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Research Briefing: Low Carbon Heat

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Research Briefing: Low Carbon Heat

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This briefing paper is the third in a series on low carbon energy in Wales. This part focuses on low carbon heat sources, including their role in decarbonisation and an overview of relevant technologies.

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1. Introduction

This Research Briefing is part of a series on low carbon energy in Wales. This paper focuses on low carbon heat sources, including their role in decarbonisation and an overview of relevant technologies. For further information on low carbon energy, refer to the other parts of the series:

- **Low Carbon Energy in Wales** discusses the national and global context for low carbon energy in relation to the energy trilemma, and outlines the policy landscape in Europe, the UK and Wales;
- **Low Carbon Electricity** describes the main low carbon electricity sources; and
- Low Carbon Transport focuses on the main options for reducing carbon emissions from transport.

Low carbon refers to a reduction in greenhouse gas emissions. These are commonly measured as carbon dioxide equivalent (CO_2e) and referred to as "carbon emissions".

2. Low carbon heat in Wales

Low carbon heat is a key component in achieving climate change and renewable energy targets (more information on these can be found in the **Low Carbon Energy in Wales research briefing**). Heating and hot water for buildings make up **40% of UK energy use and 20% of its emissions**.

The ***Environment (Wales) Act 2016*** requires the Welsh Government to set greenhouse gas emission reduction targets for 2020, 2030 and 2040, along with carbon budgets for 2016-20 and 2021-2025, by the end of 2018. These will set the trajectory for an 80% reduction in greenhouse gas emissions in Wales by 2050 (compared to 1990 levels).

This is a particular challenge in Wales since a large proportion of carbon emissions come from large point sources (known as 'big emitters') such as refineries, steel works and power stations. **Around 55% of emissions in Wales** are covered under EU Emissions Trading Scheme (EU ETS) (compared to 40% across the UK). While action is needed reduce the emissions from these large point sources, this is very challenging in some cases, and Wales has limited devolved powers in these areas. Greater savings will have to be made in other sectors in Wales relative to the UK as a whole to compensate for emissions from the 'big emitters'.

UK Committee on Climate Change recommendations

The **Welsh Government asked** the UK Committee on Climate Change (UK CCC) for advice on designing carbon targets and setting carbon budgets. The UK CCC published this advice in two stages. The first, **Advice on the design of Welsh carbon targets**, was published in April 2017. The second, **Building a low-carbon economy in Wales**, was published in December 2017, and provides advice on how carbon budgets should be set, as well as how the targets may be achieved.

The UK CCC policy recommendations for Welsh Government include:

- Updating building standards to ensure that new buildings have a high standard of energy efficiency and are designed for low carbon heat;
- Providing funding and 'soft' support for building energy efficiency and low-carbon heat;
- Developing a heat decarbonisation strategy for Wales; and
- Encouraging the use of waste heat from industry.

The second UK CCC report shows that to achieve the Welsh Government target of an 80% reduction in carbon emissions by 2050, emissions from buildings will need to reduce by around 85% compared to 2015 levels (*Figure 1*).

