WHY HYDROGEN FROM BIOENERGY CANNOT REDUCE GREENHOUSE GAS EMISSIONS

Aug 2022

Executive Summary:

Hydrogen is being strongly promoted by governments, especially in Europe and North America, as part of their 'net zero' climate strategies. This is despite the fact that, so far, 98% of hydrogen has been made from fossil fuels, resulting in even more CO_2 emissions than burning the same fossil fuels directly for energy. This is even true in the small number of cases where CO_2 from hydrogen production is being captured. However, there is growing momentum for expanding so-called 'green hydrogen', made from renewable electricity.

The direct greenhouse gas footprint of hydrogen made using wind and solar power is small; however, using such power to make hydrogen will divert wind and solar power from other uses where they would do far more to reduce carbon emissions. This remains the case for as long as the majority of energy is still produced from fossil fuels. Furthermore, heat pumps and electric vehicles are significantly more efficient than switching to hydrogen.

Eventually, assuming meaningful action to reduce dependence on burning carbon for energy, there could be a case for using hydrogen from renewable electricity in certain industries. However this briefing sets out in detail why there will never be a case for using biomass to make hydrogen, regardless of how the biomass is sourced. Bioenergy already has the highest land footprint of all types of energy, because relying on photosynthesis to convert solar radiation to useful energy is extremely inefficient. Most of the

energy in biomass is then lost during conversion to electricity or, for that matter, during the three-stage process of making hydrogen from biogas. Furthermore, large-scale bioenergy will rely either on cutting down trees or on converting land to grow energy crops, both of which result in very high overall greenhouse gas emissions.

Hydrogen-from-bioenergy proposals, such as one made by Onyx in Wilhelmshaven in Germany should therefore be rejected.

What is hydrogen and how is it used in energy systems?

Hydrogen is an element found in water and many other substances. Only very small quantities of pure hydrogen gas (H2) exist in the atmosphere. When pure hydrogen is combusted, it reacts with oxygen to form water, releasing energy at the same time. This makes hydrogen an energy carrier. It is normally stored in fuel cells, in which it is reacted with oxygen to generate electricity, and it can also be supplied via special corrosion resistant gas pipelines to provide heat.

According to a report by the International Energy Agency in 2019, 76% of all hydrogen is currently produced from fossil gas and 23% from coal, most of it using a process called steam-methane reforming. 2% of hydrogen is made using electricity to split water (electrolysis).

Hydrogen infrastructure and production are being expanded as a result of government subsidies and incentives, especially in the EU and USA. A 2019 report by Corporate Europe Observatory revealed that fossil gas companies had by that time spent at least €58.6 million on lobbying EU policy-makers to support large-scale hydrogen production and use. In the USA, gas companies successfully lobbied the Biden administration, procuring $9.5 billion in the 2021 Infrastructure Act to support hydrogen, much of it from fracked gas.

Can hydrogen play a role in reducing greenhouse gas emissions?

Fossil gas hydrogen plant in India

For hydrogen derived from fossil fuels, the simple answer is no. According to the International Energy Agency, today's hydrogen production emits around 900 million tonnes of CO_2 a year into the atmosphere. Life-cycle greenhouse gas emissions of a unit of energy from combusting fossil-gas derived hydrogen are even higher than those from conventional fossil gas energy, while hydrogen from coal gasification is even worse. Carbon capture and storage is proposed as a solution for fossil-fuel derived hydrogen, although very little of this is happening so far: the Global CCS Institute lists just three operational projects of this type worldwide, two of which involve the Canadian tar

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sands industry. And, according to a recent study, greenhouse gas emissions from fossil-gas hydrogen with carbon capture are still 20% higher than those from burning fossil gas directly for heat.

The only way in which hydrogen could result in emissions reductions is to produce it from genuinely low-carbon renewable energy sources. Hydrogen generated through electrolysis of water using renewable electricity is called "green hydrogen". There are also proposals to make hydrogen from biomass gasification or steam methane reforming of biomethane. Those are discussed at the end of this briefing.
However, for 'green hydrogen' to actually result in emission reductions, two additional conditions need to be met:

1) Hydrogen must not replace an equally low-carbon but more efficient way of generating energy, AND

2) Low-carbon renewable energy[1] must not be diverted from another use where it would result in greater emission savings.

Are there any sectors where electrification would not be a more efficient way of switching to renewable energy than 'green hydrogen'?

