1. via electricity

- In principle any source of low carbon electricity can be used: renewable, fossil fuels with CCS and /or nuclear.
- But heat adds significantly to existing demands (as well as electrified transport)

Heat electrification implications for demand



Eyre and Baruah, 2015

The issues with high electrification

- Dependence on heat pumps increases UK space heating electricity demand by ~75 TWh/year.
- Thermal mass, thermal storage and control can mitigate diurnal peaks, but seasonal impacts are more difficult. The increase in peak demand will be ~40 GW (current peak load ~57 GW).
- Capital costs of power generation are ~£500/kW - >£3000/kW. This is in addition to the investment in heat pumps. It would be ~£50-£100 billion.

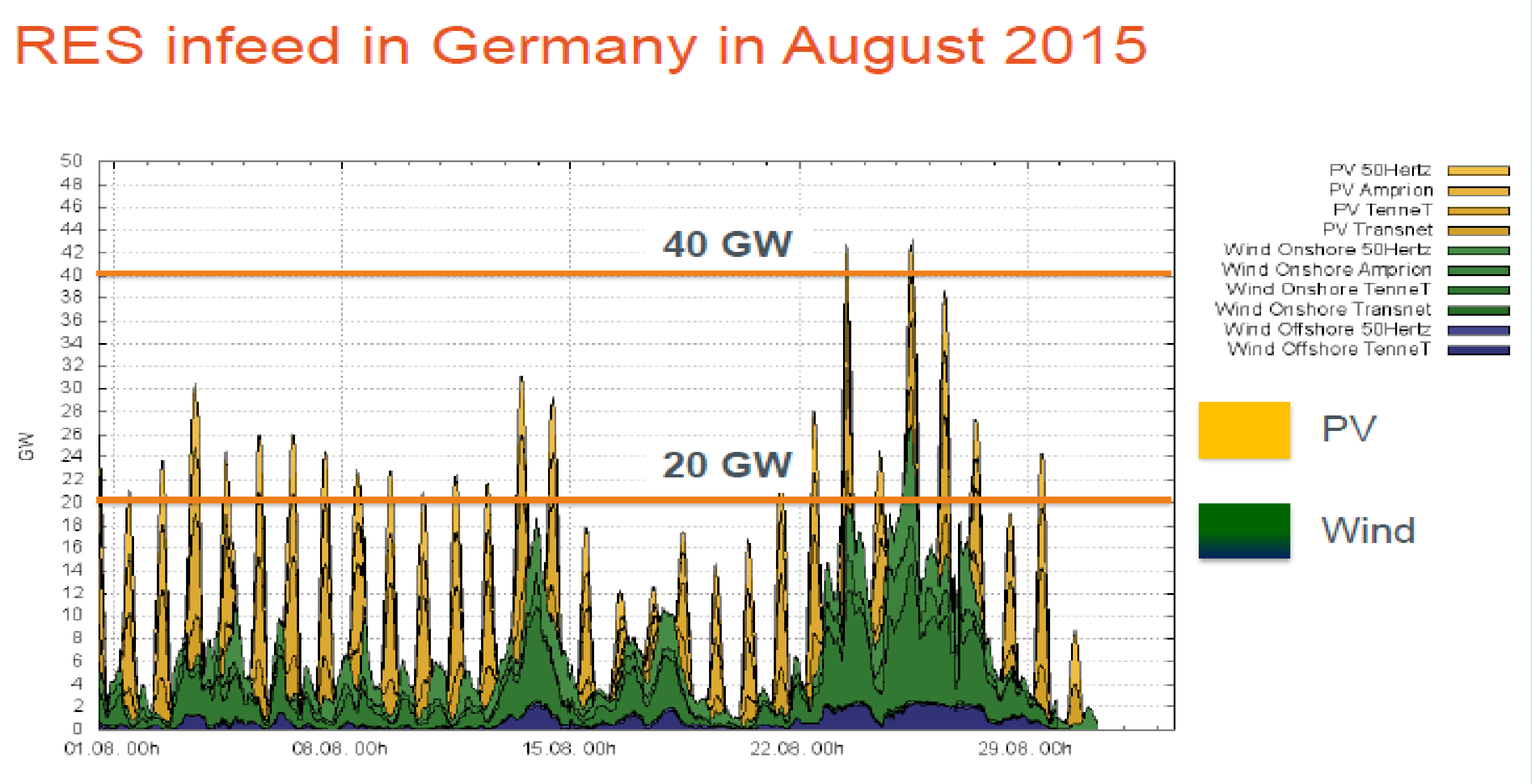
The sources of low carbon heat
2. Heat networks

