Cadent
Your future Gas Network

Converting wind into hydrogen

for heating homes

How much wind generation capacity is needed to make hydrogen for domestic heating?

"Having a good grasp of the technical issues on decarbonisation is vitally important to help policy makers make properly informed, evidence-based policy decisions. This paper takes a fresh and rigorous look at how much wind capacity could be needed to make green hydrogen for heating, an area where previous reports have produced numbers that could lead to policy makers drawing incorrect conclusions on the viability of hydrogen for domestic heating."

Dr Angie Needle
Director of Strategy

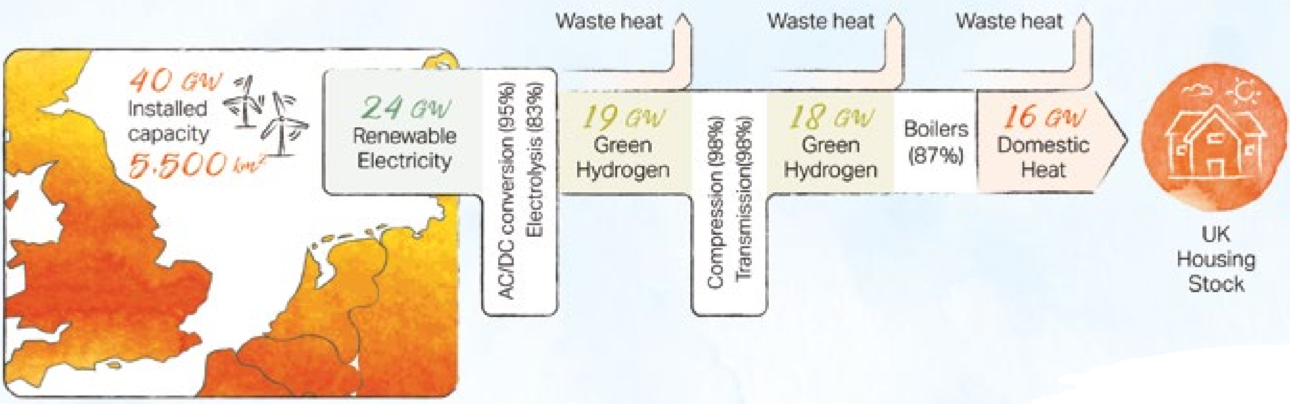
Overview

When energy is converted from one form to another some of it is inevitably lost. The number of conversions, and the impact of each step is important in determining the overall efficiency of the process. Some academics, commentators and heat pump proponents have argued that heating with hydrogen created from wind generation and electrolysis (also called 'green hydrogen') is an inefficient process.

They have implied there will be insufficient wind to meet possible demand for hydrogen for domestic heating. Our view set out in our previous report 'Our Green Print – Future Heat for Everyone' is that both heat pumps and hydrogen are likely to play a key role in decarbonising heating in the UK and we therefore wanted to take a fresh look at the data and analysis of this complex issue to understand how much wind is likely to be required to make green hydrogen for heating, and indeed whether this could therefore be a constraint.

Our conclusion is that **there could be enough wind capacity to decarbonise domestic heating using hydrogen**. To supply every home currently connected to the gas network with green hydrogen for heating by 2050 would require **80 GW** of offshore wind capacity, assuming the same level of energy consumption (which is a conservative estimate as properties should in future be better insulated). The overall efficiency of the process to convert electricity into hydrogen and then into heat generated is estimated at **66%** (which is calculated by dividing heat demand by electricity output).

The 80 GW we calculate would reduce further to around **40 GW** by recognising that hydrogen will be only one of the long-term technologies for decarbonising heating and that many homes may choose to install heat pumps or other heating solutions. A pragmatic assumption would be to assume that half of the homes currently connected to the gas network are converted to hydrogen (and use the same amount of energy for heating). This aligns with the Climate Change Committee's 'headwinds' scenario, where hydrogen demand for residential heat is 145 TWh/year in 2050, around half of current annual residential natural gas demand.



When you factor in hydrogen storage and the fact that some consumers will choose heat pumps, green hydrogen for heating homes needs 40 GW of wind.

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A summary of the ten steps in our analysis

Our analysis of how much wind generation is likely to be needed to make hydrogen for domestic heating is set out in ten steps illustrated in Figure 1 below using demand data from 2021. The starting point for our analysis is the level of heat demand. As there are no direct calculations of heat demand, this must first be derived from the calculated supply of gas that flows into people's homes. Government data shows that the supply of gas to residential homes in 2021 was 318 TWh. This equates to 73 GW as a rate across six months.

