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Commentary

Is heating homes with hydrogen all but a pipe dream? An evidence review

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Introduction

Energy used for purposes of heating and cooling accounts for around 50% of total global final energy consumption. Of this, almost half is consumed for heating buildings, and most of the energy used is fossil fuel based.[1]

It is therefore clear that without fully decarbonizing space and hot water heating, net zero greenhouse gas emission goals are not attainable. Most analyses agree that regardless of the fuels used, one important lever to reduce emissions from buildings is improving the building fabric through energy efficiency measures.[1,2] But there is still a sizable residual energy demand for heating even after energy efficiency improvements,[1] and the question is which technologies can deliver zero- or very-low-carbon heating.

Low-carbon and zero-carbon hydrogen has been promoted by gas and heating industry representatives as a key solution to replace especially fossil gas in the distribution grid.[3,4] It has received significant media attention over the last 2–3 years and featured in some of the many national hydrogen strategies launched recently.[5]

It is important to point out that there are many legitimate current and potential end-uses for green hydrogen from renewable electricity, for example as a feedstock in industry, for high-temperature processes, in shipping, and for long-term energy storage for electricity production.[1,2]

An important question is whether the available evidence supports a case for heating homes with hydrogen. This paper reviews independent analyses on the use of hydrogen for space and hot water heating. "Independent" in this context is defined as "not carried out by or on behalf of a specific industry (e.g. gas, oil, electricity, heat pumps, boiler manufacturers)." The review includes a total of 32 studies carried out at international, regional, national, state, and city level by a wide range of different organizations including universities, research institutes, intergovernmental organizations such as the IPCC[2] and the IEA,[1] and consulting firms. Industry-funded studies have been excluded because such studies are often carried out on behalf of industry groups in order to support a position that suits their vested interests. This is not to say that there are no robust analyses funded by industry, but for the purpose of this review of independent evidence, they have been excluded.

The evidence assessment shows that the widespread use of hydrogen for heating is not supported by any of the 32 studies identified in this review. Instead, existing independent research so far suggests that, compared to other alternatives such as heat pumps, solar thermal, and district heating, hydrogen use for domestic heating is less economic, less efficient, more resource intensive, and associated with larger environmental impacts.

Background

More than 95% of global hydrogen production is currently based on fossil gas and coal with no carbon abatement.[6] Because it is energy intensive to

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produce hydrogen, it results in more emissions than the fuel it is made from. Carbon capture and storage (CCS) could in principle reduce those emissions if high capture rates are achieved and if upstream leakage of methane is minimized. However, so-called blue hydrogen can never be zero carbon, and analysis of existing carbon-capture facilities suggests that current blue hydrogen production is associated with significant residual emissions.[7] Green hydrogen made via electrolysis using electricity can be zero carbon if all of the electricity used is from zero-carbon electricity sources. In order to achieve full decarbonization of heating, only green hydrogen from 100% zero-carbon electricity is able to deliver on this.[8]

The attractiveness of replacing fossil fuels used for heating with hydrogen is the apparent ease of the transition: so-called hydrogen-ready boilers have already been developed. Industry representatives propose that such boilers are being installed gradually as existing heating systems are being replaced and could be converted to hydrogen later on when it is available.[3] However, significant uncertainties over the viability of converting the gas network to hydrogen exist. These include the suitability of pipework, both external and internal to homes and buildings, how and where hydrogen will be produced or imported from, and how much this approach would cost.[9] Ongoing trials with 100% hydrogen heating will help address some of these uncertainties over time.

Existing independent studies on heating with hydrogen

The topic of heating with hydrogen has been studied by a wide range of analyses. Through a rapid evidence assessment (REA), 32 independent studies have been identified and summarized in Tables S2–S5. Those analyses have been conducted at a global level; European level; national level, including Czechia, Germany, Italy, the Netherlands, Poland, Spain, and the UK; state level in California; and at city level in Hamburg and São Paulo.

The categories of studies undertaken broadly fall into four different categories that emerged from the REA:

(1) Energy systems modeling. Several studies model the most cost-optimal pathways from a system cost perspective considering a range of cost categories including electricity generation capacity, network costs, electrolyzer costs, heating appliance costs, etc.
(2) Consumer cost modeling. Other studies have calculated the total consumer costs of alternative clean heating technologies (including both capital and running costs) and found that heating with hydrogen is a significantly more expensive option compared to other clean heating technologies such as heat pumps and district heating.
(3) Environmental impact assessments. One study modeled the environmental sustainability of a range of heating technologies and scenarios on a life cycle basis for 19 different impact categories.[10] They found that boilers using hydrogen (from electrolysis or steam methane reforming) have the highest environmental impacts in 19 out of the 19 categories and that electric air source heat pumps are the lowest-impact option to decarbonize heating.
(4) Evidence reviews. Assessments of the validity of hydrogen for heating by reviewing the existing evidence was undertaken by multiple studies.