- The most cited examples (e.g. Denmark) rely mainly on gas, but aim to transition to biofuels.
- The UK is “biomass poor”, so other options are
  - Solar, geothermal, waste heat – all of which are quite constrained
  - Large heat pumps, i.e. via electricity
  - Hydrogen, i.e. via gas
- The key options for heat sources use the other key vectors (electricity and gas networks), so the only advantages of heating networks are that they can allow more efficient use of electricity and hydrogen.

The energy sources for low carbon heat 3. via repurposed gas networks

- Biogas can make a niche contribution, but not a large portion of UK heat needs
- The main options for hydrogen from one of two routes
  - Steam methane reforming (SMR), with CCS
  - Electrolysis
- SMR is well-established for industrial hydrogen. CCS less commercialised.
- Electrolysis is not cost effective at typical current electricity prices. Could that change?

Electricity increasingly relies on ‘variable’ source



Wind and solar currently supply 15% of German electricity. At higher penetration, excess generation will be a major issue

eci

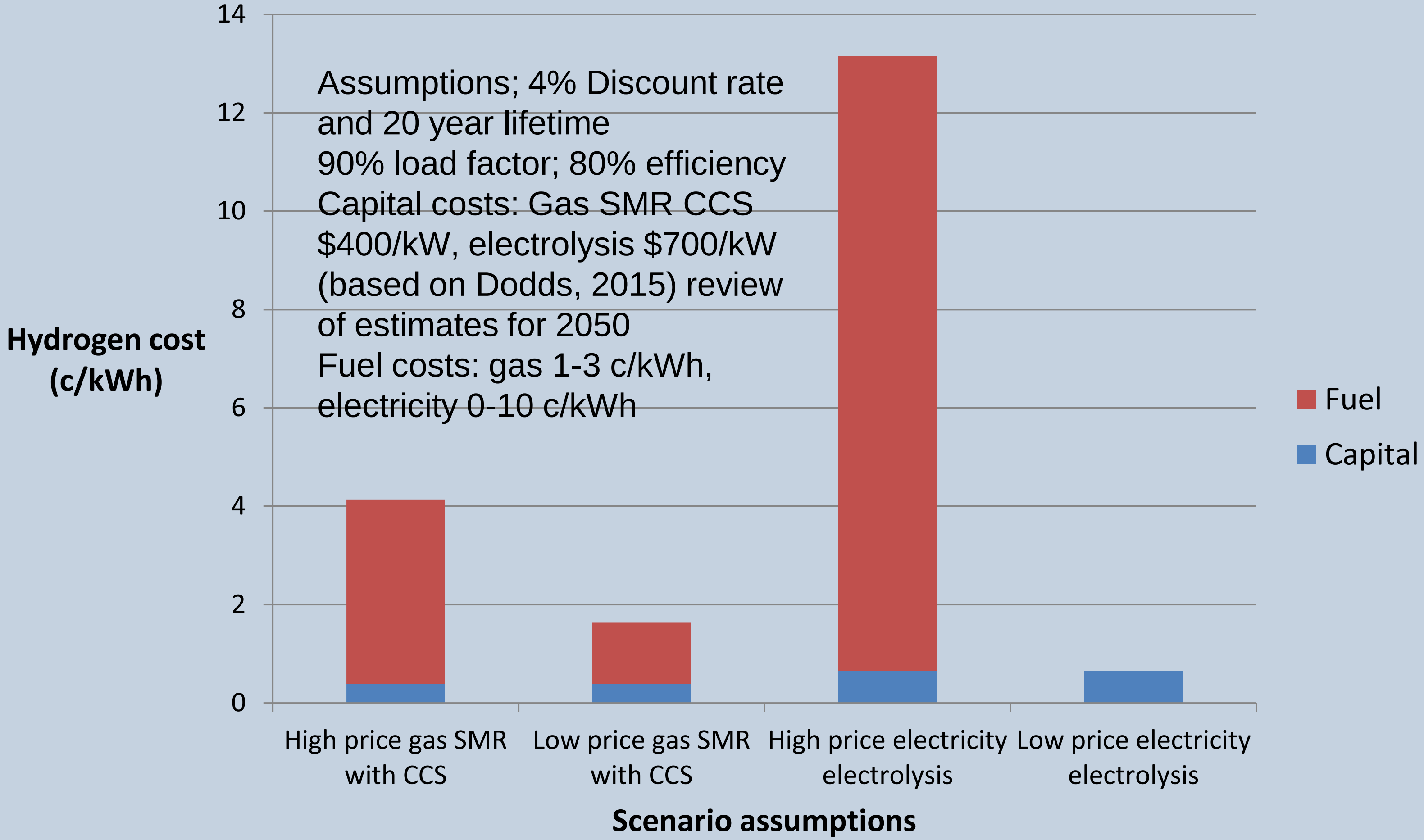
UNIVERSITY OF OXFORD

OXFORD MARTIN SCHOOL

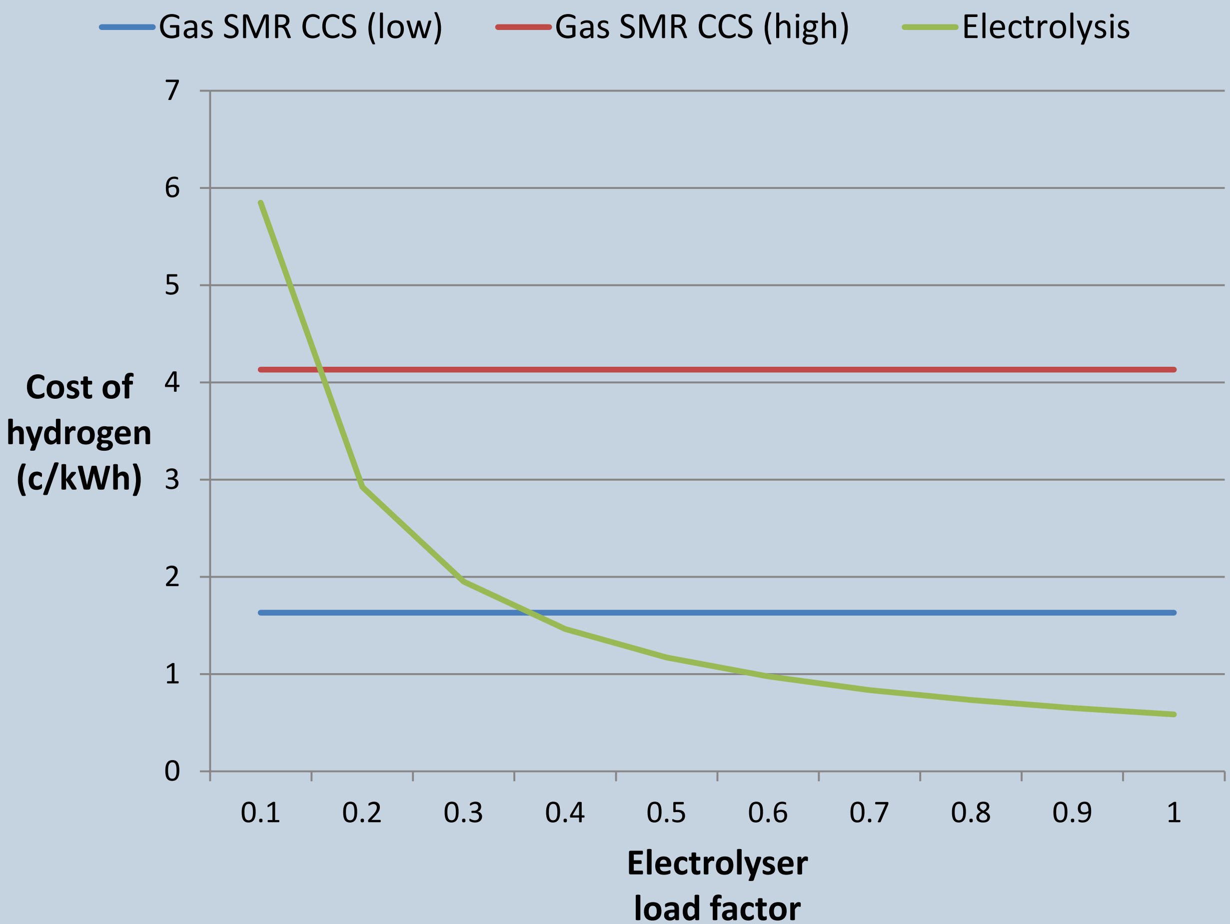
Could we use intermittent electricity for heating?