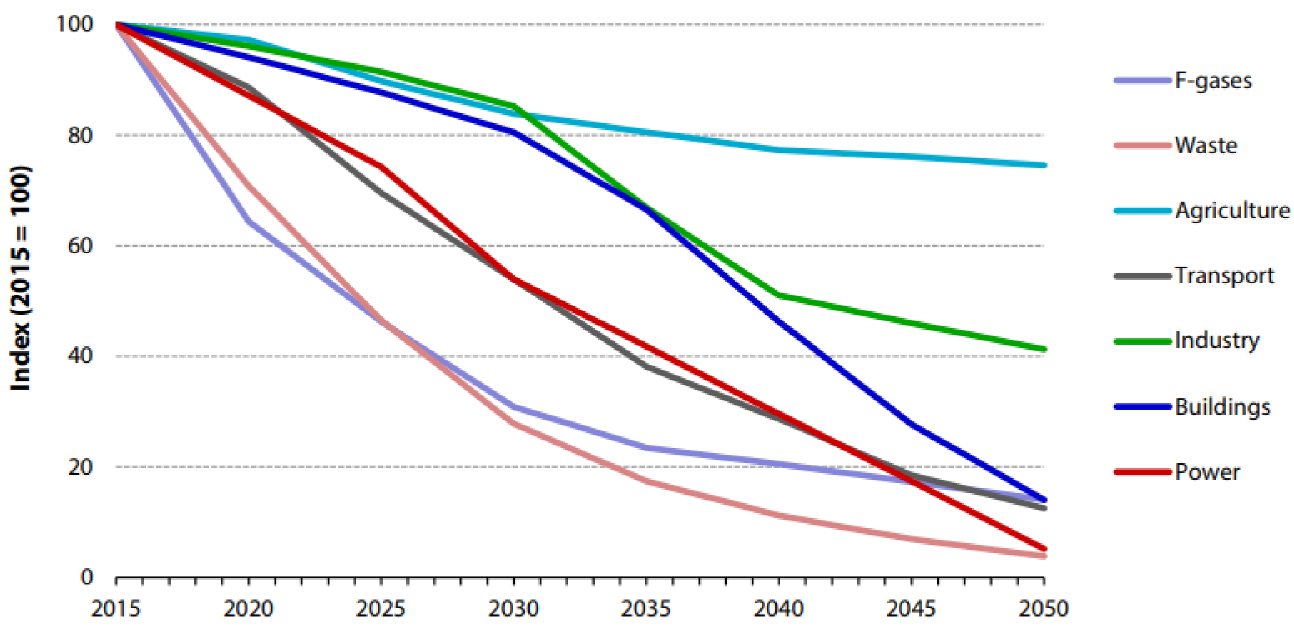

Figure 1 Sectoral emissions reductions to achieve 80% reduction on 1990 levels (**Source: UK CCC**)

During the Fourth Assembly, the Environment and Sustainability Committee conducted an **inquiry into a Smarter Energy Future for Wales**. The recommendations of the inquiry included the introduction of "near-zero" carbon emissions building standards and extension of existing Welsh Government retrofit schemes (**Arbed** and **Nest**).

These recommendations generally align with those provided by the UK CCC for the UK in **Next-steps for UK heat policy**. This emphasises "low-regrets" policies in the near term, including:

- Ensuring new build is energy efficient and designed to accommodate low carbon heating;
- Promoting energy efficiency improvements to existing buildings;
- Building low carbon heat networks;
- Installing heat pumps in buildings not connected to the grid; and
- Injecting 5 % biomethane into the gas grid.

The UK CCC report includes the **Arbed scheme** in Wales as an example of the broader benefits of an area-based retrofit programme. Near-zero carbon emissions building standards and extending retrofit programmes have been recommended as priorities in each examination of how to reduce carbon emissions in Wales.

Looking further to the future, the UK CCC report highlights the need for the UK Government to make a decision, between 2020 and 2025, to prioritise either heat pumps or a hydrogen gas network for homes currently on the gas network. Either option could be deployed alongside district heat networks and heat pumps for off-grid homes.

3. Energy efficiency and funding schemes

Wales has slightly higher **per capita residential emissions**, at 1.8 t CO_2e per person per year, than the UK average of 1.7 t CO_2e per person per year. Local climate affects this, but Wales also has more inefficient buildings than England on average, as indicated by **Energy Performance Certificates (EPCs)** (*Figure 2*).