As confirmed in a 2019 report by the International Renewable Energy Agency (IRENA), 'green hydrogen' used for space heating or cooling as well as for most road transport requires significantly more renewable energy than heat pumps or electric vehicles respectively. Although IRENA suggested a case for 'green hydrogen' for buses and trucks, a subsequent study has shown that battery-powered electric buses are significantly more efficient than hydrogen-powered buses.[2] According to data obtained and presented by Transport & Environment, electric lorries, too, are more efficient than lorries running on hydrogen. Note, however, that using electric trolley buses and shifting transport from road to rail wherever possible are far better options for reducing greenhouse gas emissions than switching to battery-powered large vehicles. Across the road transport sector, encouraging a shift to active travel and public transport and reducing the need to travel (e.g. through planning policies and supporting hybrid or home working) are the most effective ways for cutting greenhouse gas emissions.

Many industrial processes, too, can be more efficiently replaced with electric ones, rather than swapping fossil fuels for hydrogen. The only potential uses for which no more efficient electric option exists would be aviation, shipping and certain industrial processes.

However, for aviation, hydrogen will not be a feasible option until 2050 at

1 We are referring here to 'low-carbon renewable energy' because not all energy classed as renewable is indeed 'low-carbon'. Biomass energy is commonly associated with very high carbon emissions, as are many hydropower plants.

2 Note that it has been suggested that under very specific conditions (hilly urban areas with a warm, humid climate), the reverse may be the case, i.e. that hydrogen buses could be more efficient than buses running on batteries: https://www.wired.co.uk/article/future-buses-hydrogen-electric

Does hydrogen gas in itself contribute to global warming?

Hydrogen itself is not a greenhouse gas. However, an estimated 20-30% of hydrogen that leaks into the atmosphere reacts with a molecule called hydroxyl (OH). In doing so, it reduces the amount of hydroxyl in the atmosphere. This is highly problematic because the powerful greenhouse gas methane is removed from the atmosphere by reacting with OH. Anything else that reacts with hydroxyl, including leaked hydrogen gas, makes methane stay in the atmosphere for longer, causing more warming. It is uncertain precisely how large the indirect warming impact of leaked hydrogen is, however, it could be very substantial. (See: https://acp.copernicus.org/articles/22/9349/2022/acp-22-9349-2022.pdf)

the earliest, except perhaps for short haul and regional flights. Yet replacing short-haul flights with train journeys would go much further for climate change mitigation. In shipping, too, major obstacles would need to be overcome before hydrogen could be used.

It is difficult to make a case for any commercial production of "green hydrogen" at a time when wind and solar power together account for just 4.1% of total energy in Europe, 2.6% in the USA, and 2.2% worldwide. For example, Germany has the biggest industrial sector of all EU countries, yet Germany's greenhouse gas emissions from the industrial sector are a mere 9% of those from the energy sector, with fossil fuel burning having generated 44% of electricity and 76% of heat in 2021.

"Green hydrogen" from biomass electricity?

Logging site in Estonia linked to wood pellet production, Photo: Karl Adami

Per unit of energy, burning biomass for electricity emits no less CO_2 than burning coal. Across the EU, most biomass energy comes from burning forest wood. 500 scientists warned in an open letter in early 2021: "*As numerous studies have shown, this burning of wood will increase warming for decades to centuries. That is true even when the wood replaces coal, oil or natural gas*." More information about the impacts of forests biomass energy in particular can be found here: environmentalpaper.org/biomass-faq/.

An exceptionally wasteful use of biomass for energy:

As shown above, large-scale biomass energy, especially if it is sourced from forests and from dedicated crop and tree plantations is fundamentally inefficient and linked to high greenhouse gas emissions. Coupling biomass electricity generation with hydrogen production would be an exceptionally wasteful forms of energy conversion:

Comparison of forest biomass and solar electricity in Germany

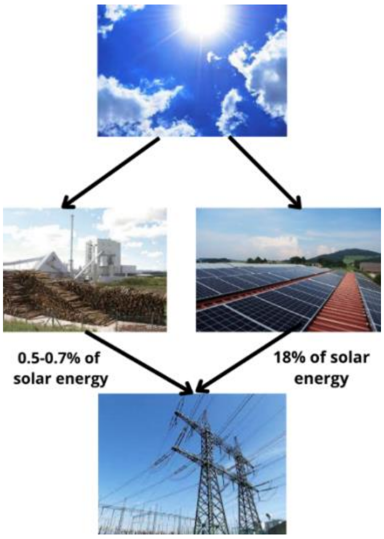
Every year, German forests convert around 1.85% of incoming solar radiation to chemical energy. If all of a forest's annual growth or increment was harvested to generate electricity, the power output would represent between 0.52 and 0.7% of solar radiation, i.e. the original source of the energy. An efficient heat or heat-and power plant would raise that figure to a maximum of 1.48%.