- Diurnal balancing of intermittency is achievable via demand response and modest improvements in battery technology.
- The bigger issue is seasonality. Inter-seasonal storage is much more difficult.
- Batteries are too expensive.
- More plausible options are thermal storage and hydrogen.

Economics of hydrogen production (1)



Economics of hydrogen production (2)

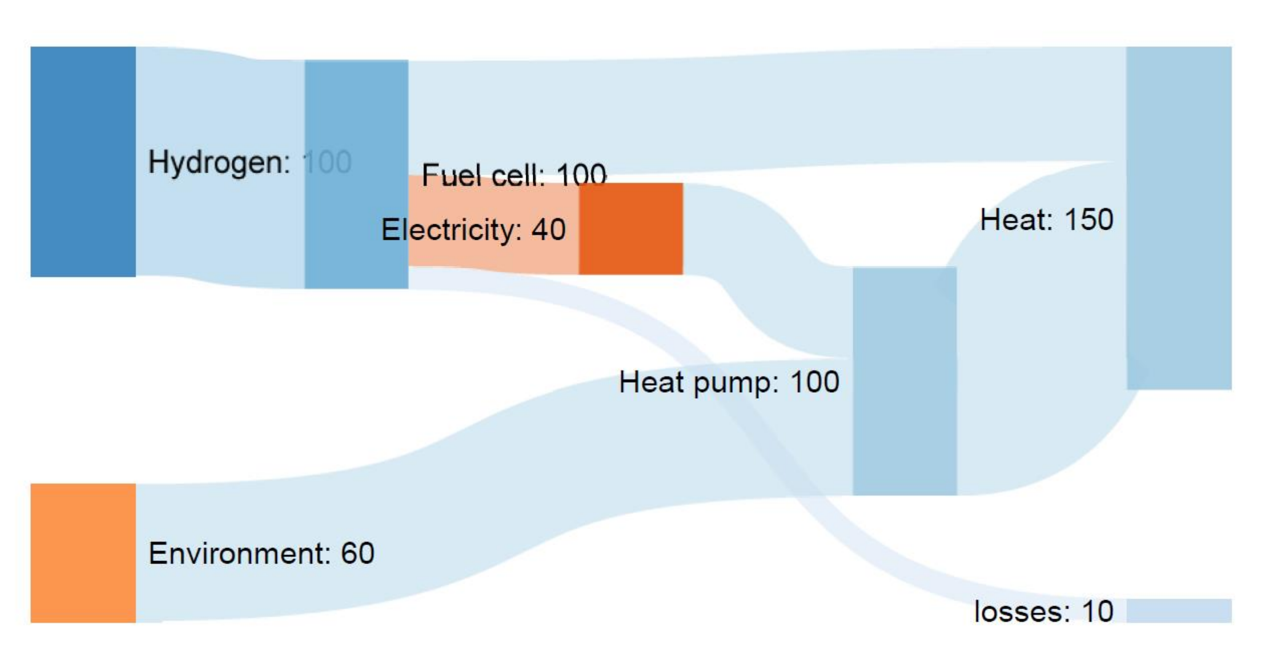


Variable load factor
Zero price electricity
Assumptions; 4% Discount rate and 20 year lifetime
80% efficiency
Capital costs: Gas SMR CCS $400/kW, electrolysis $700/kW (based on Dodds, 2015) review of estimates for 2050
Fuel costs: gas 1-3 c/kWh,

ECI | University of Oxford | Oxford Martin School

Thermodynamics of hydrogen use (1)

- The best way to use hydrogen will be for CHP not in a boiler
- Assuming the concern is peak electricity demand, a mixture of heat pumps and hydrogen fuel cells can be used, with no net effect of building sector electricity demand.

