Burning question:

why hydrogen boilers are not the answer

coolproducts for a cool planet

ecos

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Executive summary

Fossil fuels are the predominant energy source for space and water heating in residential buildings, accounting for 12% of greenhouse gas (GHG) emissions in the EU [1]. **This has a dramatic impact on the climate**.

Some trade associations and appliance manufacturers endorse hydrogen as a viable pathway to decarbonise the built environment. But, as this paper will go on to show, hydrogen heating in residential buildings cannot deliver on such a promise. **Hydrogen – whether blended with gas, or pure – should not be used to heat households**.

A recent study performed by Eunomia [2] outlined a number of techncial and safety obstacles that still need to be overcome for hydrogen boilers to be deployed in homes. In addition to putting lower energy efficiency appliances (resulting in higher heating bills) on the market, there are **serious concerns over safety and maintenance**.

Other mature alternatives, such as electric heat pumps, offer dramatically more efficient [3] (and realistic) solutions for the large-scale transition that is needed to decarbonise the built environment. For this reason, studies have shown that residential heating has the lowest priority of all hydrogen applications [4]. This has been echoed by the Joint Research Centre of the European Commission, which stated that for heating and cooling, hydrogen in the built environment has no benefit at all, even in its renewable form [5].

Fossil fuels play a big role in the generation of hydrogen [6]. Only a miniscule 0.04% of hydrogen is produced using electricity. And even when it is, it is still not the most efficient option. Electrolysis supplied with renewable electricity generates hydrogen with the lowest life-cycle climate impact. But around 30% of energy is lost in the transformation process. **Renewable hydrogen is scarce**, so we must be strategic about its end use.

Renewable hydrogen should be channelled to those sectors that are 'hard-to-abate' (e.g., heavy industry, long-haul aviation, shipping, and chemicals), where electrification is still not economically or technically feasible. Channelling hydrogen to other sectors, like residential heating, would mean wasting this valuable resource. More efficient and climate-friendly solutions exist and should be used, such as electric heat pumps.

Heat pump technology is highly performant even in colder climates, reducing energy needs threefold to serve the same heating purpose as gas boilers. Buildings also need to be renovated to decrease energy demand, especially the worst performing ones. They will need to accommodate low-temperature heat pumps.

However, **electric heat pumps are not the silver bullet** to decarbonise every individual heating system in buildings. In some cases, other solutions are valid alternatives, including district heating (powered by large-scale heat pumps, solar energies, and clean waste heat sources), solar thermal energy, geothermal power, or solar PV (and/or combinations to be coupled with electric heat pumps).

Importantly, we do not know what effects using hydrogen to heat residential buildings would have on appliances. The Eunomia study analysed the obstacles to a transition to hydrogen boilers – both those fed by blends of fossil gas and hydrogen, and those that are 100% hydrogen-operated. They concluded that technical readiness for 100% hydrogen boilers has not yet been achieved, and several important existing barriers will need to be overcome. **Hydrogen should not be used in heating at all**.

A wide range of studies also show that **hydrogen heating would be economically damaging for end users** [7]. Households would be locked into a fossil fuel-based system for decades to come. And new infrastructure to transport hydrogen for such widespread usage would further increase costs for consumers. This would jeopardise the contribution of the built environment towards the EU's 2050 climate neutrality targets.

The EU's ecodesign policy measures have announced **2029 as an end date for "stand-alone" fossil fuel boilers** being placed on the market[8]. Such a ban would be a step in the right direction. But it is not quick enough. Due to the long lifetime of heating systems, **we urge the EU to take the bold step of banning fossil fuel heating appliances in buildings from 2025** (in its fossil fuel forms, such as gas and oil, and hydrogen, no matter its origin). This would bring the EU in line with the IEA's Net Zero by 2050 study[9].

ECOS & Coolproducts recommendations

Hydrogen should not be used to heat households. Instead, it should be channelled to those sectors that are hard-to-abate' (e.g., energy-intensive industries such as steel or aluminium)), provided it is produced from renewable sources.