1. The first step is to adjust for half of homes currently connected to the gas grid converting to hydrogen, this halves the supply needed to **36 GW** as a rate across six months.

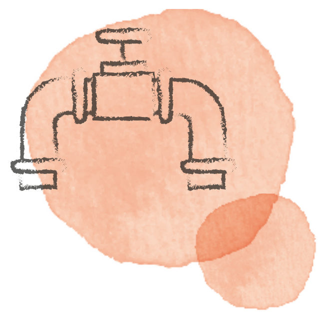
2. Next we can convert this into a demand for heat which we do by removing the amount lost due to boiler inefficiency, 87%, giving **32 GW** of heat demand.

3. Demand for gas, and in turn hydrogen, will be seasonal (76% is used in the autumn/winter months October-March), as such storage can play a significant role in reducing the electricity production and offshore wind generation capacity for hydrogen. Our calculations show that adjusting for the availability of seasonal storage could reduce the capacity needed to meet demand by 50% – giving us heat demand of **16 GW on an annualised basis** rather than across six months.

4. The next step is to convert heat demand back into the amount of hydrogen required to enter the home by adjusting back for the efficiency of a hydrogen boiler (this in essence reverses out the earlier adjustment made for gas boiler efficiency). This is stated in analysis for the Climate Change Committee (CCC) as 87% – giving us **18.2 GW**.

5. We then adjust for losses incurred through the transmission of hydrogen through the gas network which we determine as 2% – giving us **18.5 GW**.

6. Step five is to adjust for losses incurred through the compression of hydrogen as it is injected into the transmission network, which is calculated as a further 2% – giving us **18.9 GW**.



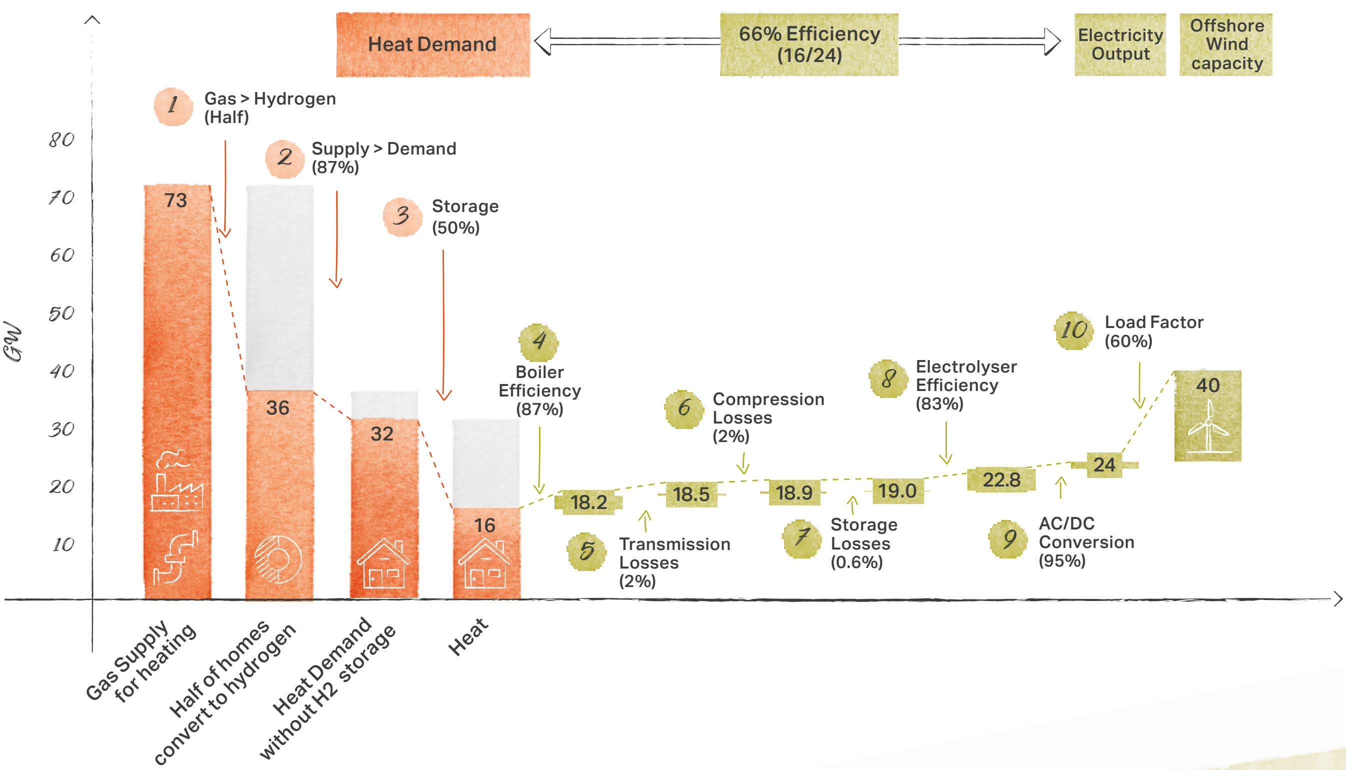
7 A proportion of the hydrogen produced in summer months would need to be stored to help meet higher winter demand. This requires additional compression, assessed as consuming another 0.6% of the total hydrogen supplied, adding less than 1 GW, so still around **19 GW**.