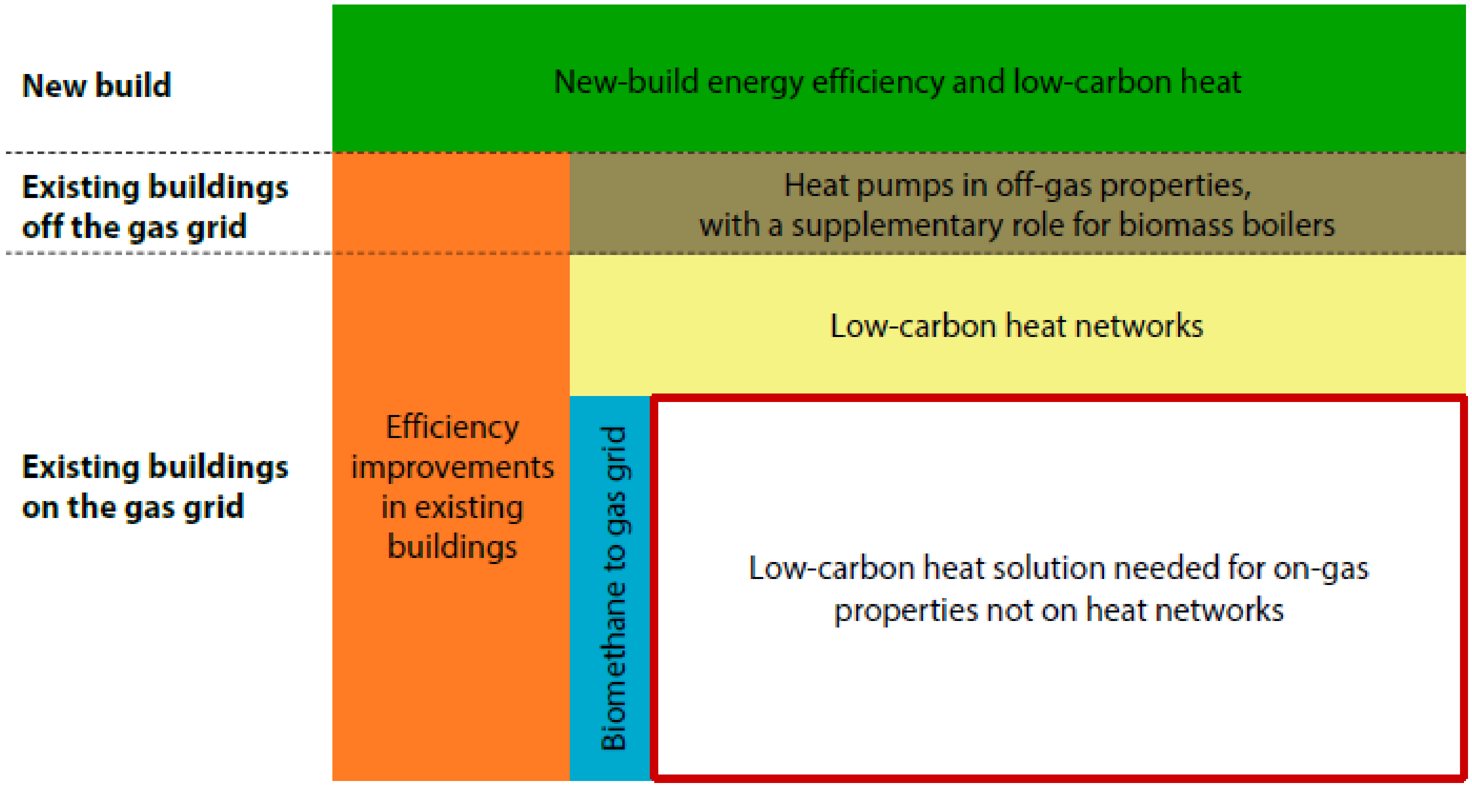


Thermodynamics of hydrogen use (2)

- For fuel cells with heating efficiency, H and electricity efficiency, E, and heat pumps with efficiency HP. It can be shown that
- Total efficiency of using hydrogen = H + (E*HP). For typical values of H, E and HP this leads to efficiencies in the range 150% to 250%.
- Ratio of heat outputs from heat pumps and fuel cells is E*HP/H. For typical values of H, E and HP this leads to ratios in the range 2 to 4.
- This implies that a mixture of heat pumps and fuel cells might be the optimum solution.
- The economic optimum will depend on the investment costs of fuel cells, heat pumps, central generation capacity and network infrastructure upgrades.

Current thinking on UK heat decarbonisation

Figure 2.2. Low-regrets measures and the remaining challenge for existing buildings on the gas grid



Committee on Climate Change. Next Steps for Heat Policy, 2016

UNIVERSITY OF OXFORD

OXFORD MARTIN SCHOOL

Key fuel and infrastructure options

Fuel	Infrastructure Option			Comment
	Electricity	Gas	Heat	
Direct solar				Resource constrained
Geothermal				Resource constrained
Industrial waste heat				Resource constrained
Biofuels				Resource constrained
Nuclear energy				Badly located for heat
Fossil fuels with CCS				Key option for H_2
Intermittent renewables				Direct or via H_2
Demand reduction				Key for early action

eci

UNIVERSITY OF OXFORD

OXFORD MARTIN SCHOOL

Conclusions

- Decarbonising heat will be a challenge because of scale, diversity, affordability and seasonality
- There is no consensus on either vectors or sources of energy
