Imperial College London

Developments in Long-Term Sustainable Energy

Prof. Nigel Brandon OBE FREng
Director, Energy Futures Lab

energy futures lab

Energy Futures Lab: an institute of Imperial College London

•Established in 2005 to promote and stimulate multi-disciplinary research, education and translation in energy at Imperial College London.

•Imperial has around 600 researchers undertaking energy research, plus dedicated energy Masters programmes.

•A flagship 'Global Challenge' institute of Imperial College London with the remit to:

- Build strategic energy research programmes with partners.
- Support and widen participation in energy research across the College.
- Develop energy professionals of the future.
- Engage with business and policy makers.
- Offer an award-winning Outreach programme with the Outreach Lab.

Introduction

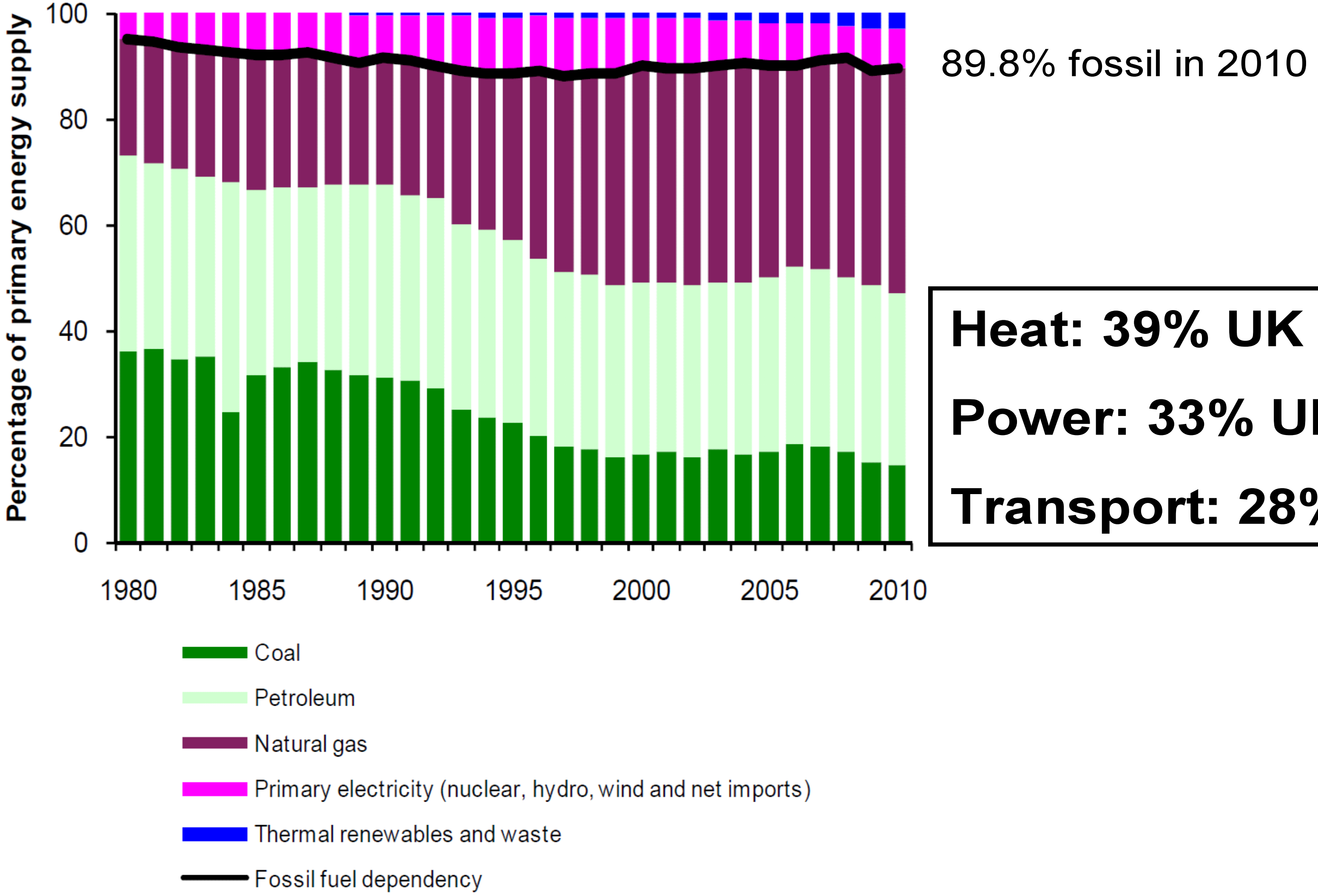
Energy Services

- Electricity
- Thermal comfort (heal, cool)
- Mobility

Key Themes and Drivers

- Energy vectors – electricity, gas, liquid fuels
- Smarter energy systems
- Sustainability, affordability and security

