Low-carbon boilers

By Paul Stevenson, director, Larkdown Environmental

We have got used to natural gas as a cheap, clean, easy-to-control fuel. It took over from town-gas and solid-fuel in the 1960s, so many of us have now had over 50 years of natural gas providing most of our thermal needs: washing, cooking, cleaning and space-heating.

However, natural gas boilers are likely to become a thing of the past. In the UK, gas boilers are to be banned from new housing in 2025, and households will no longer be able to buy a gas boiler from 2035. The EU stopped short of banning them from 2030, but the directive states that member states should only subsidise new fossil fuel boilers until 2026.

The search is on to find an alternative way of generating hot water at 60-80°C that is both cost-effective and environmentally acceptable.

It seems irrational to focus on looking for novel fuels, which are certain to be more expensive than natural gas, without first doing all we can to reduce demand.

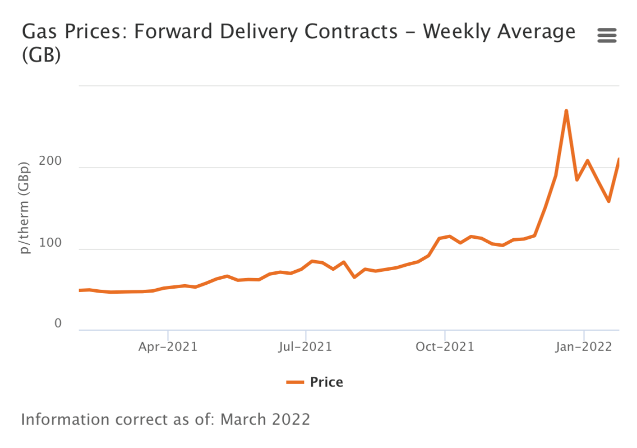
Back in early 2021 gas was still relatively cheap - wholesale gas was £0.50/therm, or £0.017/kWh[1] - see Fig 1.

Yet even at 1.7p/kWh, it was cost-effective to reduce the energy required to heat a building, through:

- infrastructure improvements: wall/ loft/ floor insulation, draft-proofing, improved glazing, pipe insulation, heat recovery from HVAC systems;
- boiler upgrades (more so industry and commerce): burner control, optimum gas-air balance, economisers, shut-off valves; and
- "softer" interventions: building energy management, turning off equipment when not needed, not setting the thermostat at 24°C in winter then 16°C in summer.

These were the "no-regret" interventions, the "low-hanging fruit" that characterise the ideal combination of decarbonisation plus positive life-cycle cost benefits. Time and again, attention to these areas has substantially reduced fuel demand.

Fig. 1 In early 2021 wholesale gas was £0.50/therm



Gas prices increased rapidly late 2021 then became volatile end-2021/ early-2022, hovering around £2.00/ therm (£0.068/kWh). With the recent Russian invasion of Ukraine, energy security became another reason to wean ourselves off fossil-fuels.

So it's now four times more cost-effective to make energy efficiency (EE) interventions than it was last year, while simultaneously helping greatly towards national decarbonisation targets and improving fuel security. What's not to like?

Least-efficient housing

The UK has some of the oldest and least energy efficient housing in Europe. Around 19m homes (2/3 of the total) have an Energy Performance Certificate rating of "D" or worse.

Fig. 2 shows (*page 18*) Carbon Brief's report on "How will the UK's heat and buildings strategy help achieve net zero?"[2] Things were going well until late 2012, then David Cameron's government stopped spending on energy efficiency in early 2013. Since then, the number of loft insulation retrofits in UK plummeted from about 1,200m per year in 2010-12 to about 50,000 per year in the period 2017-20. It's a similar story for cavity wall insulation.

Again, this seems irrational. It was cost-effective to improve insulation 5-10 years ago, so surely the argument is four times stronger now? And if any new fuel is going to be even more expensive then it can only get worse.

Next, can we decarbonise the fuel? There are several options:

- continue to use natural gas boilers and "offset" CO_2;
- blend hydrogen into natural gas;
- hydrogen;
- biomass boilers;
- bio-gas boilers;
- electrification of heat; and
- air source and ground source heat-pumps.