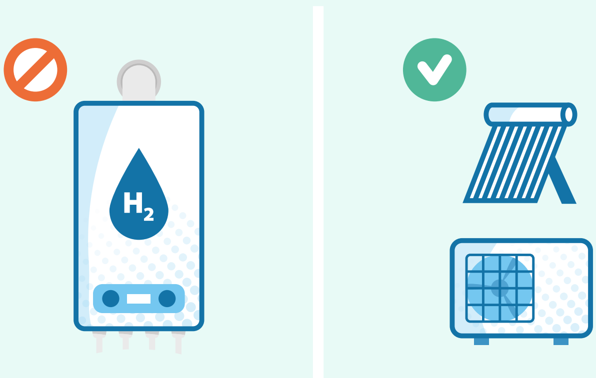
Focusing on other mature heating options should be a priority. For example, electric heat pumps, district heating (powered by large-scale heat pumps, solar energies, and clean waste heat sources), solar thermal energy, geothermal power, or hybrid solutions that use mainly renewable energy.

To EU institutions

- Remove the inclusion of "renewable" fuels (in which hydrogen could be included) from Article 7 and 8 of the EPBD.
- Prevent the blending of hydrogen in the fossil gas network for the upcoming trialogue on the Gas Directive.
- Be ambitious in the implementation of the Energy Efficiency Directive by stimulating investments in improving the energy efficiency of buildings, as well as exploiting renewable heating technologies.

To EU Member States

- Back the EU Save Energy plan provision to phase out 'stand-alone' fossil fuel boilers and anticipate the date to 2025. This will de facto ban gas-, oil- and, potentially, hydrogen-based appliances via ecodesign regulations for central heating applications.
- Comprehensively assess district heating and cogeneration potentials.



Introduction & policy context

With the adoption of the European Green Deal, the European Commission set EU targets for climate neutrality by 2050. Buildings are the largest energy consumer in the EU, responsible for a staggering 40% of energy use and 36% of energy-related greenhouse gas emissions. Decarbonising the built environment in general, and heating in particular, will be crucial in the energy transition. But the steps needed to reach net zero require profound socio-economic, technological, and geopolitical transformations – unprecedented in scale.

Frontrunning alternative technologies include electric heat pumps, a hyper-efficient and climate-friendly solution that can enhance renewable electricity and natural refrigerants, helping consumers to save money on bills and emit zero pollutants. Moreover, countries can also increase energy independency by moving away from imported fossil fuels[10].

Even though proven alternatives such as heat pumps can – and should! – be rolled out as a logical next step, some trade associations and appliance manufacturers have put forward hydrogen-based or hybrid boilers as a viable pathway to decarbonise the heating sector. These solutions are strongly supported by the gas industry, as a way to ensure that gas continues to be consumed and investments made in the gas grid. While hydrogen has the potential to enable the decarbonisation of some energy sectors (such as primary steel production[11]), it should *not* be seen as a solution for residential heating – contrary to assurances by heating industry and trade associations.

Policy landscape

In March 2023, the European Parliament adopted its ambitious position on the revised Energy Performance of Building Directive (EPBD). The Directive aims at guiding the replacement of inefficient heating systems as well as paving the way for building renovation. The EP position foresees 2035 as an end date for fossil fuel use in all buildings, as well as an end date for public fossil fuels subsides in buildings from January 2024. However, Articles 7 and 8, where Member States can introduce measures to phase out the installation of fossil fuel heating in buildings (both new and existing), include an exemption for “hybrid heating systems, boilers certified to run on renewable fuels and other technical building systems not exclusively using fossil fuels hybrid.”

This loophole, which we hope will be removed in the upcoming trialogues, undermines the ambition of the Directive by including fossil-based “renewable” fuels for boilers, and unclear definitions for hybrid systems.

Another relevant policy discussion is happening in the context of the revision of the Ecodesign Regulation for space and water heaters. In May 2022, the European Commission expressed their intention to ban 'stand-alone fossil fuel boilers (non-hybrid units) as of 2029' through Ecodesign in its EU Save Energy plan. By raising the minimum energy efficiency requirements for central heaters, this will effectively ban hydrogen-based boilers from the market.

In July 2020, the European Commission adopted its EU Hydrogen Strategy [12] and created the European Clean Hydrogen Alliance with the intention to facilitate and implement the Strategy. Although it was not supported by civil society, the Alliance's Buildings Roundtable has strongly advocated in favour of hydrogen applications in the built environment, despite several barriers they themselves acknowledged [13].