UK: Share of fuels contributing to primary energy supply



Heat: 39% UK CO_2

Power: 33% UK CO_2

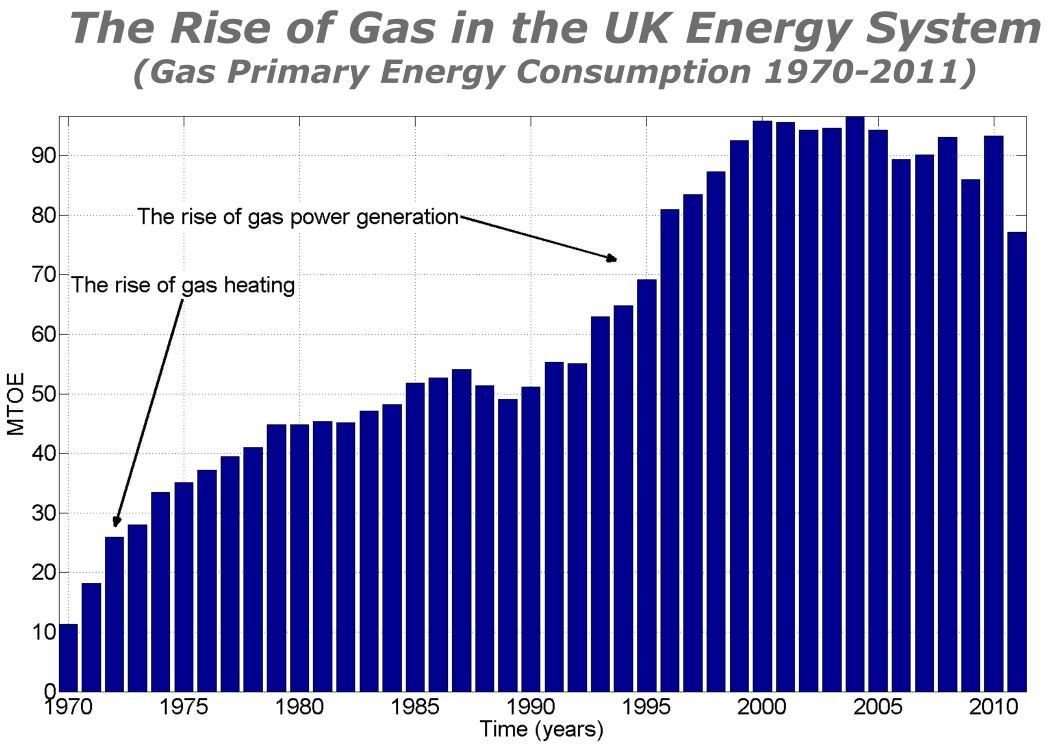
Transport: 28% UK CO_2

Source: UK Energy Sector Indicators. 2011. DECC.

Imperial College London

The rise of gas in the United Kingdom

- *Over the last 40 years, gas has become a key player in the UK energy system*
- *Sustained by a coal -> gas switch in heating, and introduction of central heating*
- *Consolidated by the "dash for gas" in the 1990s for power generation*