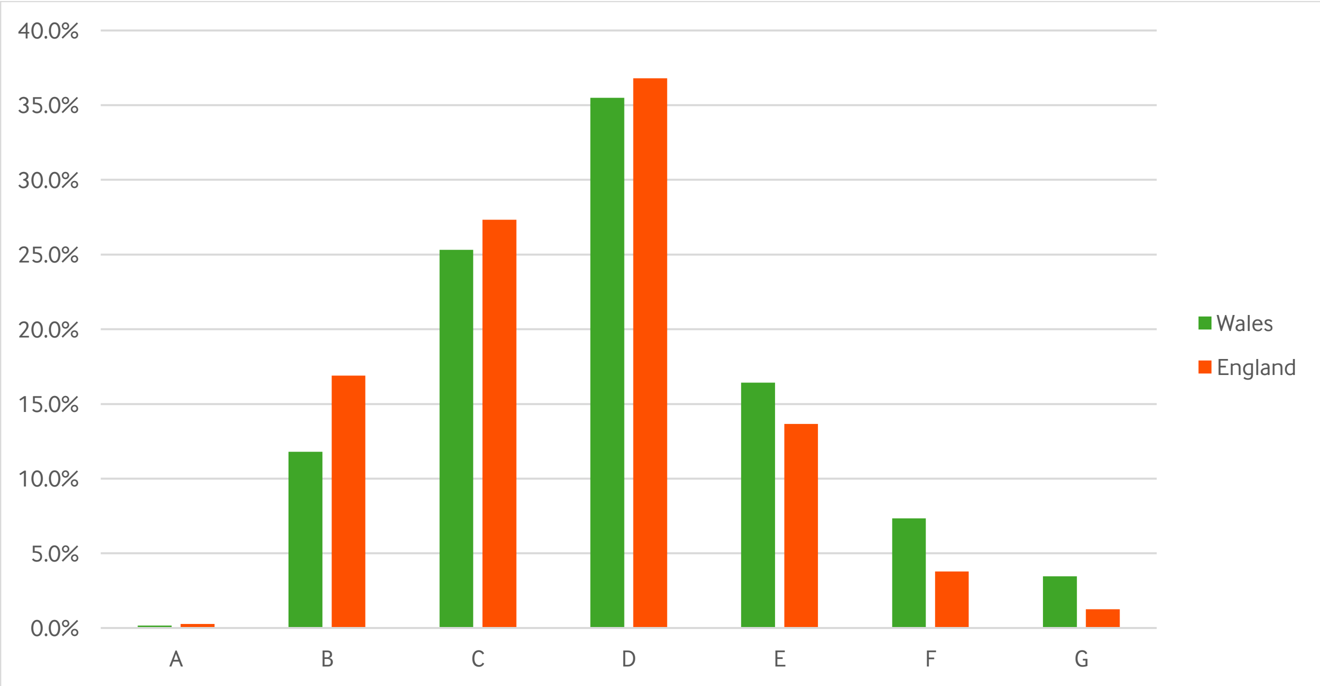

Figure 2 ***EPCs lodged in 2017 in England and Wales by Energy Efficiency Rating*** (Only includes houses sold or let in 2017)

This energy inefficiency, along with lower than average household income, contributes to fuel poverty. The Welsh Government has a commitment to **eradicate fuel poverty**, as far as reasonably practicable, by 2018 but currently **23% of households** in Wales live in fuel poverty. England has a significantly lower **fuel poverty level of 11%**, although this is measured differently.

Two contributing factors are that Wales has a higher proportion of solid-wall homes (**29% compared to 27% for the UK**) and properties off the gas grid (21% compared to 15% for the UK). These factors correlate strongly with **fuel poverty in England** (analysis unavailable for Wales).

Improving energy efficiency

In its advice to the Welsh Government, the **UK CCC identifies energy efficiency improvements**, such as solid wall insulation, as having the potential to provide 8% of the reduction needed to reach the 2050 carbon emissions target. These improvements, when correctly installed, have the potential to improve comfort, remove damp and reduce fuel poverty. The UK CCC recommendations include a full housing condition survey (last carried out in 2007) and new low-carbon building standards to avoid costly retrofits in future.

Although new building standards can help significantly in reducing emissions, 70% of the housing stock that will **exist in Wales in 2050 was built before 2000**. In order to improve the energy efficiency of these homes, the Welsh Government has invested £240 million in the **Warm Homes Programme** since 2012, and is investing an additional £104 million in the four years from 2017 to 2021.