8 The next step is to factor in that the process of producing so-called green hydrogen through electrolysis which is not 100% efficient and is in fact set out in government analysis as 83% efficient. This adjustment gives us **22.8 GW**.

9 To convert this figure into electricity output requires us to adjust for the conversion of electricity from alternating current (AC) as it is produced from wind turbines to the direct current (DC) needed by electrolysers, this process is 95% efficient. This gives us an electricity output of **24 GW**.

10 Finally, to convert electricity output into the requirements for offshore wind capacity requires us to adjust for the so-called load factor as wind farms do not always run at full capacity, largely because of variable wind speeds. This is conservatively calculated at 60% for new build wind turbines – giving us **40 GW** of required wind capacity.

Figure 1: How much wind generation is required to make hydrogen for domestic heating?



Our analysis in greater detail

Our analysis of how much wind would be required starts with total UK domestic heat demand in 2021, which has to be derived from the stated figure for gas that flows into people's homes, as there are no direct calculations of heat demand available. The government's energy statistics (DUKES)[2] show 2021 residential gas demand as 318 TWh or 73 GW, if stated as a rate across six months.

The ten steps to calculate the amount of wind capacity required to meet future heat demand using electrolytic (green) hydrogen are set out below citing the various authoritative sources we have applied in our calculations.

Step 1 Conversion from gas heating to hydrogen-for-heat

The first step is to scale down demand to the estimated level of conversion from gas to hydrogen - half of homes currently connected to the gas grid. This reduces the supply needed from 73 GW – as stated as a rate across six months, to 36 GW on the same basis.

Step 2 Heat demand from hydrogen

The next step is to convert gas output into a demand for heat which we do by removing the amount lost due to boiler inefficiency, which is stated in CCC analysis as 87%[1,2] – giving **32 GW** of heat demand if stated as a rate across six months.

Step 3 The impact of storage

Storage has a key role to play in the supply of hydrogen for domestic heating. This is because residential gas demand is spread across the year. The majority is driven by heating demand across the winter months of October to March[3] (76%). Across the remaining six months of the year, heating demand reduces into the summer with hot water and cooking demand throughout, before heat demand rises again as the next winter approaches. This is illustrated in Figure 2 below.

The hydrogen needed to generate heat does not of course need to be produced when the demand occurs.

One of hydrogen's most significant benefits relative to electricity is its ability to be stored over long durations, e.g., in purpose-built salt caverns, of which the UK has numerous suitable geologies. This ultimately reduces the amount of wind capacity required. In their analysis for the government, Element Energy estimated the storage potential from UK salt beds as 322 TWh.[4] Hydrogen can also be stored in depleted gas fields in and around the UK, as has been documented in several publications[5] with Edinburgh University suggesting that more than 2,000 TWh could be stored in depleted UK fields. Centrica have recently set out plans to convert the Rough gas storage field to enable up to 10 TWh of hydrogen storage by itself.[6] For comparison, even bullish hydrogen demand scenarios imply a total storage requirement of 56 TWh by 2050,[7] far below the storage potential identified in the publications referenced above. So, in the future hydrogen can be readily stored when demand is low, with supply then being available to be released to meet peak demand later in the year.