DISCUSSION

There are key conclusions that can be drawn from the 32 studies.

First, hydrogen for heating is associated with higher energy system costs compared to alternative technologies that deliver decarbonized space and hot water heating such as heat pumps, district heating, and solar thermal.[8] Much of this is driven by the higher electricity needs for green hydrogen compared to electrification via heat pumps.

Second, hydrogen for heating results in higher consumer heating costs (including the upfront and running costs of heating systems).[11] There are uncertainties about the extent that costs will change over time and how that will impact consumer costs, but the evidence identified suggests that heating with hydrogen will be more expensive for consumers.

Finally, hydrogen for heating leads to higher environmental impacts, necessitates more energy supply infrastructure, uses more resources, and requires more land.[10] However, the REA only identified one environmental impact assessment of hydrogen versus alternative technologies for heating. Further research in this category would be useful to expand the evidence base beyond a single study.

A critical issue driving the aforementioned observations is the inefficiency of hydrogen production and consumption. Electrolysis efficiencies are around 80%, and average boiler efficiencies of 85% are typical resulting in an overall efficiency of hydrogen heating of 70%.[8] A heat pump uses one unit of electricity and generates about three to four units of heat.[12] Because of these efficiencies, it takes about five times more electricity to heat a home with hydrogen than it takes to heat the same home with an efficient heat pump, either individually or as part of a district heating network. As a result of this inefficiency, the required build rates for renewables would be extremely challenging as the UK Committee on Climate Change points out.[13]

The research identified as part of this REA often makes assumptions regarding the future costs of hydrogen and alternative heating technologies. The costs of green hydrogen produced from renewable electricity are likely to fall significantly over the coming decades,[2,14] largely associated with drops in the cost of renewable electricity generation. However, reductions in the cost of renewable electricity generation would also lead to cheaper heat electrification. Because of the efficiency differences of hydrogen versus electrification, the relative cost differential between green hydrogen and heat pumps would remain, suggesting that heat pumps are likely to be cheaper than using green hydrogen to generate heat.

While the evidence identified and analyzed clearly cautions against the widespread use of hydrogen for bulk space and hot water heating, there might be complementary applications for heating with hydrogen. Hybrid heat pumps, which consist of a heat pump operated in combination with a hydrogen boiler, can be deployed to reduce peak electrical demand. This may be relevant in areas where the costs of electricity network upgrade are particularly high, and hybrid heat pumps in combination with hydrogen boilers could play a role.

At European level, so-called hydrogen valleys have been discussed. Hydrogen valleys are particular areas with significant local hydrogen production and use with hydrogen being transported over short distances. In such areas where hydrogen infrastructure is being built to deliver hydrogen to industrial uses, for example, heating with hydrogen might be a more viable option. However, so far there is insufficient evidence on this.

District heating systems could take advantage of waste heat from electrolyzers, and the use of hydrogen to deliver peak heat demand in district heating systems to compliment other heat sources has been suggested too.[15]

Importantly, even though hydrogen may play a complementary role for heating in some applications, the available evidence does not support the notion that fossil gas used for heating should be replaced like-for-like with hydrogen. This raises important questions for the future viability of the gas distribution grid.

Conclusion

Despite the significant attention heating that hydrogen has received, independent evidence does not support widespread use of hydrogen for space and hot water heating. This review of the evidence identified 32 independent studies, and none of them provides evidence that would support the case for widespread use of hydrogen for heating, although some identify complementary roles of hydrogen particularly in district heating and hybrid heating systems. Policymakers are therefore well advised to consider the existing research carefully before allocating significant public funds for hydrogen heating.

This is also because there are many competing high-priority applications where hydrogen is essential. This includes, for example, replacing existing hydrogen use with green hydrogen (for example, in fertilizer production) and replacing fossil fuels in high-temperature industrial processes, shipping, and long-term energy storage for electricity production.[2] Given the scale of hydrogen needed for those applications where few alternative decarbonization options exist, it seems sensible to focus efforts in the heating sector on the roll-out of established technologies.

There is also a risk that the discussion on hydrogen for heating leads to a delay in deploying alternative clean heating technologies that are available today and reduce greenhouse gas emissions now, including energy efficient heat pumps, district heating, solar thermal, and others. Given the urgency of reducing carbon emissions, policies and regulations should focus on increasing deployment of technologies available today rather than anticipating widespread availability of hydrogen later.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.joule.2022.08.015.

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