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Northwest Gas proposal on mixing pyrolytic hydrogen with natural gas[1]

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This short paper analyzes a Northwest Gas company proposal to produce hydrogen from natural gas using pyrolysis; the hydrogen would be mixed with natural gas in existing pipelines. This analysis is focused mainly on climate issues, but also touches on some others.

1. Production of hydrogen using pyrolysis of methane

Methane (chemical formula: CH_4) constitutes about 95% of natural gas. Pyrolysis involves the following reaction, which is shown in its ideal form (i.e., no losses):

CH_4 (16 kilograms) → C (12 kg) + $2H_2$ (4 kg) ---- Equation (1).

It takes a theoretical minimum of 4 kilograms of methane to produce 1 kilogram of hydrogen. In addition, some energy is required for heating the methane. Additional natural gas can be used; in the alternative, some of the hydrogen produced can be fed back into the process and used as fuel for heating; however, it is important to note that more natural gas is used to produce the extra hydrogen.

Current methods of producing hydrogen also use natural gas, but in reaction with steam; the process is called "steam methane reforming," usually abbreviated as SMR. The net reaction (with no losses) is:

CH_4 (16 kg) + $2H_2O$ (36 kg) → CO_2 (44 kg) + 4 H_2 (8 kilograms) ---- Equation (2)

The advantage of pyrolysis is that no CO_2 is created; none would be emitted *but only if the carbon is sequestered in some way for the long-term by methods that do not involve net increases in climate impacts*. The possible processes of sequestration, whether in useful materials or in underground storage, are not addressed in this memorandum. The main disadvantage is that pyrolysis requires twice the amount of natural gas as steam reforming to produce a given amount of hydrogen.

2. Climate implications

The fact that pyrolysis takes twice as much natural gas to make the same amount of hydrogen as the current method (steam reforming of natural gas) has critical implications for climate even though no CO_2 is emitted in the pyrolysis process. The climate impact of pyrolytic hydrogen comes from natural gas

[1] Prepared at the request of an Oregon legislator. Dr. Thom Hersbach of the Stanford Linear Accelerator Center kindly reviewed a draft of this memorandum, which helped improve it. As its author, I alone and responsible for its contents, including any errors that might remain.

leaks throughout the system from the production fields to the pyrolysis plant. If some of the hydrogen is used for the heat needed in the pyrolysis process, it would take about 5 kilograms of methane to produce 1 kilogram of usable hydrogen; 4 kilograms to make the marketable hydrogen and 1 kilogram for heating methane. That is the approach taken for the calculations below.

Natural gas leaks vary by production field and pipeline. Nationally, the leak rate is about 2.7% of the amount consumed at the point of the end-use (in this case the pyrolysis plant). Using a 2% to 3% range, each kilogram of usable hydrogen produced using methane pyrolysis would result in 0.1 to 0.15 kilogram of methane leaks. Methane has a 20-year warming potential of 82.5 (relative to the CO_2 warming potential of 1). Thus, the warming impact of methane leakage per kilogram of hydrogen would be in the range of 8 to 12 kilograms CO_2-equivalent (rounded). The estimate corresponding to the national average leak rate of 2.7% would be about 11 kilograms. This is nearly three times the DOE "clean hydrogen" standard of 4 kg CO_2-equivalent per kg H_2.

Main conclusion: The result is that pyrolytic hydrogen from natural gas has about the same climate emissions as using the same amount of energy from natural gas directly – about 11 kilograms of CO_2-equivalent. In effect, all the expense produces no climate benefit at all.

That is why the DOE itself has noted the following:

> To realize "low/no-carbon" hydrogen from methane (by methane pyrolysis, SMR+CCS or other), we need to *radically eliminate methane leaks* in the supply chain and in the conversion process.[2]

Note that I have not included methane leaks in the pyrolysis process itself; only leaks in the natural gas system from the production point up to the pyrolysis plant are included in the above calculations. Including leaks at the pyrolysis plant would increase climate impacts, possibly beyond those of burning natural gas directly for the energy end use.

3. Mixing hydrogen in natural gas pipelines

NW Natural, a natural gas company in Oregon, plans initially to mix 0.2% hydrogen with natural gas.[3] This is a very small concentration. From the leak testing activities mentioned on the company's website, it appears that the aim is to increase the hydrogen concentration in natural gas pipelines to 5% and perhaps even higher, to 20%.[4] However, the cited webpage provides no data on the leak rates at 5% and 20% based on the company's own testing and no information on what types of pipes are being tested, including whether they are of the types vulnerable to hydrogen-induced degradation.