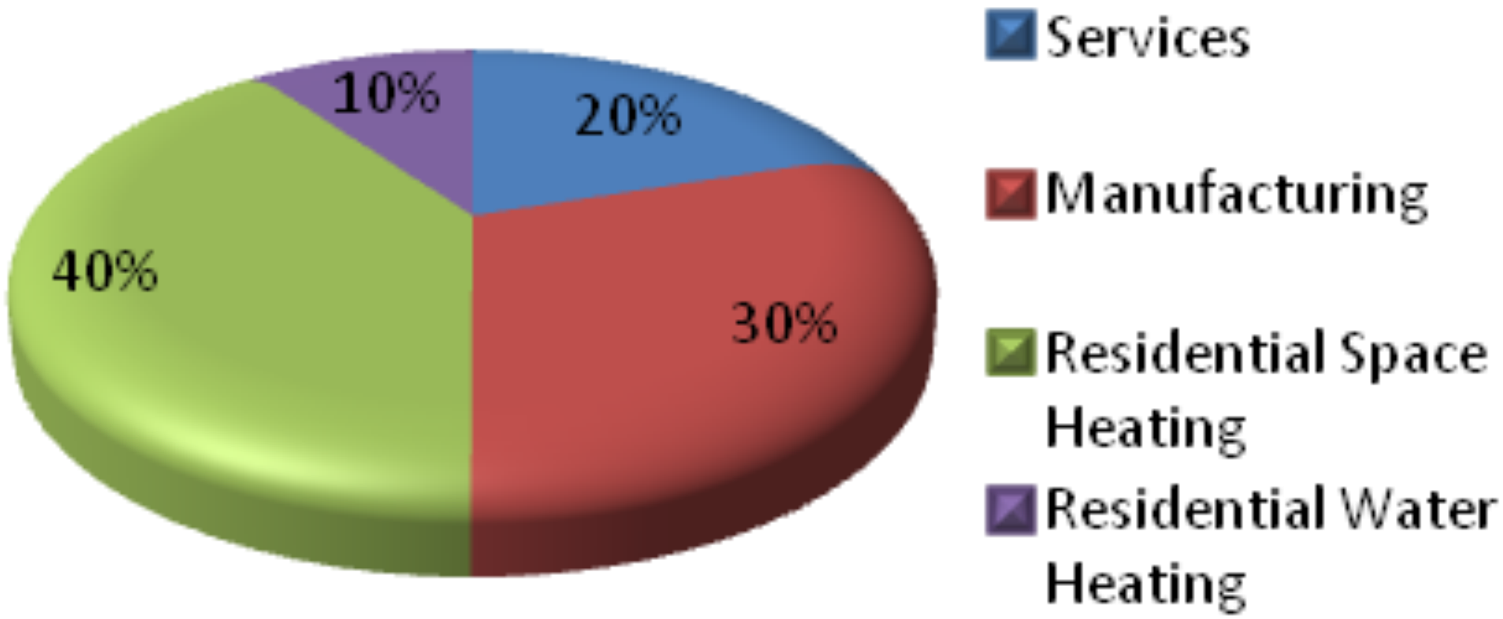


Source: Digest of UK Energy Statistics, 2012

Imperial College London

Final UK Energy Consumption of Thermal Energy

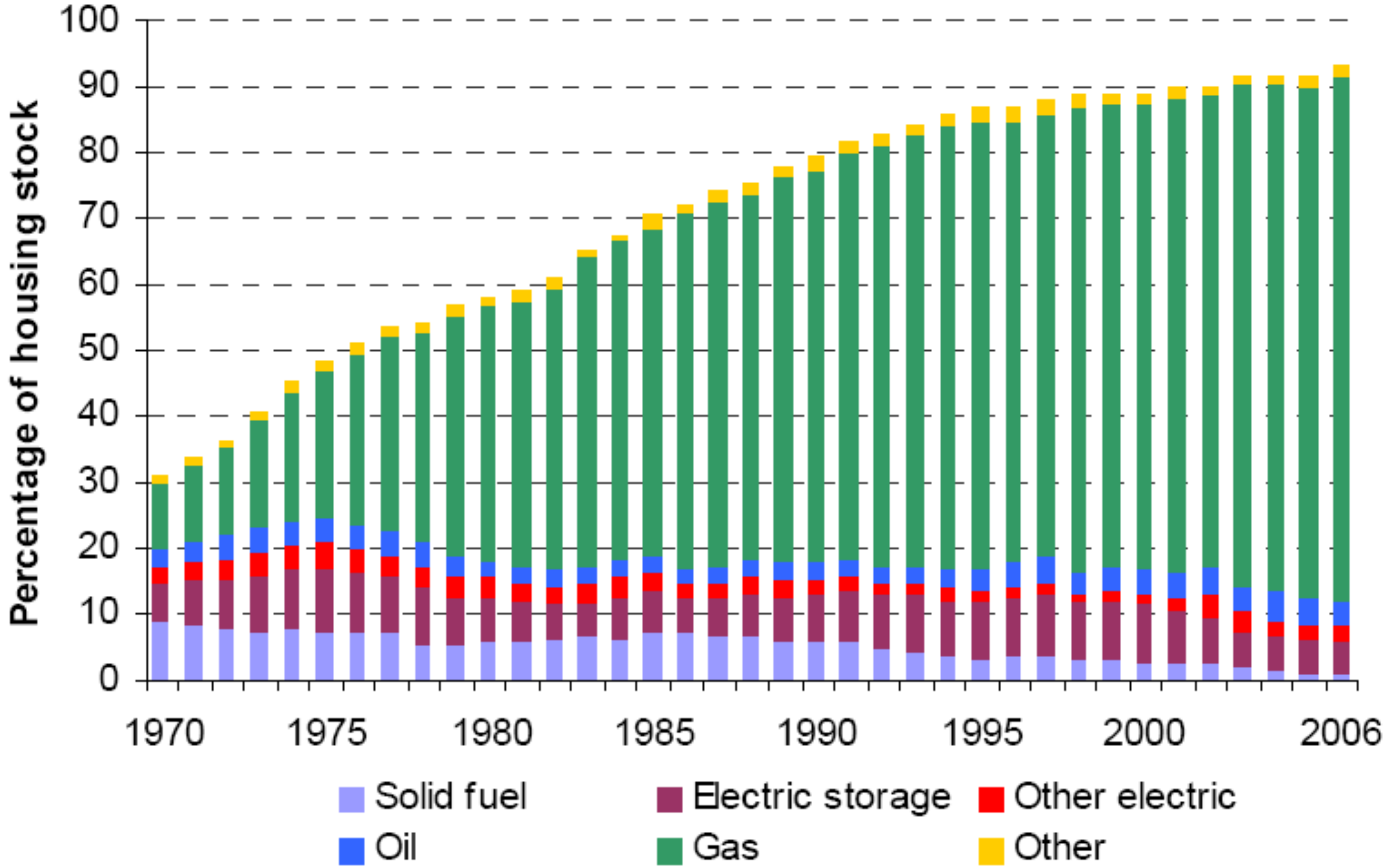
Space heating and hot water in UK residential sector = 78Mt CO_2 pa. In 2008



BERR, Energy Trends: September 2008 (Special feature – Estimates of Heat use in the UK). 2008, Department for Business, Enterprise & Regulatory Reform (now Department of Energy and Climate Change): London, UK. p. 31-42.