Using National Grid's daily Seasonal Normal Demand values,[8] all peaks and troughs of daily annual natural gas (or future hydrogen) demand could be met using a production source outputting every day at a flat rate if 28% of annual demand could be stored. This is illustrated in Figure 3 below.

These points on the role of hydrogen storage are important as assuming hydrogen can be produced all year and stored when needed changes the heat demand to be met from 32 GW to **16 GW**.

Figure 2: National Grid daily and cumulative heat demand

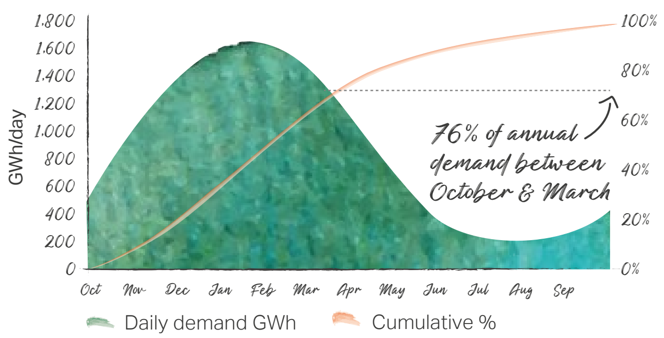
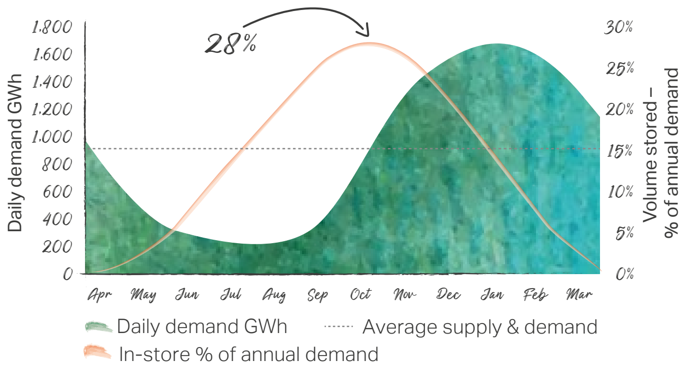


Figure 3: National Grid Gas demand with storage stock needed



Step 4 Boiler efficiency

The next step is to convert heat demand back into the amount of hydrogen required to enter the home by adjusting back for the efficiency of a hydrogen boiler, 87%[9] – which in essence reverses out the earlier adjustment made. This gives a requirement for 18.2 GW of hydrogen to meet the 16 GW of heat demand.

Step 5 Transportation losses

Losses of gas/hydrogen are driven by the need to use compressors to facilitate the transport of gas from large transmission pipes, through the distribution network and ultimately into people's homes, as well as losses from leakage during transportation.

Compressors can be driven by consuming some of the fuel being transported, i.e., hydrogen. To understand the proportion of losses from the use of compressors, we utilise the findings from a paper written in 2006 by Ulf Bossel.[10] This notes that compression to transmit hydrogen through pipelines would consume '1.16% of the local flow'.

In terms of losses through leakage, whilst the characteristics of hydrogen mean any leaks would release 1.2 to 2.8 times as much volume as natural gas,[11] the energy density of hydrogen is a third of natural gas. This means the energy lost from leakage will at worst be around the same as the energy lost from distributing gas today, which is approximately 0.5%.[12]

Combining these factors and erring on the conservative side, we assume future losses from transporting hydrogen in pipelines to be 2% overall. This means **18.5 GW** of hydrogen needs to be injected into the distribution network to deliver 18.2 GW of hydrogen to customers' properties.

Step 6 Losses from the compression of hydrogen before it enters the transmission network

Before hydrogen enters the transmission system it needs to be compressed, which results in some losses. Electrolyser output pressure is given by government as 3 MPa (or "MegaPascal")[13] and would need to be compressed up to 7 MPa, which is the entry pressure of the transmission system.[14] Applying this analysis means that, compression at this scale would result in energy losses of 2%. The 18.5 GW hydrogen required post-compression therefore gives a requirement for **18.9 GW** hydrogen pre-compression.

Step 7 Compression losses from seasonal storage

Storing hydrogen at scale would involve increased levels of compression. However, only a proportion of the hydrogen supplied would need to be stored – up to 28% as set out above. Again, in reference to Bossel (2006) we can assess the losses involved in compressing hydrogen from 7 MPa to storage pressures of ~20 MPa.[15] This assessment implies losses of a further 2% for the hydrogen that is stored – up to 28% of overall supply. Across the full supply volume, this then implies efficiency losses of up to 0.6%. This increases the amount of hydrogen to be produced to marginally, so still around **19.0 GW**.