- We will need both innovation and major infrastructure investments
- Hydrogen seems likely to play a role…
- ..but the balance of production technologies is not clear
- …and understanding of hydrogen/heat economics is fairly rudimentary
- More research needed!....but some action as well.

eci

UNIVERSITY OF OXFORD

OXFORD MARTIN SCHOOL

Acknowledgements

The underpinning research for this presentation is supported by three grants:

- The underlying model of residential energy demand was developed within the Infrastructure Transitions Research Consortium supported by the Engineering and Physical Research Council under grant number EP/I01344X/1.
- Research on uncertainties in the future energy system formed part of the UK Energy Research Centre Phase 2 supported by the Natural Environment Research Council under grant number NE/G007748/1.
- Research on the policy and governance issues of energy systems with high levels of renewable energy is supported by the Oxford Martin Programme on Integrating Renewable Energy

eci

UNIVERSITY OF OXFORD

OXFORD MARTIN SCHOOL

Related publications

Key publications are:

- Eyre, N. and Baruah, P. (2015) Uncertainties in Future Energy Demand in UK Residential Heating. *Energy Policy* 87 641-653.
- Eyre, N. and Baruah, P. (2014) Uncertainties in Energy Demand in Residential Heating. UK Energy Research Centre Working Paper.
- Baruah, P., Chaudry, M., Qadrdan, M., Eyre, N. and Jenkins, N. (2016) Energy Supply and Demand Planning. Chapter 4 in *“The Future of National Infrastructure: A System-of-Systems Approach”* (Hall, J., Nicholls, R., Tran, M., Hickford, A. and Otto, A. (eds)). Cambridge University Press, Cambridge, UK.