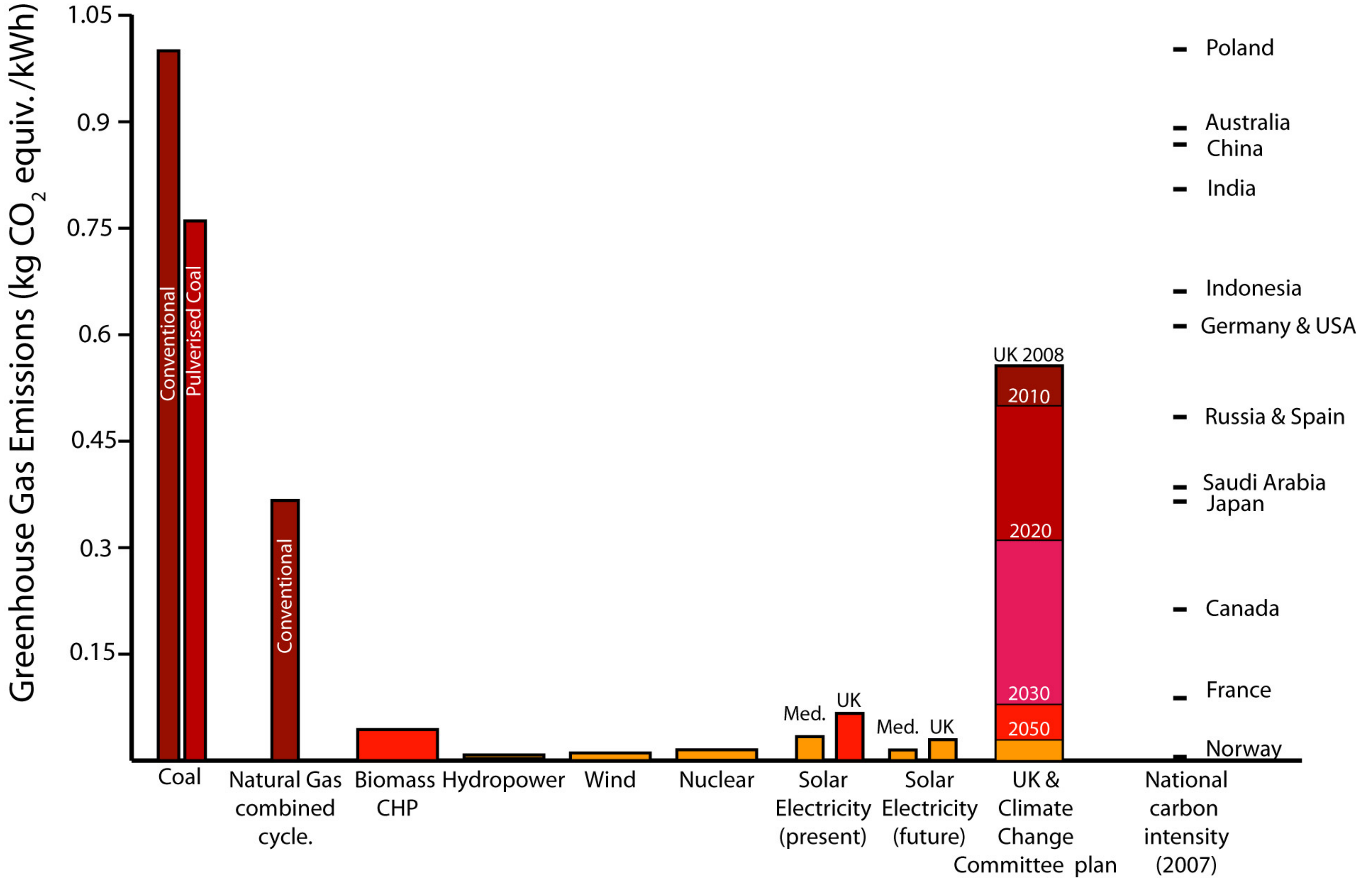
energy futures lab

Growth of central heating in UK housing stock



Source: GfK Home Audit from the Domestic Energy Fact File. Building Research Establishment.