Step 8 The efficiency of electrolysers

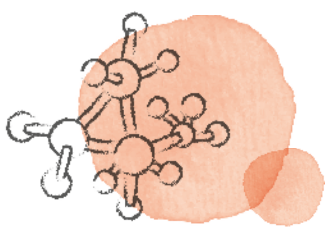
The technology in electrolysers has evolved significantly over the last twenty years and will continue to do so as we move into the 2030s. For this reason, the UK Government project electrolyser efficiency in the 2030's will be 83%,[16] which is higher than has been assumed in historical academic assessments, with potential for emerging technologies to increase efficiencies still further. This means **22.8 GW** of energy is needed to reach this point of the process.

Step 9 The conversion of current from AC to DC

Electricity for a wind farm needs to be converted from the AC turbine output to the DC input needed by an electrolyser. This is estimated to result in losses of around 5% of the energy.[17] This means **24 GW** of electricity output is needed to meet **16 GW** of heat demand.

Step 10 The efficiency of wind farms (and load factors)

Wind farms do not always run at full capacity, largely because of the variability of wind speeds. The historical average load factor for UK wind farms is 39%. As new build turbines get larger between 2030 and 2040, the UK Government expect them to run at between 57% and 63% capacity.[18] For the purposes of our analysis, we use the midpoint of 60% efficiency. This means **40 GW** of offshore wind capacity energy is required to supply 24 GW of electricity output and in turn 16 GW of heat demand.



A comparison with the Hydrogen Science Coalition's work

Our analysis contrasts markedly with an assessment published by the Hydrogen Science Coalition (HSC). In their analysis published in 2022[19] the HSC assess the efficiency of hydrogen conversions as we have done here, but with differing and often outdated or poorly evidenced assumptions.

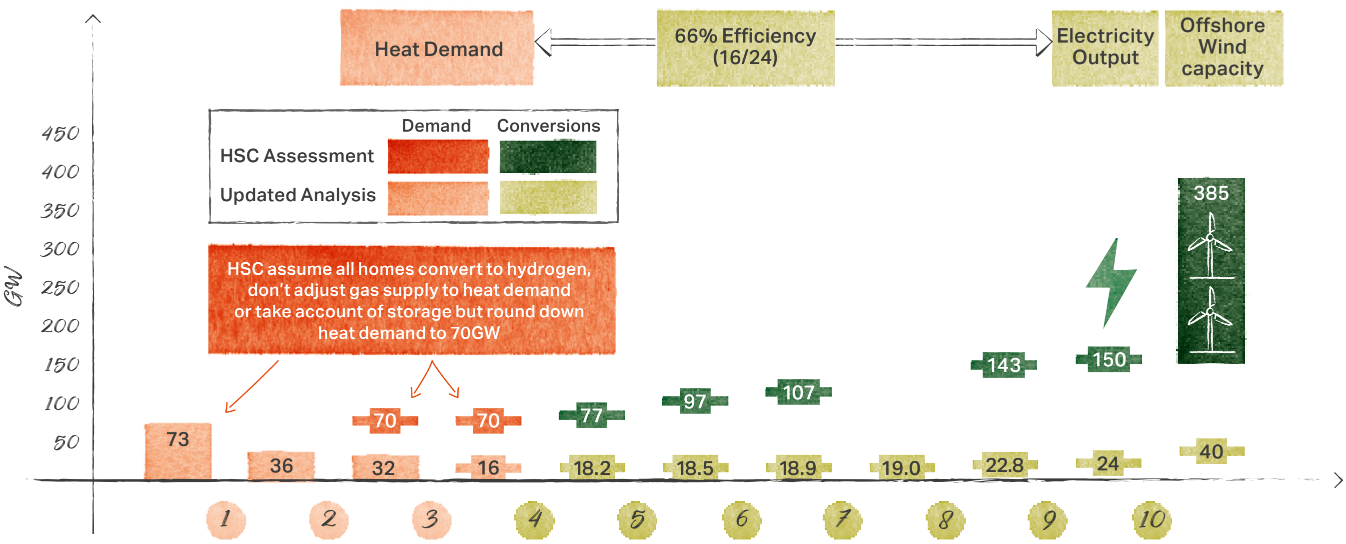
Their analysis suggests a huge 385 GW of wind is needed to produce the green hydrogen necessary to heat all UK's homes supplied by gas – nearly five times the 80 GW we calculate – and nearly ten times the 40 GW needed if only half the number of homes are connected for hydrogen, which is more plausible.