The Warm Homes Programme has consisted of different schemes throughout its existence:

- **Arbed phase one** funded measures for 7,500 homes between 2009 and 2012. These included renewable heat sources such as air source heat pumps and solar hot water, alongside energy efficiency improvements;
- **Arbed phase two** operated between 2012 and 2015. It provided efficiency measures for 6,500 homes, a significant proportion of which received external wall insulation; and
- **Nest** began in 2011. It provides advice to help reduce energy bills and home assessments with efficiency improvements for residents on means tested benefits.

The schemes each received positive evaluation reports **(Arbed**, **Nest**) with most recipients reporting high levels of satisfaction with the home improvements.

Renewable Heat Incentive

The Renewable Heat Incentive (RHI) is a UK Government scheme that provides funding for installation of renewable heat schemes for **domestic** and **commercial** customers. It began in 2011 and includes funding for heat pumps, solar hot water and biomass heat supplies.

Under the non-domestic RHI **1,768 schemes have been installed in Wales** with a total capacity of 350 MW, representing 9% of the capacity installed under the non-domestic RHI in Great Britain. There have been over 4,000 domestic installations in Wales, 7% of the domestic RHI total.

In February 2018, the National Audit Office assessed the value for money of the RHI. Discussing the success of the scheme rolled out by the department for Business, Energy and Industrial Strategy (BEIS), **it concluded that**:

> The Department showed flexibility in rolling out the scheme, adjusting scheme objectives to respond to a changing strategy and over optimistic initial planning assumptions and it is learning lessons for the future. Measures it introduced to control the scheme's costs have enabled it to avoid the budget control problems that occurred on a similar scheme in Northern Ireland.
>
> However, the Department has not achieved value for money. It does not have a reliable estimate of the amount it has overpaid to participants that have not complied with the regulations, nor the impact of participants gaming them, which could accumulate to reduce the scheme's value significantly.

The UK Government has also launched a **scheme to drive innovation** in low carbon heating technologies. Innovative technologies, processes and business models are eligible for support and grants of between £200,000 and £2 million. The total funding for the scheme is £10 million. It aims to produce better ways of providing low carbon heat in existing buildings.

4. Low carbon heat sources

District Heating

District heating replaces individual gas boilers in homes with a centralised heat source. Hot water is piped around the network to provide each home with heat. District heat networks vary in size, from small groups of properties to thousands of homes. They are typically **more common in non-domestic buildings and high-rise dwellings**, where there is a predictable heat demand in a concentrated area. However, there is interest in developing heat networks in order to supply low carbon heat to larger areas.

District heating can provide zero carbon heat by using sources such as biomass boilers or heat pumps (see below). Alternatively, it may use waste heat from large facilities such as industrial processes, power stations, or energy-from-waste plants. While not strictly zero carbon, these heat networks provide a dramatic increase in efficiency by using heat that would otherwise be discarded. Using excess heat from industry in Wales through district heating was a key policy recommendation for the Welsh Government **from the UK CCC**.