Note that removing 100% of a forest's annual growth means that the forest no longer sequesters any carbon, i.e. that more of the carbon dioxide emitted from burning for example coal would remain in the atmosphere, causing additional warming.

By comparison, an average solar PV panel in Germany converts around 18.5% of solar radiation to electricity. None of these figures include life-cycle emissions, such as panel manufacture for solar PV, and harvesting, processing and transporting wood, nor the energy required for building a biomass power station.

The data and methodology on which those figures are based can be found in the Annex below.

1) Firstly, ***biomass electricity, together with transport biofuels, has the highest land footprint of all forms of electricity generation.*** This is due to the fact that photosynthesis is a very inefficient way of converting solar radiation to energy stored in biomass, and that on average ***between 62 and 72% of that energy is lost during conversion to electricity, in addition to the energy required to harvest, process and transport biomass***. An efficient heat or combined heat and power plant will have significantly less energy losses during conversion. However, optimising efficiency requires maximising heat output at the expense of electricity. Yet electrolysis to make hydrogen relies on electricity alone, so it would be in companies' interest to minimise heat generation at the expense of overall efficiency.



2) Secondly, as the report by IRENA highlights: "Currently, significant energy losses occur in hydrogen production, transport and conversion." The UK Committee on Climate Change – an independent statutory body advising the UK Government, estimates that 26% of

electricity is lost during conversion to hydrogen. If the hydrogen is stored in fuel cells, another 40% is lost during conversion to electricity. Conversion to heat also results in energy losses, although smaller ones. Finally, unless users are linked up to hydrogen pipelines or hydrogen is stored in fuel cells produced next to electrolysers, it will need to be liquefied or converted to ammonia, methanol or liquid organic hydrogen. Liquefying hydrogen or further converting it results in significant further energy losses.

Thus, at the end of a conversion chain of biomass – electricity – hydrogen – fuel cell – electricity end use, between 83.1 and 87.6% of the energy contained in the biomass will have been lost.

Has anybody actually proposed burning biomass in order to electrolyse water to hydrogen?

Biofuelwatch is aware of at least three, possibly four such proposals, although there may well be others:

- ***Wilhelmshaven, Germany***: Energy company Onyx has been looking at the option of converting its coal power plant in Wilhelmshaven to biomass since 2020. Onyx is a fully owned subsidiary of Riverstone Holdings, who are the biggest shareholder in Enviva, the world's largest wood pellet producer. Environmental NGOs and reporters have been documenting for years how Enviva is routinely sourcing wood from clearcut highly biodiverse coastal hardwood forests for pellets. In December 2021, the Port of Wilhelmshaven set out a draft 'vision', according to which biomass electricity from a converted Onyx coal plant would be used to produce 'green hydrogen'. This proposal appears to be linked to Uniper's "Green Wilhelmshaven" project which is to "establish an energy hub for the large-scale import and production of green hydrogen". Wilhelmshaven is a North Sea port with a significant offshore wind potential, but there is no obvious rationale for converting a coal plant to biomass in order to produce more hydrogen – except, of course, to secure Riverstone Holdings' assets and business interests.
- ***Tasmania:*** A start-up company called HIF Global has secured significant private investment to produce "green hydrogen" for transport. The company is primarily looking at the wind power for its hydrogen production – except in Tasmania. There, HIF Global has applied for an environmental permit for an electrolyser coupled with electricity generation from a "biogenic source", i.e. a biomass power plant. As shown above, using hydrogen as a transport fuel is far less efficient and thus more wasteful than switching to electric vehicles. Moreover, the state generates all of its electricity from hydro power and wind energy. There is no reason why additional electricity demand could not be met from wind and solar power instead of biomass.
- ***Estonia:*** Estonian energy company Utilitas Group has obtained government support to build an electrolysis plant to supply new hydrogen buses. The electricity will be taken from an existing biomass cogeneration plant in Tallinn, which burns wood. At least in its current phase, the project is small and will not require additional wood to be

burned, although it will use energy that is currently going to the grid. Nonetheless, the aim of the project – to demonstrate that Utilitas can produce hydrogen for buses via electrolysis seems misguided since, as shown above hydrogen buses are far less efficient than electric ones. Using biomass electricity for this purpose is particularly wasteful.