If we continue with natural gas boilers and "offset" the CO_2 the numbers don't look good. There are about 28m households plus 2m non-domestic business or public sector buildings in UK, admittedly not all on gas. According to UK Energy in Brief stats for 2021[3], the domestic sector consumed 299TWh natural gas, the energy

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industry 89TWh, industry 99TWh and commercial/ services 90TWh. That's 577TWh/y.

Perhaps a hundred or so of the largest fossil-fuel power-plants, refineries, steel, cement, lime, glass and brick-works could be considered large enough point-sources to merit carbon capture. The rest would need off-setting. Assuming 420TWh gas is boilers and other small point source emitters, combined these emit 80MtCO_2/y.

Carbon sequestration from forestation varies considerably depending on species, location and management[4]. Using 8t/Ha/y and 50y to reach maturity of 400t CO2/Ha would mean we'd need to afforest 200,000Ha (2,000km^2) per year, just to offset these emissions. After 50 years, we would have had to afforest 100,000km^2 of land. The UK is only 242,000km^2. And that still doesn't address fuel security issues. So not really feasible.

What if we partially decarbonise the gas network by blending 20 per cent hydrogen into 80 per cent natural gas. This is about as much as we can blend in without needing to repurpose the gas-grid or replace millions of burners. Hydrogen-blend is mentioned several times in the recent UK Net Zero (NZ) Strategy and is being trialled in NW England.

Partial decarbonisation

So we have partial decarbonisation without infrastructure upgrades or new burners. So far, so good. If we replace 20 per cent methane with hydrogen, the inference one might draw is that the blend will save 20 per cent CO_2 emissions. But it doesn't. By volume, hydrogen's calorific value is only 30 per cent that of methane's, so an 80/20 blend will have a CV 86 per cent that of natural gas. To deliver the same energy, we actually need a 93.0/23.3 blend. This means that CO_2 savings are 7 per cent (only if the hydrogen is "green"). Better than nothing, but this point should be made clearer.

The economic case doesn't look too attractive. A recent EU study suggests 20 per cent hydrogen blend would add 11 per cent to the unit cost for domestic users, 24 per cent for industrial users.[5] Furthermore, there will be additional pumping to force the extra 16 per cent blend around the distribution network. As for offsetting, we would still need to afforest 93,000km^2 over 50 years.

Overall, it's not deep decarbonisation; it feels more like tinkering at the edges.

Hydrogen has been widely heralded as the "fuel of the future", but many believe it is being promoted as a panacea for, well, just about everything.

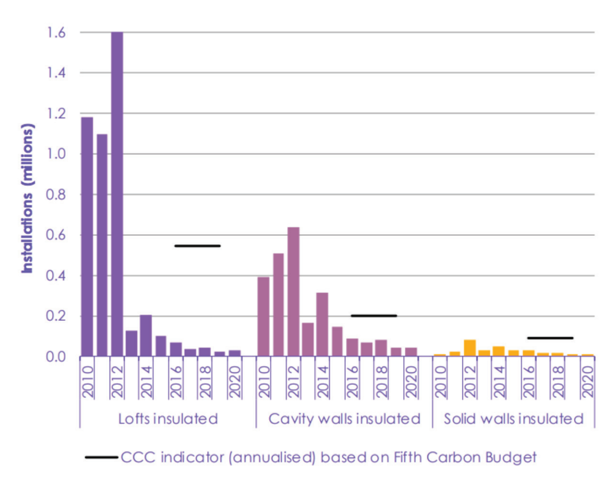

Fig. 2 Government pending on energy efficiency came to a halt around 2013

Hydrogen is a man-made energy carrier. It is a 'zero-carbon-at-use' fuel, but has to be made from either fossil fuel or electricity.

Globally, 80Mt/y hydrogen is currently made for ammonia/ fertilisers, methanol, oil-refining and de-sulphurisation. It is used where there is no real alternative. The process requires hydrogen as an ingredient as well as benefitting from the energy it releases, i.e. "dual fuel and feedstock".

Over time, this list may grow to include "hard-to-decarbonise" processes: metal refining from ore, marine or rail transport and seasonal energy storage. For instance, ore refining could use "just enough" hydrogen to strip away the oxide or sulphide and hydrogen storage would be one of several storage systems.