Many of these barriers are significant, not least the susceptibility of heating system materials to degradation and inefficiency. Several studies show that the use of hydrogen in households is not recommended for reasons of efficiency, technological readiness, and economic considerations [14,15,16,17,18]. Additional analyses also consider more closely health risks that this hydrogen transition would bring. For example, a declaration from US doctors stating such appliances "put lives at risk" [19], which lead to consumer protests [20,21].

In fact, hydrogen combustion in homes would have far more safety and technical implications than existing gas boilers. There are more real-life NOx and CO emission risks, more material vulnerabilities, and a higher possibility of explosions.

Locked-in fossil fuels with hydrogen and gas blends

Blending hydrogen is the practice of injecting hydrogen into the existing gas grid to replace a portion of it. This has been brought into the spotlight by trade associations and gas network operators, along with the promise of lowering the sector's overall carbon footprint. This, however, would require a continuous supply of fossil gas, locking in Europe's reliance on an energy source that contributes to global methane emissions.

Blending is unfortunately not a viable solution - not even for sectors other than heating, such as energy intensive industries. In fact, the EU Gas Regulation, still under revision at the time of writing, does acknowledge that blending diminishes the value of hydrogen – even if it fails to forbid the practice.

A study from Fraunhofer IEE[22] showed that the infrastructure needed to deploy hydrogen for the heating sector has the highest infrastructure requirements of all sectors. According to the Eunomia study, manufacturers and independent sources agree that approximately **20% hydrogen is the maximum blend** for safe and technical limits in most existing gas boilers (within their original design parameters and testing limits). This would lock-in consumers to at least 80% of fossil gas.

In the EU and UK, fossil gas appliances have been tested with hydrogen blends[23]. This research found, like most other European trials, that a common share of 20% hydrogen to 80% fossil gas was the most suitable blend when considering safety and technical performance.

- The HyDeploy trials suggest that the technical and performance implications of burning 20% hydrogen are limited. However, a conventional fossil gas boiler burning **hydrogen will be less efficient** compared to boilers designed to burn hydrogen as factory setting.
- The Ameland test shows that, at maximum operation with a 20% hydrogen blend, flames are **closer to the burner** and less well mixed with air prior to ignition. This potentially increases the risk of explosion. These issues are even more predominant in full hydrogen combustion, as analysed in the next chapter.

Considering that installed gas boilers have not been optimised for accommodating hydrogen blends, the performance and efficiency to the end user is likely to be lower than a brand-new 100% hydrogen boiler.

Technical studies and trials have demonstrated that, in the case of hydrogen boilers, there are no reported increases in gas escapes, CO alarm activations, or flammable substance detections. However, **hydrogen-compensated CO sensors** will be required to avoid false-positive activations[24].

Theoretically, burning hydrogen may also increase NO_x emissions. But there is mixed evidence on whether this is true for domestic boilers. According to a recent study[25], any fuel composition modifications, via hydrogen admixture, in pre-mixed burner system, will directly affect the main combustion processes and NO_x formation.

Higher blends of hydrogen share will likely require heavy upgrades and alterations to various internal boiler components. Within a fossil gas boiler, events such as flame-out (where the flame is extinguished) were observed when the share of hydrogen within the blend was higher than 20%. This is why manufacturers are focusing on hydrogen-ready boilers that initially run on fossil gas and only up to 20% hydrogen, but can be later converted to 100% hydrogen, once and if the distribution network switches from fossil gas to 100% hydrogen. A conversion of the hydrogen-ready boilers is required for any blended mix above 20% hydrogen (with many other hurdles that we will go on to explain), but this, as we will see, is far from feasible.

The pipe dream of 100% hydrogen

While a hydrogen-ready boiler has almost all the components to combust 100% hydrogen, **a conversion process would be required to fully switch** to a hydrogen-firing appliance. If hydrogen is blended with fossil gas at grid level, appliances will need to be carefully and meticulously aligned at the same time (according to the specific blend share). This would result in a **'dead zone' for blending between 20% and 100%**, where the grid cannot serve retrofitted gas boilers any longer; and new ones must be installed instead.