The key differences are that the HSC:

1. Assume all homes currently connected to the gas grid convert to hydrogen; we recognise the role of heat pumps in satisfying a share of heat demand so assume half convert to hydrogen.
2. Do not adjust gas supplied to obtain heat demand as we have done and therefore start with an inflated demand number – in essence double-counting the impact of boiler inefficiency (i.e., they miss step two in our analysis).
3. Do not adjust gas supplied to obtain heat demand as we have done and therefore start with an inflated demand number in essence double-counting the impact of boiler inefficiency (i.e., they miss step three in our analysis).
4. Through their analysis (steps four to nine) they assume a lower level of efficiency in transmitting electricity output into heat demand. They assess this as 47% versus our calculation of 66%.
5. They have assumed a much lower load factor in wind generation of 39% compared with the 60% we used because the base their assessment on historical performance.

Figure 4: HSC analysis in comparison

This illustrates how the HSC's analysis differs to our own more contemporary position.



Our assumptions and sources of data

We have set out in Table 1 below the key assumptions we have made and compared these with those used by the HSC. We also set out the key documents the sources we have used in our analysis.

Table 1: Our calculations, assumptions, and sources

		HSC	Updated	Source
Target heat demand	**Reported Gas Demand**	318 TWh	318 TWh	DUKES
	Implied Heat Demand	318 TWh	277 TWh	CCC
	6-Months Implied GW	73 GW	63 GW	Calc
	50% Conversion to H2	36 GW	32 GW	Calc
	Annual Implied GW	18 GW	16 GW	Calc
Capacity required	**Heat**	70 GW	16 GW	Output
	Boilers	90%	87%	CCC
	Transmission	80%	98%	BEIS
	Compression	90%	98%	Bossel (2006)
	Storage	n/a	99.4%	Bossel (2006)/ Foster-Wheeler
	Electrolysis	75%	83%	Hydrogen Strategy
	AC/DC conversion	95%	95%	Fan et al.
	Electricity	150 GW	24 GW	Calc
	Load Factor	39%	60%	BEIS
	Installed capacity	385 GW	40 GW	Calc

References

1. Climate Change Committee, Sixth Carbon Budget Data Set.
2. Digest of UK Energy Statistics (2022).
3. Annex_2_-_wholesale_cost_allowance_methodology_v1.14.xlsx, Ofgem (2022); CWV and Seasonal Normal Demand, National Grid.
4. Hydrogen supply chain evidence base, Element Energy (2018).
5. Does the United Kingdom have sufficient geological storage capacity to support a hydrogen economy? Estimating the salt cavern storage potential of bedded halite formations, Williams et al (2022).
6. Centrica.
7. Future Energy Scenarios (System Transformation Scenario), National Grid (2022).
8. CWV and Seasonal Normal Demand, National Grid.
9. Hydrogen in a low carbon economy, Climate Change Committee (2018).
10. Does a Hydrogen Economy Make Sense?, Ulf Bossel (2006).
11. H21 Phase 1 Technical Summary Report.
12. Gas Governance Shrinkage Assessment and Adjustment 2021-22.
13. Hydrogen Production Costs, BEIS (2021).
14. Gas Quality Parameters at NTS Entry Points, National Grid.
15. Hydrogen Storage and Flexible Turbine Systems WP2 Report – Hydrogen Storage, Foster-Wheeler for the ETI.
16. Hydrogen Production Costs, BEIS (2021).
17. Wind-farm and hydrogen-storage co-location system optimization for dynamic frequency response in the UK, Fan et al.
18. Electricity Generation Cost Report, BEIS (2020).
19. Hydrogen for heating? A comparison with heat pumps (Part 1), Hydrogen Science Coalition (2022).

Click the reference titles to read more online

About Cadent

Cadent is the largest gas distribution company in the UK

We deliver natural gas to over 11 million homes and businesses throughout the North West, West Midlands, East Midlands, South Yorkshire, East of England and North London. We are responsible for the installation and maintenance of the gas distribution network, ensuring that it operates safely and reliably for those who need it. We also help homes, businesses and renewable gas suppliers connect to our network.