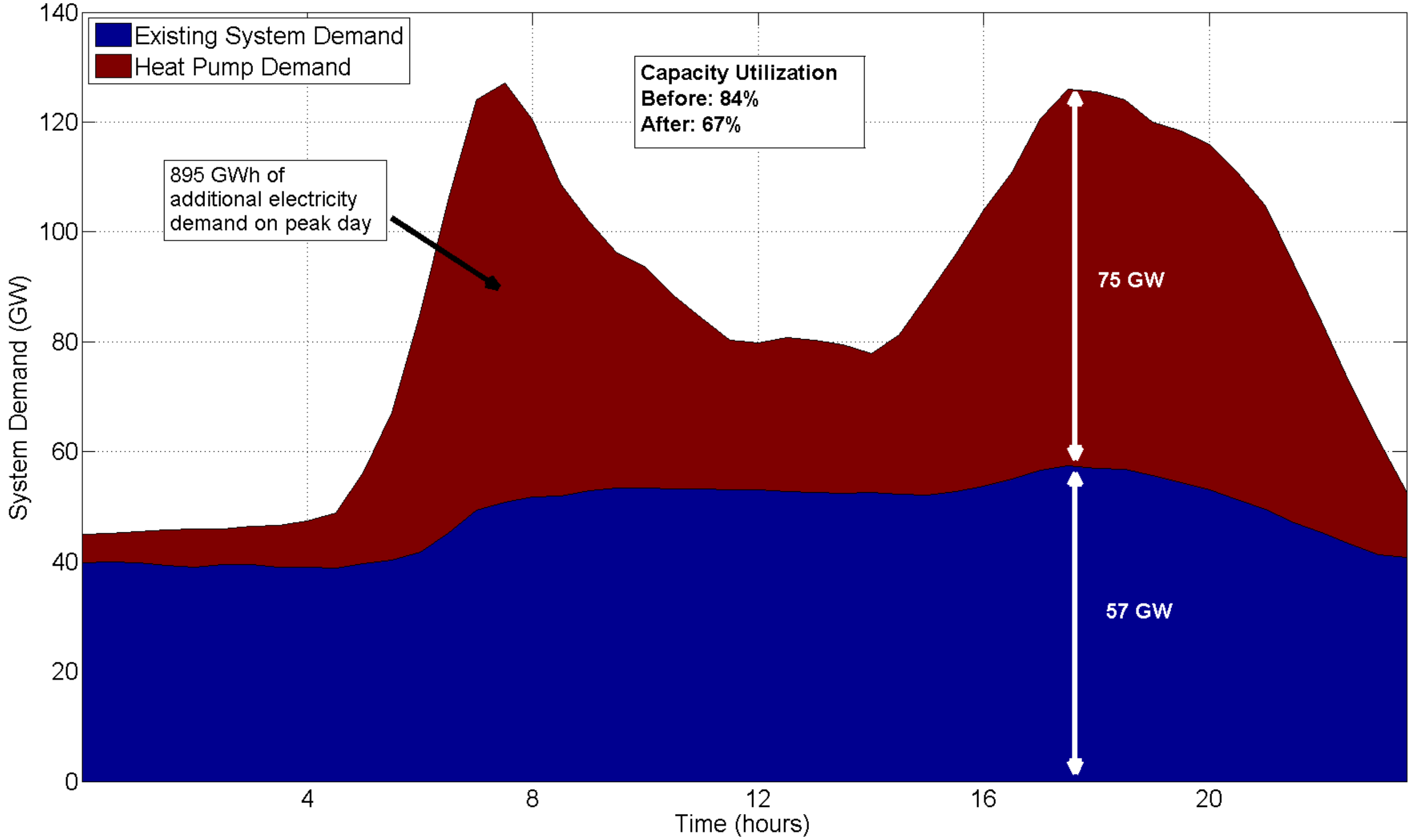
Carbon Intensity of Electricity Options



Imperial College London

Does electrification of heat make sense in the UK?

analysis of UK electricity demand if electrical heat pumps are used to displace gas in the heating sector showing the large increases in peak load



(Adapted from: Hawkes AD, Brett DJL, Brandon NP, (2011) Role of fuel cell based micro-cogeneration in low carbon heating, PROC IMECHE PART A-JOURNAL OF POWER AND ENERGY 225 pp198-207).

energy futures lab

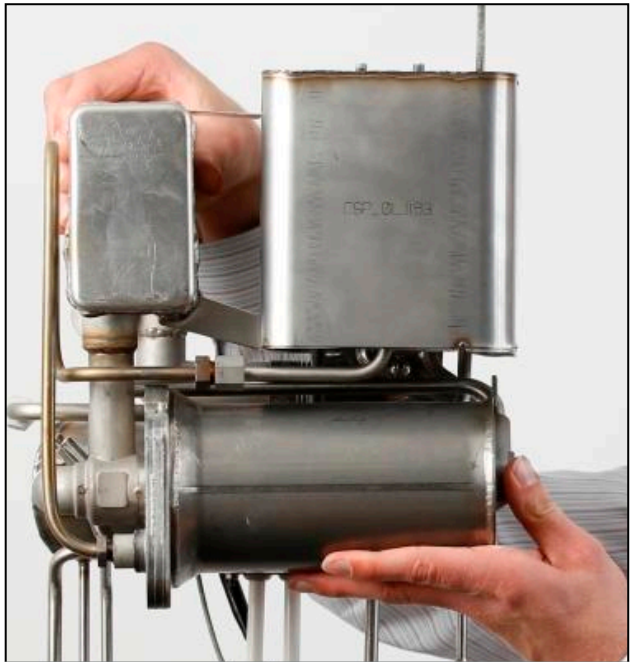
The need for flexibility in future low carbon energy systems

- There is increasing challenge (and hence economic opportunity) in delivering flexibility at the system level as more renewables and nuclear enter the system. For example we have recently* explored the economic benefits of energy storage, showing a value of the UK energy system of as much as £10B per annum by 2050 for some scenarios.