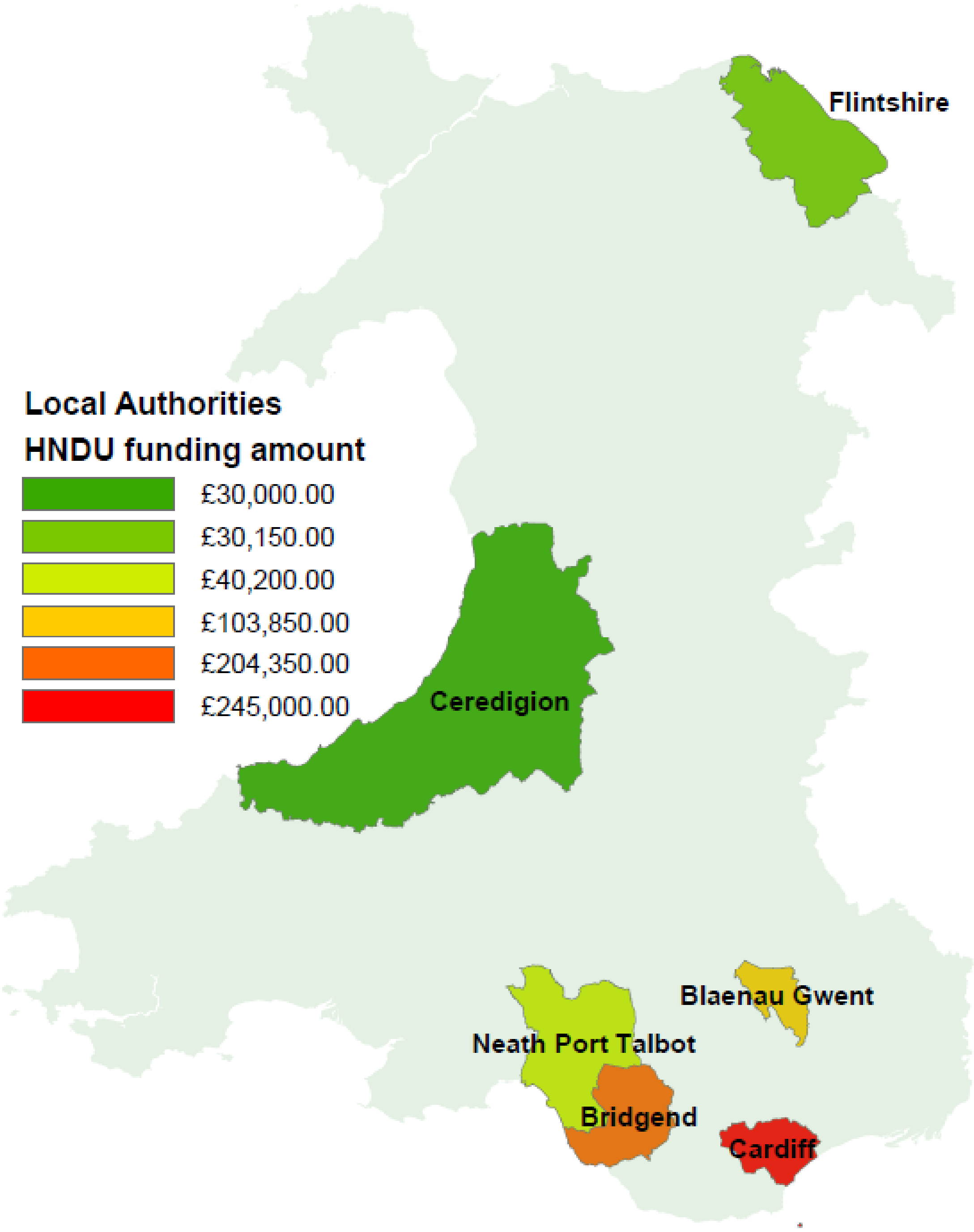

Figure 3 Map of HNDU funding for local authorities in Wales (Source: Research Service)

The UK Government's **Heat Networks Delivery Unit** (HNDU) provides funding and support for local authorities for heat network project development. Five percent of the total funding of £14 million has been provided to local authorities in Wales (*Figure 3*).

Cardiff has received the most funding of local authorities in Wales. This was granted in 2013 for consideration of a district heating scheme using heat from **Trident Park Energy from Waste Plant** (Figure 4). Cardiff Council has considered another scheme using heat pumps (see below).

Examples of existing large-scale district heating networks elsewhere include:

- Nottingham, which is the **largest system in the UK**. Heat from an energy-from-waste facility is distributed to over 5,000 domestic users and 100 commercial buildings;
- Southampton, which uses heat from gas fired **combined heat and power**, alongside geothermal sources, saves around 10,000t of CO_2e per year;
- Iceland, **95% of homes are supplied by district heat, mainly from geothermal sources;** and
- Denmark, **64% of households are supplied by district heat**, mainly from fossil fuel combined heat and power. The system is now transitioning to heat pumps and energy-from-waste plants.

Figure 4 Trident Park Energy from Waste plant (Copyright Gareth James and licensed for reuse under Creative Commons Licence*)*

The Scottish Government supports district heating through its £5 million **District Heating Loan Fund**. It also established the **Heat Network Partnership**, a collaboration of agencies focused on the promotion and support of district heating schemes in Scotland. This is supporting the development of numerous district heating schemes including a **£3.5 million water source heat pump in Glasgow**.