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[2] Marc von Keitz, *Methane Pyrolysis for Hydrogen–Opportunities and Challenges*, Hydrogen Shot Summit Thermal Conversion with Carbon Capture & Storage, August 31, 2021, Slide 9; italics added. "SMR" in the quote stands for "steam methane reforming." "CCS" in the quote stands for carbon capture and sequestration. https://www.energy.gov/sites/default/files/2021-09/h2-shot-summit-panel2-methane-pyrolysis.pdf

[3] Alex Baumhardt, "Environmentalists, customers raise concerns over NW Natural hydrogen project," *Oregon Capital Chronicle*, August 5, 2024. https://www.opb.org/article/2024/08/05/nw-natural-hydrogen-project/

[4] Emerging opportunities for hydrogen and carbon capture, NW Natural, Company website at https://www.nwnatural.com/about-us/environment/hydrogen viewed on 2024-11-10

Hydrogen has less than 30% of the energy content of natural gas per unit volume. As a result, providing the same *rate* of energy (Btu per hour) to the heating device requires an increase in distribution pipeline pressure. This in turn increases the natural gas leak rate. Further, hydrogen, being a smaller molecule, leaks at a rate 3.8 to 4.6 times the leak rate of natural gas. Hydrogen can embrittle some kinds of steel and degrade polyethylene pipes. Thus, it is important to know what types of pipelines will be used to transport the hydrogen-natural gas mixture. Finally, burning hydrogen produces nitrogen oxides, causing air pollution.[5]

These considerations at the are not very important if hydrogen is mixed with natural gas at the small rate of 0.2%. By the same token, a 0.2% hydrogen mixture serves essentially no practical energy purpose. And at present natural gas leak rates, it serves no climate purpose.

Figure 1 below shows the climate impact of using natural gas directly compared to natural gas blended with 5% and 20% hydrogen, for three methods of hydrogen production. Even green hydrogen (which is hydrogen produced with solar or wind electricity) missed at 5% would yield a marginal benefit of just 1% compared to natural gas alone. At 20% hydrogen, the CO_2-equivalent emission reduction would be just 6%.

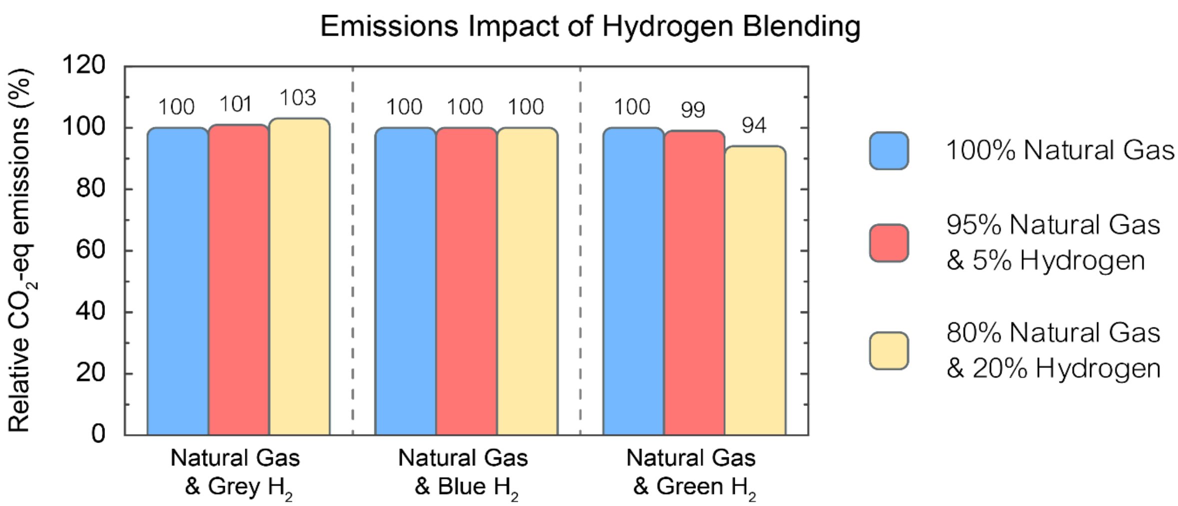

Figure 1: Comparing the emissions impact of hydrogen blending for different methods of hydrogen production. "Grey" hydrogen is produced by steam reforming of natural gas (equation (2) above; "blue" hydrogen is grey hydrogen with carbon capture and sequestration of the CO_2. Green hydrogen is produced using wind or solar electricity to electrolyze water.
Source: Makhijani and Hersbach 2024.

At present natural gas leak rates, emissions from pyrolytic hydrogen would be most comparable those shown burning natural gas itself so long as natural gas leaks are comparable to present levels.

[5] Arjun Makhijani and Thom Hersbach, Hydrogen: What Good Is It?, Institute for Energy and Environmental Research 2024. https://ieer.org/wp/wp-content/uploads/2024/06/What-Good-Is-Hydrogen-IEER-report-for-Just-Solutions-January-2024.pdf

There are some potential uses of green hydrogen that could reduce emissions, such as using green hydrogen to produce ammonia instead of hydrogen made from natural gas ("grey" hydrogen), as is the current practice. Mixing hydrogen with natural gas in pipelines is a waste of money and resources for little or no benefit even with green hydrogen. It is counterproductive in the case of pyrolytic hydrogen produced from natural gas.