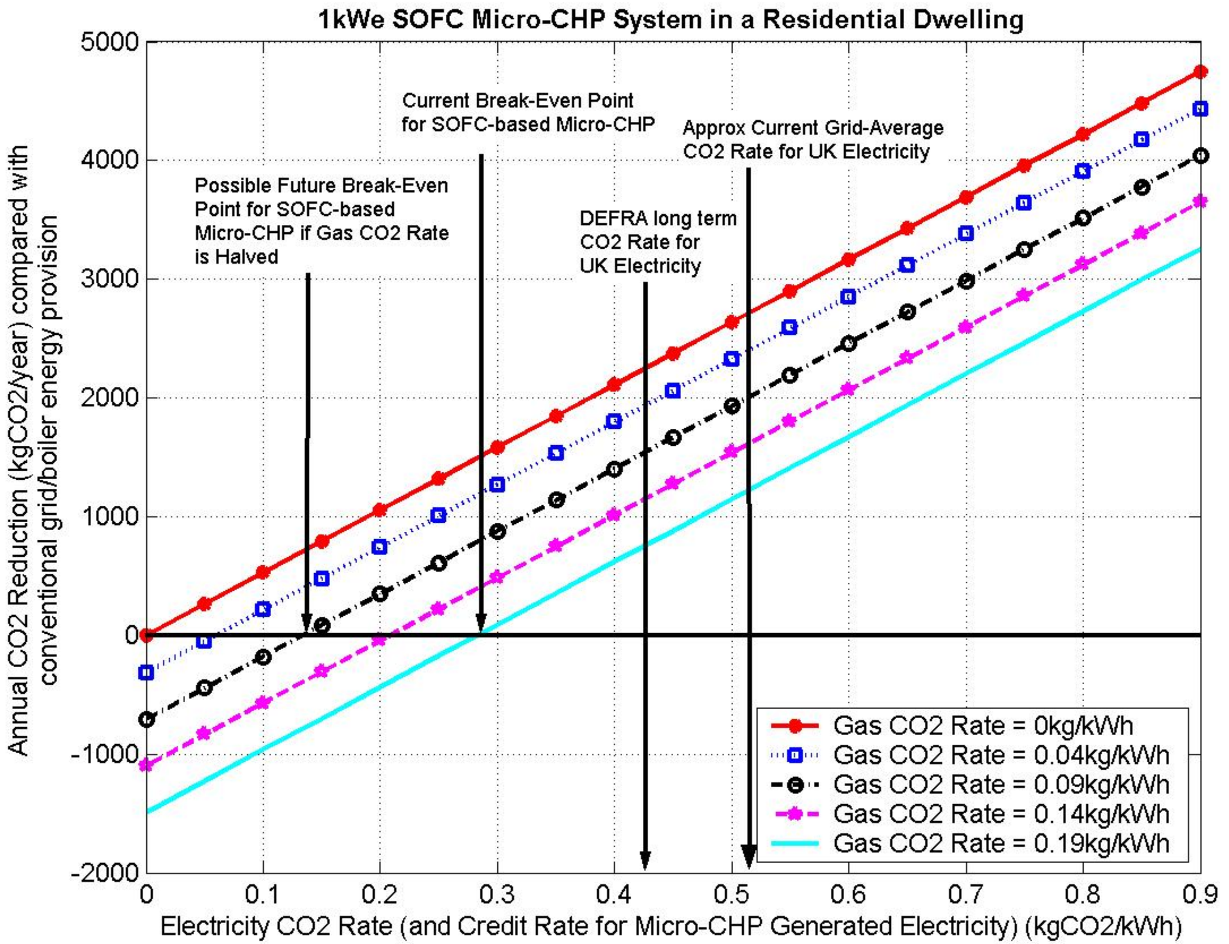
- This flexibility could also be provided by natural gas, for example via high efficiency natural gas fuel cell generators (operating at >60% efficiency at 1MWe in scale, and >50% at 1kWe) distributed around the energy system, by hydrogen derived from CCS and/or electrolysis, or by the methanation of CO_2.

**www.carbontrust.com/resources/reports/technology/energy-storage-systems-strategic-assessment-role-and-value*

Natural Gas Fuel Cell 1kWe and 100 kWe generators



Environmental benefits of NG fuel cell mCHP showing how the carbon benefits depend on the carbon intensity of grid electricity