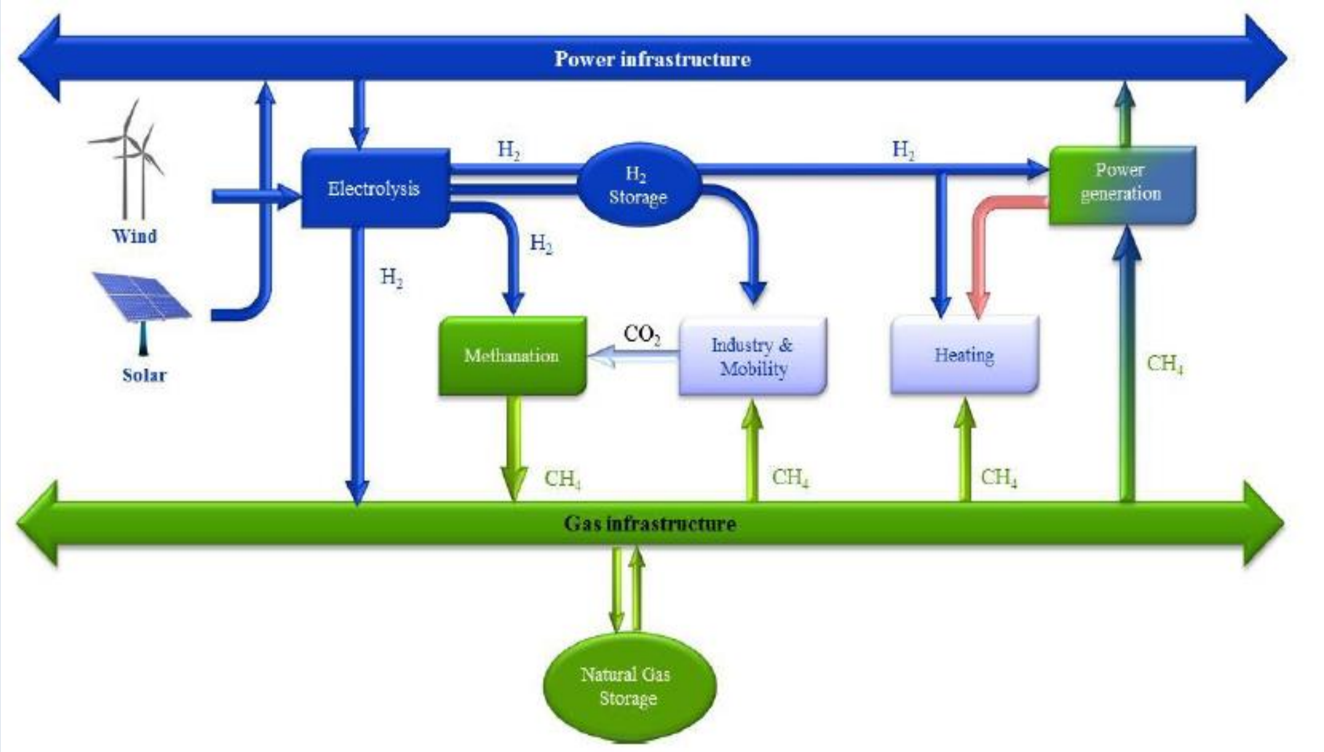
Thank you

More details:

Nick Eyre
nick.eyre@ouce.ox.ac.uk
www.eci.ox.ac.uk/people/neyre.html

Spare slides

“Power to Gas” – The Concept



/www.europeanpowertogas.com/about/power-to-gas

The “Power to gas” concept involves:

- Using electricity to make a gas at times of high supply / low demand.
- Storing the gas.
- Using the gas for heating or power times of low supply/ high demand.