Gas grid operators would also need to convert their grids abruptly and drastically from a blend of 20% hydrogen in fossil gas to pure hydrogen. Every component of the gas supply system would need to be verified, and every consumer connected to that gas supply system would have to be ready to move to hydrogen boilers all at once. While this labour-intensive and time-consuming conversion takes place, the gas system would need to be switched off, leaving all connected consumers in the cold, if not carried out during summer season.

As hydrogen-ready boilers cannot automatically detect the share of hydrogen at their inlet, external checks would be needed on real-life operations as soon as the blended grid network moves to any hydrogen blend above 20%. This process takes a qualified gas engineer approximately 1-2.5 hours (for an estimated cost of €200) on top of the high energy bills that consumers already pay. All this is *in addition* to the initial replacement of gas boilers with new hydrogen-ready boilers.

For safety reasons, only qualified gas engineers are allowed to undertake this conversion. It is also **very unlikely that there would be a universal toolkit** available to end-users to perform such work, due to the multitude of different brands and models of boilers on the market (plus other considerations such as commercial confidentiality and intellectual property)[26]. Today, there is no evidence to suggest that such a toolkit could ever be developed.

It is clear that such a transition would require a **tremendous economic investment from consumers**, with a 4-digit price tag per household[27]. And the gas grid would not be converted from 20% to 100% in one go either. Costs would increase to include further checks of the appliance after the increase of the hydrogen blend in the network.

Prototype hydrogen-ready boilers have been produced, though **none are presently available on the market**. In the next section, we highlight the main considerations of such a transition from technical and safety perspectives.

1. Technical and performance implications of switching to 100% hydrogen

Compared to conventional fossil gas boilers, some components may need to be redesigned to remove materials and configurations unsuitable for use with 100% hydrogen.

The efficiency and lifetime of a hydrogen boiler is expected to be around 12 years ; however, **there is currently limited evidence on its real durability**, as most trials reviewed have had 4- or 5-year lifespans[28]. Additional research is still required to verify the efficiency and useful operating lifetime of hydrogen boilers.

Below, we highlight the main boiler components impacted by a higher share of hydrogen:

Burner

The burner is the most affected component in the switch to hydrogen. Hydrogen has different flame properties compared to fossil gas, meaning that the **burner plate is a key component to be replaced** during the conversion process.

Adjustable burner systems that can fire both 100% fossil gas and 100% hydrogen are technically challenging. As a result, economic considerations are likely to guide the replacement of the burner to 100% hydrogen as part of the conversion.

Flame detection

Flame detector systems need to be adjusted. Hydrogen flames are shorter in length. In consequence, the position of the monitoring apparatus may need to be differently located, requiring a redesign of the pilot dimensions, gas flow rate and flame monitoring sensors.

Also, ionisation probe-based methods of flame detection used in fossil gas boilers are not suitable for 100% hydrogen.

Faster-acting Flame Failure Devices may also be required, replacing current thermoelectric models with UV or infrared alternatives.

Valves and other considerations

Some of the **materials used in valves, seals, and gaskets may need to be replaced** with more robust materials because they come into regular contact with hydrogen.

Similarly, the **code plug settings** (the software file of the boiler) need to be modified so that the boiler is coded to run on hydrogen instead of fossil gas. It is doubtful that boilers will be able to detect the fuel at the inlet and automatically switch their settings, so **a manual update would be needed** alongside the other conversion steps (such as the burner). These actions would need to be performed by a professional gas engineer, further raising the price of the hydrogen transition for households.

There are other technical considerations that also need to be taken into account:

- Due to a lower volumetric calorific value of hydrogen compared to fossil gas, **existing gas meters are unlikely to be suitable** for hydrogen. At distribution level, operators would need to replace meters when converting the local grid.
- Designs of **heat exchangers used in gas may not be optimised for hydrogen use** so would likely need to be redeveloped for 100% hydrogen. In particular, the risk for flame impingement on the heat exchanger should be carefully considered.
- Current pipework and gas valves may also have to be replaced with suitable alternatives to reduce concerns over sealing and leakage.