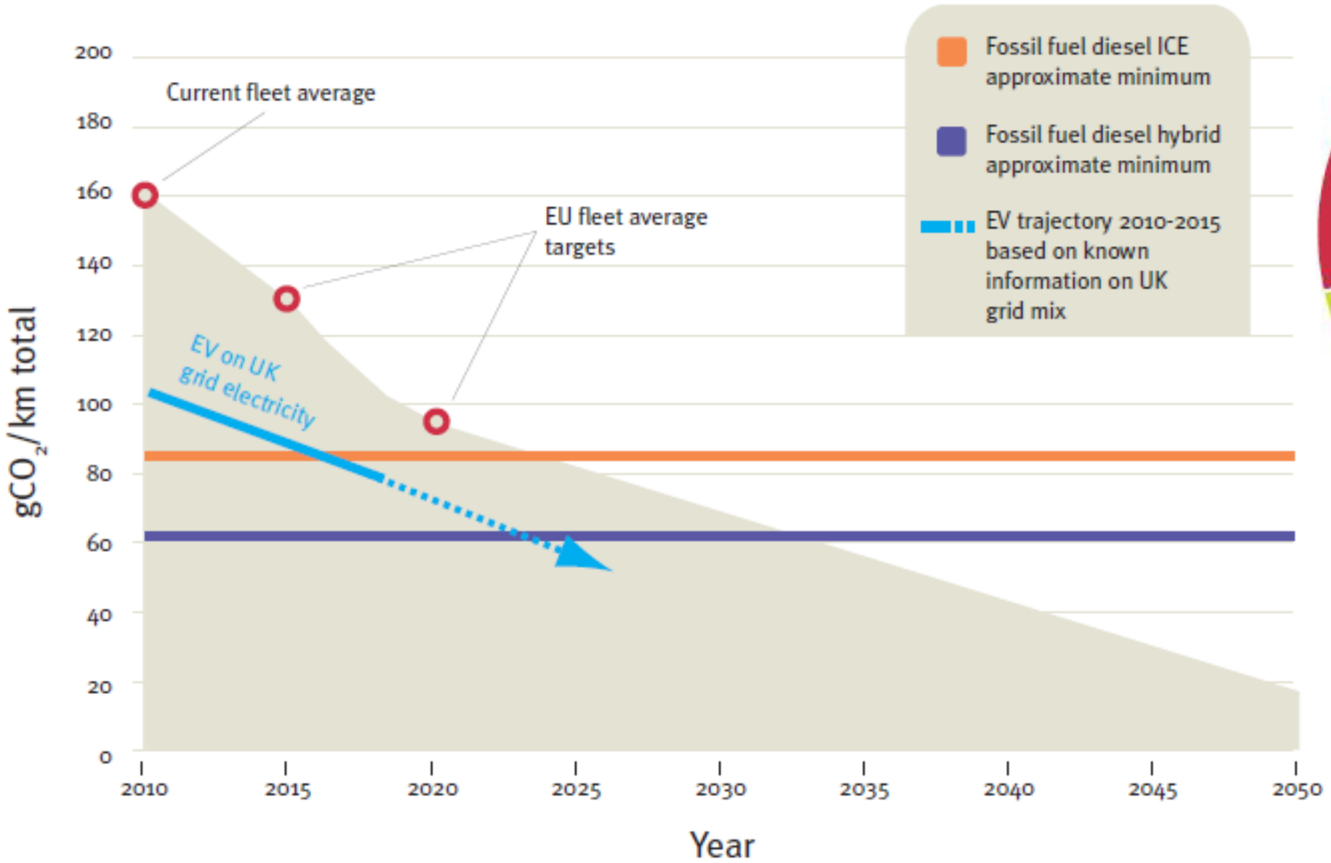


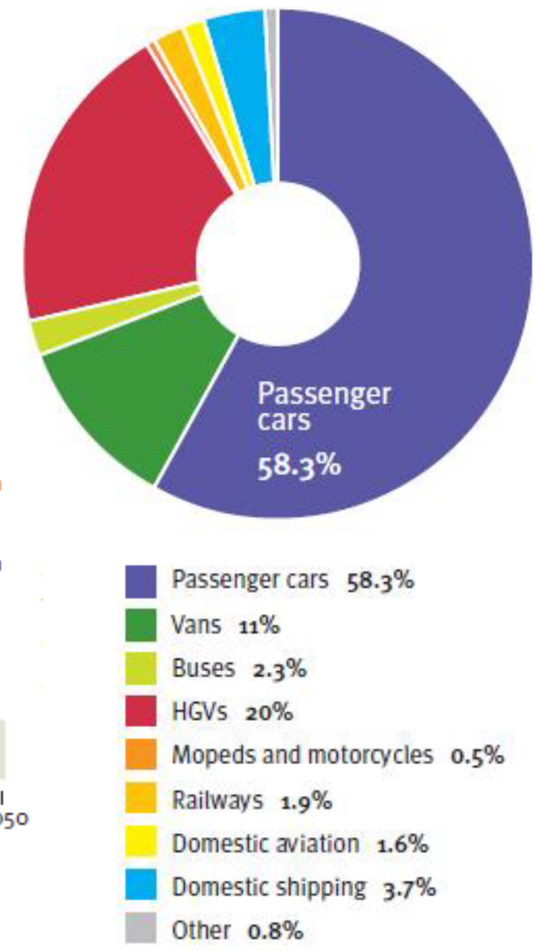
Can gas contribute to a future low carbon energy system?

- Analysis published by the European Gas Forum [*Making the Green Journey Work*, 2011] has shown that Europe can reach its 2050 greenhouse gas reduction target at lower cost (450-550B Euro) than has been suggested by other studies which emphasised electricity as the primary low carbon energy vector.
- The pathways developed make greater use of gas based generation technologies in the near term, CCS post 2030, complemented by a significant proportion of renewable energy sources (RES) in order for emissions goals to be met, with the RES share of the power mix growing to 30-34% by 2050.
- But of course we do need to address the carbon content of gas – using e.g. H_2 from CCS, biogas, etc.
- Gas can be an essential part of future affordable, secure, low carbon **smart energy systems**.

Imperial College London

Automotive carbon emission targets in Europe





Emissions can be further reduced by up to 27 gCO2/km in 2030 using blended biofuels (19%) in a hybrid vehicle
The Role of Biofuels Beyond 2020, Element Energy (2013)

energy futures lab

RAC Future Car Challenge

Involves vehicles driving the 92 km Brighton to London. EVs, plug in hybrids and up to 110 g CO2/km ICEs eligible for entry.

Vehicle powertrain electrification

- Results from datalogging the vehicles showed that the EVs consumed an average of 144 Wh/km, plug in hybrids 271 Wh/km and ICEs 550 Wh/km.
- This demonstrates the greater efficiency of the electric powertrain. CO_2 emissions equate to 89 g/km for EVs and 159 g/km for ICEs, allowing for in-efficiencies in vehicle charging. Diesel has almost half the carbon emissions per kWh compared to UK grid electricity today – so the potential for future decarbonisation is evident!
- Fuel costs on the day were £2.02 for EV, £7.16 for ICE.

Hydrogen Fuel Cell Electric Vehicles

Imperial College London

Hydrogen Fuel Cell Electric Vehicles

- Several leading car manufacturers have stated that they are ready to commercially launch hydrogen fuel cell electric vehicles (HFCEVs) in either 2015 (Toyota, Hyundai, Honda) or 2017 (Daimler, Nissan, Ford).

- In Europe, H2 Mobility studies, including that recently issued in the UK (Phase 1 results, April 2013), have assessed the infrastructure requirements and costs needed to support the commercial launch of HFCEVs.