- ***Gardanne, France:*** In Gardanne, a coal power station unit has been converted to a 150 MW wood biomass plant. After an initially unsuccessful attempt by E.On and then Uniper to operate that biomass unit, the new owners, EPH subsidiary GazelEnergie, successfully commissioned it in April 2022, following substantial investments. Google Earth images show large quantities of roundwood being sourced. Next to the power plant, German hydrogen start-up company Hy2Gen, in partnership with GazelEnergie, plans to develop a hydrogen electrolyser, a wood gasification unit, and a production plant for alternative aviation and shipping fuel ("e-kerosene" and "e-methanol"). The biomass gasifier is to use an additional 83,000 tonnes of wood every year to make synthetic methane for fuels, not hydrogen. The electrolyser, on the other hand, will use "local renewable electricity". There has been no public announcement as to whether that electricity will come from the Gardanne biomass plant.

Hydrogen production from biomass syngas and from biomethane:

Two other processes for making hydrogen from biomass are proposed: Steam methane reforming of biomethane and hydrogen separation from syngas.

Steam methane reforming of biomethane[3]*:*

This process involves three different steps:

(a) *Anaerobic digestion* of biomass to produce biogas: Biogas is widely used for heat and electricity. Across the EU, the main biogas feedstocks are manure, agricultural residues (especially straw) and crops, especially maize but also other cereals, silage grass, and sugar beet. Another suitable feedstock is food waste. A by-product of biogas production is digestate, a nutrient- and especially nitrogen-rich soil amendment.

(b) Biogas *upgrading to biomethane*: Biogas consists mostly of methane and carbon dioxide, but also contains nitrogen and small amounts of other chemicals as well as water vapour. This makes it unsuitable for example for gas engines, in LPG cars, or for mixing with fossil gas in a gas grid. For that, biogas must be upgraded to remove the traces of different chemicals and to then separate CO_2 from methane. According to one

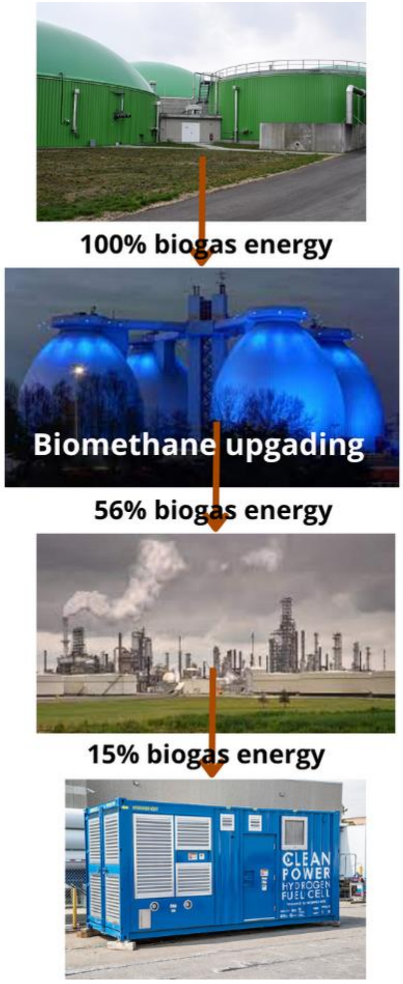
3 Note that in the USA, the term 'renewable gas' is commonly used both for (upgraded) landfill gas and biomethane. Sewage treatment plant gas is also sometimes called biogas. However, in this briefing we use the EU definition, set out in the Renewable Energy Directive, which treats landfill gas, sewage treatment plant gas and biogas as separate forms of energy.

study, 44% of energy in biogas is needed to upgrade biogas to biomethane. Upgrading more than 56% of biogas volume thus requires external energy inputs. However, biomethane can then be converted more efficiently to useful energy than is the case for biogas in most cases.