- Given the lack of space inside current boilers, and manufacturers' desire for hydrogen boilers to occupy the same space in homes as existing boilers, **any alteration or addition of parts will be challenging**.
- Due to the possible increase in NO_x emissions when burning hydrogen vs fossil gas, there may be **the need to install equipment to reduce NO_x**.
- Minor **changes to operating pressures may be required** to achieve equality with energy delivery of gas.
- Compared to gas, hydrogen combustion produces an increased amount of water vapour, which **current flue systems may not be adept** at removing.
- **An odorant would need to be added** to allow the detection of leakage.

Finally, large scale trials are not being performed yet. This is yet another mandatory step to prove the real-world feasibility of switching to 100% hydrogen.

All the abovementioned problems are hidden within the multiple policy frameworks, such as product policy for heating appliances, and standards developments on this topic, namely in the European technical committees that work on fossil fuel boilers. Hydrogen has many elements that are overlooked in policy design such as availability and disruption in the end use. This has led to many uncertainties, not least as to which stakeholders in the energy network would undertake (and pay for) the different elements of the transition.

2. Safety implications of switching to 100% hydrogen

There are similar safety concerns for pure hydrogen as there are for its blended form, the only difference being that less evidence is available in the case of 100% hydrogen usage.

Leakages and explosions are the greatest concerns

In the event of substantial leaks, there is twice as much of an explosive risk, with a greater likelihood of an explosion causing significant structural damage compared to smaller leaks. The UK-based Hy4Heat project recommended incorporating one Emergency Flow Valve (EFV) upstream of the meter and one within the smart meter to help mitigate this risk[29].

However, even with the valves, the number of critical events modelled by Hy4Heat would still be larger than for fossil gas. Further risk mitigation includes the installation of ventilation ducts in the ceilings of rooms where hydrogen is present. Hydrogen boilers should also be designed so that internal cavities are reduced.

Scenario	Predicted number of events per year	Predicted number of individuals injured per year
Fossil gas	9	17
100% Hydrogen	39	65
100% Hydrogen with risk mitigation measures	26	16

Table 1: Hy4Heat Natural Gas Base Case Compared with Different Hydrogen Scenarios

Future **trials should be undertaken in flats**, particularly high-rises, to assess the risk to those properties. This has not been the case until now, so trials do not fully represent real-life situations with such a low technology readiness level (TRL).

Policymaking puts a very high risk on consumers who, as shown in Table 1, may already experience damage and injuries as a result of their existing heating system.

Similarly to 20% hydrogen boilers, there is a theoretical **increase in NO_x emissions from burning hydrogen** compared to fossil gas (possibly up to double). Further testing is required to demonstrate the real NO_x emissions for post conversion hydrogen-ready boilers, both in the short and long term. There is also **uncertainty surrounding the long-term durability of materials** in the presence of hydrogen.

Hydrogen is also known to embrittle metals, such as steel. This means that **the existing pipework in the appliance may need to be replaced** to avoid embrittlement, with a special focus paid to joints, which may need upgrading.

Domestic gas appliances operating at low pressures in hot areas potentially have an increased degradation risk. In particular, any material that is in direct contact with the flame (which is approximately 200°C hotter than that of fossil gas) and where individual, highly reactive hydrogen atoms will transitionally be present. Because of this, and depending on the level of aeration, hydrogen could cause faster material degradation.

Conclusion

Hydrogen should not be used to heat households. The suggestion that it could be is unrealistic and complicates a question for which a simpler answer already exists. Electric heat pumps are the primary way forward. There is also a place for district heating (powered by large-scale heat pumps, solar energies, and clean waste heat sources), solar thermal energy, geothermal power, or solar PV (and/or combinations to be coupled with electric heat pumps).

Current infrastructure cannot support a transition to 100% hydrogen in the built environment. Creating it would require abrupt change at every imaginable level – from gas grids and their components to individual boilers in every home. This is not viable. Blending renewable hydrogen with fossil gas would not weigh so heavily on existing infrastructure. But it would also not materially lower emissions because it locks in fossil gas. As well as this, it would be more dangerous for consumers, who should not be expected to bear such a burden.

Hydrogen is scarce – renewable hydrogen even more so. This valuable resource must be channelled to sectors that are 'hard-to-abate', such as energy-intensive industries. It is time for us to leave behind the hype of hydrogen and focus on other more realistic – and immediately available – solutions that are both climate- and consumer-friendly.

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