There are various colours associated with hydrogen, but the three most important are:

1) Grey hydrogen

Steam methane reforming (SMR) natural gas, releasing CO_2 to atmosphere. Currently, "grey" hydrogen accounts for 98 per cent of hydrogen production. However:

- only 70 per cent of the methane's energy ends-up in the hydrogen, so we need (100/70) x methane to generate the same net energy;
- we also cause (100/70) x fugitive CH4 emissions and, with its 20-year global warming potential of x 86, anything that emits extra methane is bad news;
- the SMR process is not cheap so CAPEX and OPEX are issues;
- it still doesn't address fuel security.

So, unless you actually need hydrogen per se, why bother?

2) Blue hydrogen

The SMR plant is a point-source emitter, making it easier to capture most of the CO_2, which defines "blue" hydrogen. However:

- it has the same SMR-related issues as grey hydrogen - above;
- only 80-90 per cent of the CO_2 gets captured and we still suffer CH4 emissions;
- the CO_2 needs collecting, liquefying and pumping underground. Carbon capture and storage (CCS) CAPEX and OPEX isn't cheap and consumes energy;
- given the volumes of CO_2 that need capturing, we will quickly run-out of depleted gas/oil fields, so will need to explore saline aquifers, which are riskier;
- we need to get the hydrogen to its end-use. This means compressing and transporting it, which further reduces net energy. Even if we could repurpose the gas grid, it would need three times the energy to pump. A "leakier" gas at treble the pressure;
- houses, offices, industrial sites, etc would need new burners; and
- the environmental case also looks unclear. A recent review by Stanford/ Cornell[6] suggested that, far from being low-carbon, "blue" hydrogen actually causes greater CO_2(e) emissions when one factors in fugitive methane emissions.

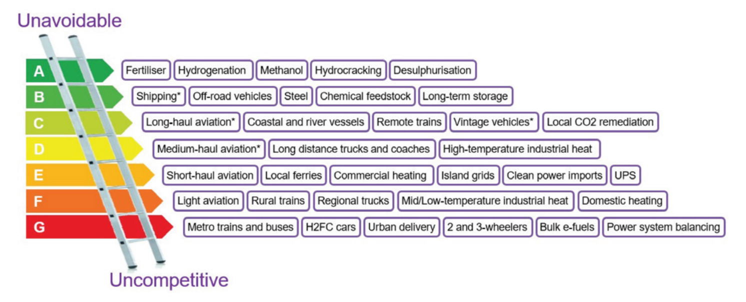

Fig. 3 The 'clean hydrogen ladder' is a guide as to where we should use hydrogen

3) Green hydrogen

Made by electrolysis of water into hydrogen and oxygen, using renewable electricity, green hydrogen is an extravagant fuel; requiring over twice electricity to generate, compress and transport, so we should be prudent how we use it.

Basically, hydrogen is not the answer to everything, especially hot water, space heating and private vehicles. These already have cost-effective low-C alternatives, so why consider an expensive/ extravagant fuel? The "clean hydrogen ladder[7]" by Michael Liebreich (see Fig. 3) provides a useful pecking-order of where we should consider hydrogen.

Several bodies have also reported that the environmental and economic case for using hydrogen as a fuel for space heating is poor. The Fraunhofer Group suggested that the economics simply didn't stack up[8] and heating all UK buildings with green hydrogen would necessitate increasing UK's existing offshore wind capacity by a factor of 40.[9]

Biomass boilers can be considered CO_2 neutral if the source is properly managed. There are already many biomass boilers, particularly away from the gas grid. Most biomass is actually used for grid power generation. By 2020, biomass power accounted for around 12 per cent per cent of the UK's electricity generation, and 40 per cent of UK's total RE contribution. However:

- in 2018, the UK imported 8Mt of wood pellets. There are Scope 3 embodied energy from upstream processing, drying and transporting the pellets to point-of-use;
- these biomass imports do not address fuel security;
- burners need to be managed to prevent emissions of soot/ particulates (PM2.5 and PM10), carbon monoxide, nitrous oxides and other pollutants. The impact from sub-standard fuels or burner systems on air quality are well-recognised and the biomass source as well as the burner system now have to meet strict guidelines.[10] and
- with increasing summer temperatures, there has been a

growing number of wildfires that have destroyed millions of hectares of forest. Globally, these emitted 1,760Mt of CO_2 in 2021[11] plus millions of tonnes of dust/ soot/ unburnt hydrocarbons, not to mention the damage to ecosystems, wildlife, human life and property.