(c) *Steam methane reforming of biomethane*: Steam methane reforming accounts for an estimated 80-85% of global hydrogen production. The process would be the same for biomethane as it is for fossil gas: heat water to a very high temperature, react it with the biomethane, using a chemical catalyst to produce hydrogen, carbon monoxide and some CO_2, then use low temperature heat and another chemical catalyst to convert the carbon monoxide and water into more hydrogen, then remove CO_2 and other chemicals. At this stage, another 74% of energy is lost during conversion. In theory, CO_2 could be captured at this stage, but this worsens the energy balances further, which is why hardly any carbon capture from fossil gas-based hydrogen production is happening. Furthermore, less than 15% of CO_2 emissions during the full biomass-hydrogen conversion cycle could actually be captured.

Clearly, ***this hydrogen pathway is another extremely inefficient and wasteful way of generating energy from biomass.***

In 2020, the UK non-profit organisation Feedback Global published a report based on a life-cycle assessment conducted together with researchers at Bangor University. The authors found that



only a very limited amount of biogas and biomethane would be compatible with governments' "net zero" targets, once indirect emissions such as from land use change for energy crops are accounted for. Losing a substantial fraction of that energy from anaerobic digestion to produce hydrogen would make little sense.

Moreover, as the authors of a recent study show, ***methane leakage from anaerobic digestion is often substantial***. Additional methane leakage also happens during upgrading to biomethane, and during the storage of digestate. Technically, methane leakage could be kept to a small minimum. However, no controls or mitigation measures are required in the EU nor, to our knowledge, anywhere else.

Hydrogen separation from biomass syngas:

Unlike the two biomass-hydrogen technologies discussed above, this one remains "at the research and demonstration phase", according to the UK's Committee on Climate Change. Gasification involves exposing a feedstock such as wood to high temperatures with a controlled oxygen stream. This produces a 'syngas' composed of hydrogen, CO_2, carbon monoxide, but also various impurities, including hydrocarbon particles called tar. Tar formation is perhaps the biggest technical challenge to biomass gasification. Unless tar particles are removed from the syngas, they will clog up or corrode boilers and pipes. All syngas needs to be cooled and cleaned before it can be used in gas engines or turbines.

However, in order to produce hydrogen, syngas would need to be cleaned to a particularly high degree of purity, before splitting the hydrogen from other molecules and converting carbon monoxide to CO_2 and additional hydrogen. The UK Committee on Climate change states: "*There remains some **uncertainty around whether biomass gasification can be deployed at scale in a commercially viable way**.*" The Committee further points out that using non-homogenous feedstock would pose an extra challenge. Clean wood pellets made from tree monocultures would then become a 'perfect' feedstock, even though cutting down trees for energy is particularly harmful for the climate, and replacing forests and other ecosystems with monocultures damages biodiversity, too.

Annex

To compare the land footprint of forest biomass electricity with that of solar electricity, using Germany as the example, we start with the current annual increment (i.e. annual wood growth) in forests. This is an estimated as 9.3 m^3 per hectare which converts to 7.61 green tonnes of wood including bark, representing the weight of the freshly cut, not yet dried wood. Assuming that 50% of the weight of this wood is water, one hectare of forest produces 3.805 dry tonnes of wood a year. The average net calorific value (i.e. energy content) of a dry tonne of wood is 5.3 MWh or 19 GJ. Thus, one hectare of forest produces 20.17 MWh of energy a year. With a conversion efficiency to electricity of 28-38%, that hectare yields between 5.65 and 7.66 MWh of electricity.

By comparison, the average solar radiation (direct normal irradiance) in Germany is around 1,088 MWh per hectare. ***The conversion efficiency from solar radiation energy to biomass electricity is thus between 0.52 and 0.7***. In reality, it is even lower, because these figures ignore the energy used during harvesting, processing and transporting the wood.

By comparison, an average solar PV panel generates at least 200 MWh per hectare. This is equivalent to around 18.4% of incoming solar radiation. This figure falls within the 16-22% range cited by the National Renewable Energy Laboratory in the US.

The fundamental reason behind the extremely high land footprint of biomass energy is the fact this is that all bioenergy is based on the conversion of solar energy via photosynthesis. Photosynthesis transforms solar energy into chemical energy (in the form of carbohydrates) to allow plants and blue-green algae to grow. However, almost all of the energy and therefore carbon fixed during photosynthesis is emitted again during plant respiration. According to a scientific study in 2008, the theoretical maximum percentage of solar energy which any plant (other than certain crops called C4 crops) can convert to biomass is 4.6%, however, the actual figure, under real-world conditions, is far lower.

Biofuelwatch provides information, advocacy and campaigning in relation to the climate, environmental, human rights and public health impacts of large-scale industrial bioenergy.