Heat pumps

Domestic heat pumps

Electric heat pumps work by extracting energy from an external heat source. Domestic heat pumps can extract heat from either the **ground** or the **air** (Table 1). Temperatures underground rarely drop below 10˚C in Wales (this allows for the higher efficiency of ground source heat pumps) and air source heat pumps can work with external temperatures down to -15˚C.

Since heat pumps extract heat from an external source, rather than generating heat directly, they can provide more heat than their electrical energy input (by a factor of 2-4 times). This results in **efficiencies of greater than 100%**, making them far more efficient than traditional electrical heating.

	Air source	Ground source
Cost of installation	£5,000-10,000	£10,000-18,000
Annual running costs	~equal to new gas boiler	~£100 less than new gas boiler
Typical efficiency	200-300%	300-400%
External space required	2 m^2 with good air flow	External ground for trench (~30m long) or borehole (15-150m deep)

Table 1 Typical parameters for domestic heat pumps

Heat pumps are most efficient when providing water at lower temperatures (45-50˚C) than traditional boilers. As a result, heat pumps require larger radiators or underfloor heating. The most efficient method for heating the home with a heat pump is gradually over several hours. This has the potential advantage of shifting energy use to off-peak hours. Savings can then be increased through dual price tariffs such as **Economy 7** that reduce the cost of off-peak electricity. **Smart tariffs**, with greater flexibility through the use of smart meters, may allow this saving to be increased in future.

Heat pumps have no emissions at the point of use. This not only reduces carbon emissions but improves local air quality, especially compared to **solid fuels**, such as coal and wood. The reduction in carbon emissions depends on the electricity mix used to power the heat pump. A fully renewable energy supply will result in zero carbon emissions but even with the current energy mix carbon emissions are cut by around **50% compared to gas boilers**.

The greatest cost savings and emissions reductions are made when replacing old LPG or oil boilers, or electric heating. For example replacing an inefficient oil boiler may result in savings of £400 per year and reduce carbon emissions by over **5t CO2e per year**. This suggests off gas network homes may be the best location for domestic heat pumps.

Currently relatively few homes have heat pumps (<100,000 across the UK), despite Government schemes to encourage their installation. 120 were installed in Wales between 2010 and 2012 under **Arbed phase one**. Between April 2014 and December 2017, 1,900 off-grid heat pumps were accredited in Wales under the **RHI**. One issue that may be slowing down roll-out is the high upfront cost of heat pumps, and the lower potential savings due to the lack of a carbon price on domestic gas consumption.

Heat pumps for off gas network buildings have been **identified by the UK CCC** as a "low-regrets" target for near-term low-carbon heat installations. Given the high proportion of off gas network homes in Wales, and the rapidly increasing proportion of renewable energy, this provides a significant opportunity for decarbonising heat in Wales.

Water source heat pumps

Water source heat pumps are typically larger scale and used for district heating schemes. They can work off surface water such as ponds, rivers and lakes or from underground water (sometimes also called ground-source). There are several sites across South Wales suitable for ground water heat pump schemes.

One potential source is water in abandoned mines. A **Cardiff University study** has assessed the potential for energy from mines in the South Wales coalfield. The study concluded that mines in the coalfield have potential for up to 72MW of power, enough to heat 6,500 homes, from currently monitored sites. A **£9.4m scheme** has been launched in Bridgend using the Caerau colliery. The scheme aims to heat 1,000 homes and reduce energy bills in one of the most deprived wards in Wales.

There is another project, funded by **Innovate UK**, which is exploring the potential for a **large heat pump** to heat Cardiff. This would extract heat from a shallow aquifer below the city, which is warmer than expected due to the urban environment. A nursery school in the Grangetown area of Cardiff **has been retrofitted with a heat pump system** as a proof of concept.