Biomass at power plants

Biomass boilers will continue to make a contribution to UK decarbonisation. However, most biomass will continue being used at power-plants, fulfilling obligation to increase the RE content year-on-year.

Bio-methane boilers are a straight substitute for natural gas, but there won't be anywhere near enough bio-methane to replace natural gas. Bio-methane (and syngas) is likely to end-up as a series of stand-alone boilers or CHP plant. Their biggest environmental challenge is avoiding methane leakage.

Bio-methane may in fact be better purposed for tackling the "difficult to decarbonise" industrial sectors, such as ore refining or high-temperature processes.

Electrification can already satisfy many low-temp thermal and transport requirements. All-electric boilers have been around for decades. Many homes, buildings and industrial sites have immersion heaters as the boiler's fuel or as back-up. Similarly, wall panels, storage heaters and IR heaters use electricity. Historically, the barrier to their widespread use was cost: electricity being typically four to five times the unit cost of gas.

If we are obliged towards greater electrification, isn't it better to generate several times more thermal energy from every unit of electricity put in?

Heat pumps combine the global growth in RE power generation with potential to generate low-grade heat via electricity, with the bonus of getting a lot more out of our system than we put in.

Heat pumps operate like a domestic refrigerator. The refrigerant fluid has variable boiling/condensing temperature, depending on pressure. By utilising this principle, they can extract heat from a colder place (garden) and "dump" it in a warmer place (indoors).[12]

For heat-pumps, we use the 'coefficient of performance' (CoP) as the measure of efficiency, where: CoP = heat output/ electrical input. In Fig 4 the CoP is 3.0, i.e. 3kWh of useful heat are delivered for 1kWh of electricity (or it is 300 per cent efficient).[13]

Fig 5 shows the CoP variations of a typical heat pump, depending on the temperature difference between source and the heat-delivery side.

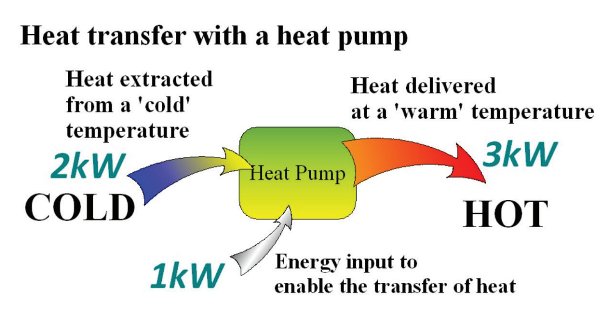

Fig. 4 Coefficient of Performance is used to measure heat pump efficiency

If the temperature difference between the boiler and outside is relatively small, the CoP will be over 4, but for very cold winters, the CoP may fall to 2.

Currently, heat pumps cost more to operate than conventional gas boilers, although with recent gas price hikes, this gap has narrowed. Historically, wholesale costs represented 30-40 per cent of domestic gas bills but will soon represent 60-70 per cent. An average UK gas-heated home was £584/y, now is £984/y (increase of £400 or 57 per cent), whereas heat pump costs have risen from £919/y to £1,251/y (£340 or 27 per cent).[14] The price of gas looks certain to continue rising faster than electricity, making heat pumps increasingly attractive.[15]

Two types of heat pumps

There are two main types of heat pumps:

- air-sourced heat pumps (ASHP) which extract heat from ambient air. These are the most common and are relatively cheap to install. Their main downside is that during winter the CoP can drop below 3 (unfortunately, when needed the most); and
- ground source heat pumps (GSHP) which extract heat from the ground. Once we get below about 2m depth, the ground tends to be 10-11°C all year, therefore the GSHP's CoP remains high during mid-winter. The downside is that these need extra costs to dig up ground or drill vertical pipes.

There are many myths and misconceptions about heat pumps, most of which have been "busted". For instance, heat pumps work well in cold climates (Scandinavia), work well in older buildings, work with standard radiators and so on.[16] Clearly, they work better if the building is properly insulated, but that's the same for any heating system.