We are in the process of demonstrating that the conversion of our existing gas network to deliver 100% hydrogen is safe, technically feasible and economical. As part of this programme, we are exploring blending hydrogen and the process of conversion to 100% hydrogen.

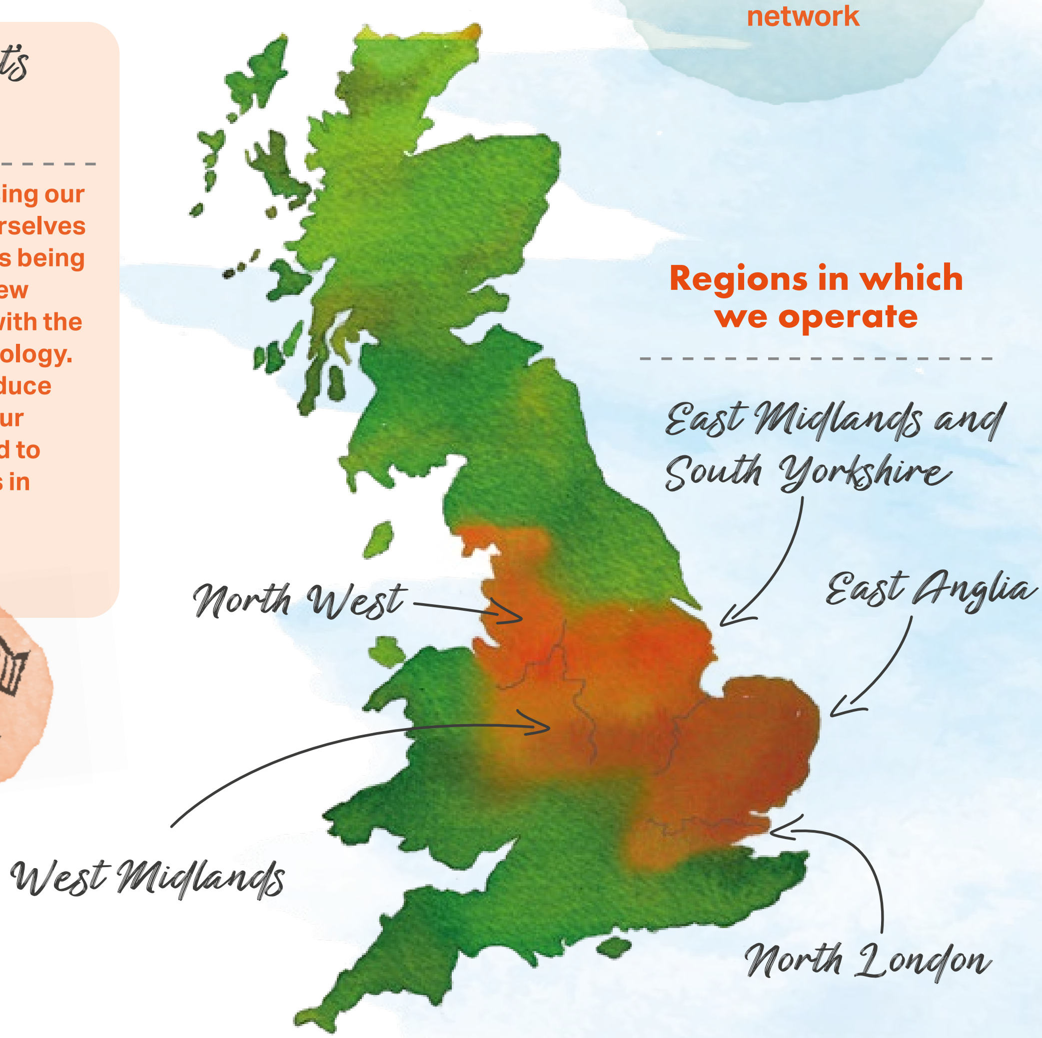
11m

homes and businesses connected to our network

What about Cadent's carbon footprint?

We are committed to addressing our own emissions, having set ourselves the ambition of our operations being net zero by 2026. We've set new scope 1 and 2 targets in line with the latest science-based methodology. We have also started to introduce zero-emission vehicles into our operations and are committed to further significant reductions in methane emissions from gas leakage.

Regions in which we operate



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