Heat pumps in other countries

While heat pumps are relatively uncommon in Wales and across the UK, there are several countries that have many more. **Several million have been installed across Europe**, particularly in countries with plentiful low carbon electricity, such as France, Sweden and Finland. One key driving factor in these countries is **lower electricity to gas price ratios**. The **Drammen heat pump** in Finland provides over 30MW for a district heating system serving over 200 large buildings.

Solar hot water

Solar hot water systems (Figure 5) use heat from the sun to provide hot water. In the UK, there is enough solar resource to provide **80-90% of hot water needs in summer, and 20-30% in winter**. It is limited to the provision of hot water, since it does not provide sufficient energy at the times of year when heating is required. Solar hot water systems are often combined with a conventional boiler or immersion heater which can provide heating and boost the hot water supply.

Figure 5 Domestic solar hot water panels (Copyright Terence Wiki and licensed for reuse under ***Creative Commons Licence***)

According to the **Energy Saving Trust**, a solar water heating system costs around £3000 to £5000 to install. Typical savings are £60 per year when replacing gas heating and £75 per year when replacing electric immersion heating, although this will vary from user to user.

Solar hot water systems were supported under Arbed, with **1,080 installations under phase one**. A further 740 schemes are been installed in Wales under the **domestic RHI**. They can reduce carbon emissions by 300-500kg CO2e per installation per year but may compete for south-facing roof space with solar photovoltaics that can provide renewable electricity.

Biofuels

Biofuels include any **renewable natural material for power, heat and liquid fuels**. The most common example for heating is wood, although biogas can be made from a range of sources.

Biofuels are generally viewed as being low carbon, since emissions produced by burning the fuel have recently been captured during growth of the fuel source. This can be combined with carbon capture and storage (CCS) (see **low carbon electricity research briefing** for more details) during burning of the fuel to result in potentially net negative carbon emissions. However, the carbon emissions from biofuels depend on the sources and production methods needed to convert them into fuels.

The greatest limitation for biofuels is the demand for land to produce crops. Biofuel production was **associated with the food price "crisis" of 2008**, although food prices have dropped since then despite increasing biofuel production. Additionally, there are a number of other uses of biofuels that may need to take precedence over domestic heating. **The UK CCC highlights that construction should be the priority for wood use,** as a very efficient form of carbon capture. Difficult to decarbonise sectors, such as industry and aviation, may need the majority of the limited supply of biofuels.

The UK CCC estimates that around **10% of our primary energy could come from biofuels in 2050**. This is similar to the **UK Government figure of 12%.** To achieve emissions reductions it is essential that biofuels are sustainably sourced and their production is low carbon. Future technologies, such as biofuels from algae or CCS, may allow expansion of their role.

Biomass

Biomass refers to solid biofuels. For the purposes of heat, this is almost exclusively wood that can be supplied as logs, pellets or chips. Domestically, biomass can be used to fuel stoves that provide heat to a single room or for cooking, or boilers to provide hot water and central heating. While the UK may seem like a suitable source of wood, **far more is imported than produced** and **95% of wood pellets for energy are imported**.

An estimated **130,000 households in Wales use wood fuel**, although a minority (~15%) use it as the only source of heat for their home. Just over 1,000 homes have had **biomass boilers installed under the RHI**. Replacing an oil heating system with biomass saves an **estimated 5-10t CO2e per year**. However, there are concerns over the impact on local air quality, particularly in built-up areas, resulting in a **potential ban on wood burning stoves in London**.

Commercial-scale biomass boilers may be used to provide heat to businesses and community buildings. For example, the Senedd (Figure 6) of the National Assembly for Wales is fuelled by a **single 360 kW biomass boiler**. The **Welsh Government provided £9.3m of funding** to the Hywel Dda Health Board to improve its energy efficiency, part of which paid for a new biomass boiler at Glangwili Hospital.

Industrial-scale biomass boilers could be used to run combined heat and power plants or district heating schemes. Examples of this include the **Llanwddyn Village Biomass Heat Network**, where a 600 kW biomass boiler was installed to provide heat to a school, community centre and 42 homes, saving over 300t CO_2e per year. Larger schemes and combined heat and power plants are more likely to make viable CCS targets.