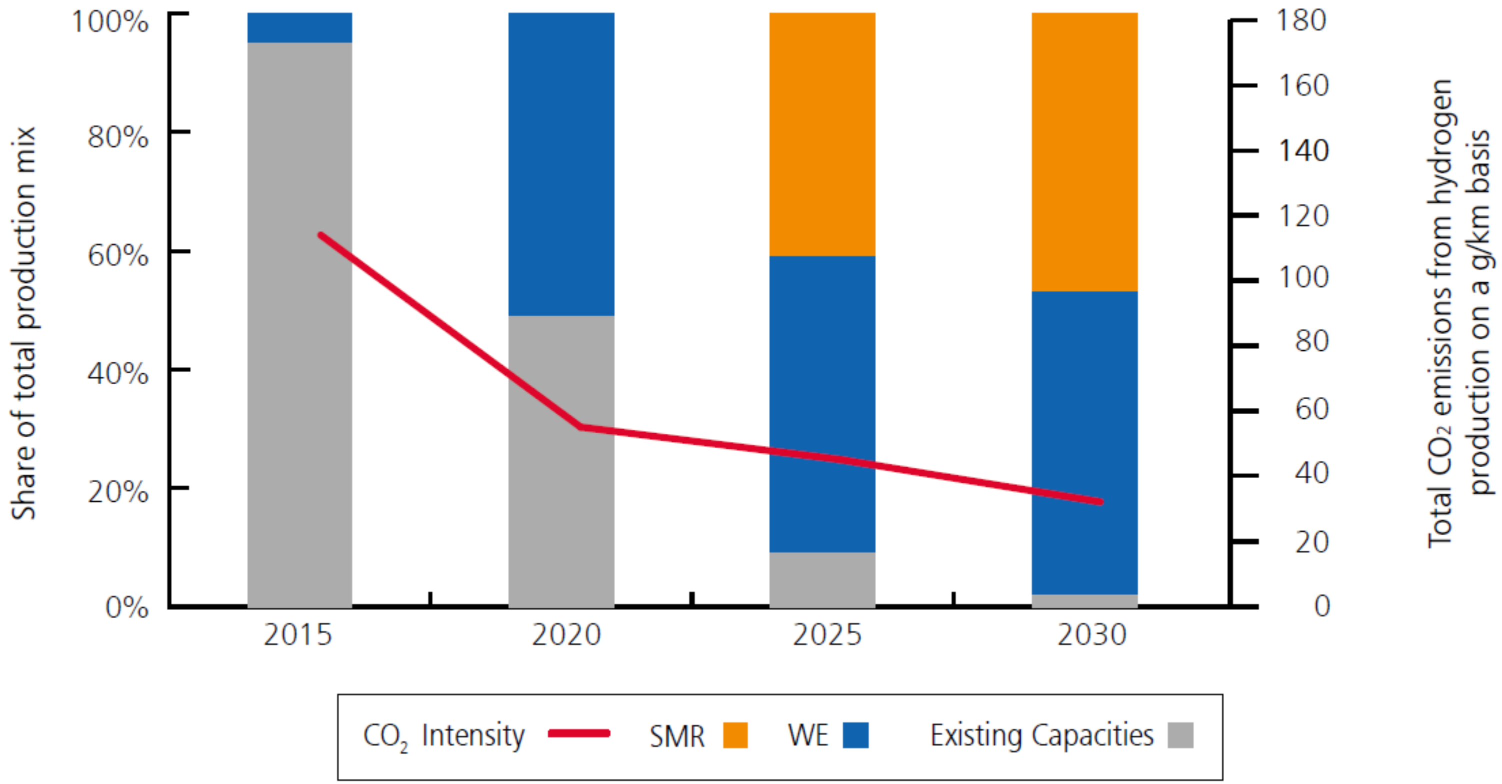
- The carbon emissions from a HFCEV clearly depend on where the hydrogen comes from, but the UK H2Mobility roadmap shows the total CO_2 emissions to be 75% less than the equivalent diesel vehicle in 2030, and on a path to zero-carbon by 2050.

- Hydrogen from CCS schemes, or generated from renewable electricity using electrolysis, offers useful flexibility to a range of future low carbon energy systems, and supports fuel security.

Hydrogen Refuelling Infrastructure

- A wide range of primary energy sources can be used in the production of hydrogen. This is a major advantage when considering diversification and flexibility of supply in an energy system.
- An adequate refuelling infrastructure (including production, distribution and retail) is clearly required for HFCEVs to be marketed as a credible and attractive alternative to conventional vehicles.
- There is significant first mover disadvantage in terms of installing hydrogen refuelling stations (HRS) – hence Government support is needed.
- UK H2 mobility reports that 65 HRS are required within the UK to allow commercial vehicle launch. 1,150 HRA are required by 2030. These become profitable after 2020 and reach break even in the late 2020s. £418M of finance is required before break even is reached.

Hydrogen production mix from UK H2Mobility



Tonnes H_2 pa: 3,000 by 2030; 51,000 by 2025; 254,000 by 2030
No CCS is assumed before 2030

From UK H2 Mobility Phase 1 Results, April 2013.

Lower Carbon Transport Options

- Electric vehicles powered by low carbon electricity are attractive for urban travel, but currently suffer challenges in terms of cost, perception and charging infrastructure.

- Gasoline/diesel/biofuel (and in time hydrogen) battery hybrids are attractive for longer journeys.

- Hydrocarbons (natural and synthetic) will remain the fuel of choice for very long journeys (e.g. long haul freight) or air transport.

- Integration is required between electricity/hydrogen generation, distribution and demand side management. Again **Smart Energy Systems** will be needed.

Summary

- The future low carbon energy system is characterised by the need for increasing interactions between energy vectors if it is to be delivered in the most cost effective and secure manner.
- This includes the combination of fossil fuels with renewable energy sources to provide a range of energy services.
- Hence we must pay attention to the development of smarter energy infrastructures and systems, that provide flexibility and reduce the need to invest capital in ‘dumb’ wires and pipes.
- High efficiency energy conversion and storage technologies will play a key role as the ‘middleware’ in these low carbon energy systems.
- New commercial challenges and opportunities will also be created by the intersection of different sectors of the economy.