We are living in interesting times with:

- high fossil-fuel price rises, which look here to stay;
- geo-political unrest and the need for better fuel-security;
- stricter environmental legislation to help limit global temperature rise to 1.5°C by 2050; and
- rapidly falling costs for RE and low-C equipment.

These factors have made that the financial case for EE and RE interventions considerably stronger. What messages should we take from this? We need to:

- embrace the road to deep-decarbonisation;
- remain aware that what is cost effective and acceptable now is likely to change. Greenhouse gas emissions will become more expensive, so it's better to get ahead of the game rather than play catch-up later;
- improve the efficiency of existing building stock, industrial processes, etc. Do this anyway, regardless of how we heat things;
- continue to develop RE and low-C resources. For the UK, this will be largely wind generation, solar PV, biomass, hydro and heat pumps. The UK is also well positioned to exploit other RE sources, in particular tidal and wave energy;
- develop additional long-duration energy storage, for both electrical and thermal energy. Hydrogen is likely to be one of several options;
- electrification where possible. Clearly, we won't be able to electrify everything, but we can electrify hot water/ space heating (and private vehicles), which combined account for a huge portion of fossil-fuel consumption;
- if we are looking to electrify heat, then get as much heat as possible per kWh of electricity, therefore heat-pumps;
- save any bio-gas and CO_2 offsetting for the "difficult to decarbonise" sectors, such as high-temperature industries;
- grow more trees;
- hydrogen will have a place in the net zero mix, but it's not a panacea. Hydrogen to generate hot water or space heating doesn't make sense. Making "green" hydrogen for boilers/space heating will gobble-up RE electricity that could be more effectively used elsewhere, helping us reach net zero quicker. Perhaps in 50 years' time, when we have excess RE and can afford to be extravagant, it will have its place. ■

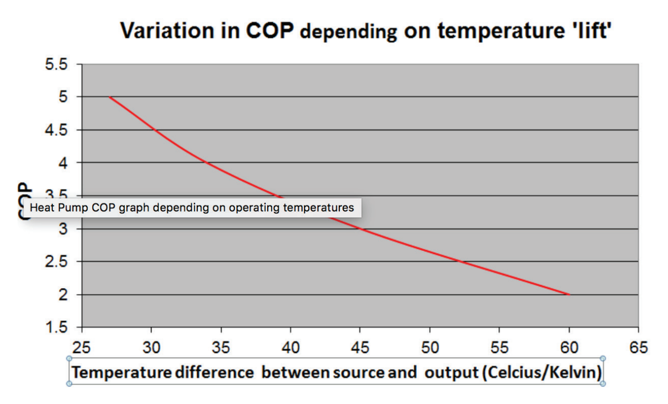

Fig. 5 CoP variations of a typical heat pump

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CPD SERIES 19 / Module 10

Boilers & Burners

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Questions

1) How much did gas wholesale prices increase during 2021?

☐ Doubled
☐ Trebled
☐ Quadrupled

2) Which of these is not a low-carbon option for boilers?

☐ Biomass
☐ "Grey" hydrogen
☐ Heat pumps

3) One hectare of mature woodland or forest is responsible for how much CO_2 absorption?

☐ 200t
☐ 400t
☐ 800t

4) If natural gas is approx 10kWh/m^3, what is the energy density of hydrogen?

☐ 3kWh/m^3
☐ 10kWh/m^3
☐ 30kWh/m^3

5) What's the difference between net zero fuel and zero emission fuel?

☐ Zero emission fuel does not release CO_2 at the point of use
☐ Net-zero fuel does not release CO_2 at point of use
☐ There's no difference

6) Globally, approximately how many tonnes of hydrogen are currently made per year?

☐ None
☐ 8Mt/y
☐ 80Mt/y

7) What is the global warming potential of methane over a 20-year horizon?

☐ x 1
☐ x 28
☐ x 86

8) What is biomass mostly used for in UK?

☐ Biomass boilers
☐ Biomass heaters
☐ Fossil-fuel power plants

9) Which of these is not a major emission concern from biomass boilers?

☐ Carbon dioxide
☐ Carbon monoxide
☐ Soot and particulates

10) Which of these sectors would be difficult to electrify?

☐ Residential and building heating
☐ Small vehicle transport
☐ High temperature industrial processes

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