Figure 6 Senedd building made extensive use of wood as a building material and is heated entirely using a biomass boiler (Source: National Assembly for Wales)

Biogas

Biogas can be produced from anaerobic digestion of waste. It can be produced from **sewage, food waste or by-products from industry or agriculture**. The gas produced can be combusted to produce electricity and/or heat, or upgraded to biomethane by removing impurities and then injected into the gas network. The use of waste material bypasses some of the issues with other biofuels.

There are around **30 biogas plants in Wales**. The largest is a food waste plant in Cardiff that **generates enough electricity to power 4,000 homes**. While the majority of biogas plants currently generate electricity, **injection of biomethane into the grid** could help reduce carbon emissions from domestic heat without changes in infrastructure or consumer behaviour. **This could contribute up to 5% of gas supply**.

5. Long term measures

The options above can all be carried out to some extent in the near term and are described by the UK CCC as “low regrets” actions. Looking further into the future, it appears unlikely that biofuels will contribute more than 10% of heat in the long term, and their use may be prioritised for other areas. The **UK CCC identified** two potential long term solutions for decarbonising heat in the UK, either:

- Heat pumps and district heating will have to be committed to and rolled out across the country; or
- Hydrogen will need to replace natural gas throughout the gas network.

Hydrogen

Production

One key challenge for hydrogen is producing it efficiently and in a low carbon manner. Electrolysis of water to produced hydrogen is possible, but converting electricity into hydrogen into heat is much less efficient than using heat pumps. As a result very low cost electricity would be needed to make hydrogen produced through electrolysis cost competitive.

One potential advantage is that hydrogen is easier to store than electricity and so could be produced from renewable energy sources when electricity supply is high (sunny and windy days) and demand is low. However, producing all of UK heat from hydrogen through electrolysis would require an additional **400 TWh per year of electricity generation**. **Current electricity demand in the UK is 360TWh** per year.

Hydrogen can be produced from biofuels, but this suffers from the same volume limitations discussed above. One possibility is combining CCS with hydrogen production from biofuels for negative emissions, if it proves necessary to maximise the carbon reducing impact of biofuels, but this will remove biofuels from other potentially critical uses such as industry and aviation.

The UK CCC identified steam reforming of natural gas as the most likely source of hydrogen. This method already accounts for the **majority of hydrogen production**. It involves using steam and high temperatures to break down natural gas to hydrogen and carbon dioxide.

CCS must be deployed to capture the carbon emissions from this process. The advantage of this process over burning natural gas is that hydrogen production would be more centralised allowing for more economic CCS.

Wales does not have a natural advantage for exploring this option. Natural gas resources in Wales are extremely limited due to the **moratorium on fracking**, and few carbon sequestration sites have been identified in Wales. The South Wales coalfield, the largest site identified in Wales to date, has a potential **capacity of 150Mt CO_2**, compared to **4,600Mt for Scotland's offshore CO_2 storage**. If Wales were to convert to hydrogen it is likely that the supply will come from elsewhere.

Converting to hydrogen

The **H21 Leeds City Gate project** studied the viability of converting the natural gas network in Leeds to hydrogen. It found that the conversion process would be very similar to that carried out in the 1970s to convert the UK gas network from town gas to natural gas. The polyethylene pipe network **currently being installed to improve safety** is suitable for carrying hydrogen.

Leeds was chosen due to its size and location. At over 1% of the UK population it represents a viable stepping stone to conversion across the UK. Steam methane reforming plants could be built alongside the gas works at Teesside to produce hydrogen, and salt caverns near the Humber could be used for hydrogen storage. The safety concerns for hydrogen distribution are viewed as being no greater than those for natural gas.

Domestic appliances would require upgrading to burn hydrogen. The H21 project estimated that this would cost just over £1 billion, around half the total cost of conversion, for 250,000 homes and over 100 industrial users.

BEIS is now undertaking a **£25 million project** to explore the potential use of hydrogen gas for heating UK homes and businesses. This will include testing hydrogen appliances and developing a hydrogen quality standard.