Cornell University

Department of Ecology and Evolutionary Biology

Statement of Robert W. Howarth, Ph.D.

before a hearing of the Pennsylvania State Senate on
Exploring the Impacts of Hydrogen in Pennsylvania

December 4, 2023

My name is Robert Howarth. I am an Earth systems scientist with a B.A. from Amherst College and a Ph.D. jointly from MIT and the Woods Hole Oceanographic Institution. I joined the faculty of Cornell University in 1985 and was appointed the *David R. Atkinson Professor of Ecology & Environmental Biology* in 1993. I also am an Adjunct Senior Scientist at the Marine Biological Lab in Woods Hole, MA, and am Co-Editor in Chief of the journal Ocean-Land-Atmosphere Research. My statement today reflects my professional opinion but should not be construed as an official position of any of the institutions with which I am affiliated.

I have published over 250 scientific papers, reports, and book chapters and have edited or authored eight books. My peer-reviewed papers have been cited more than 83,000 times in other peer-reviewed literature, making me one of the most cited environmental scientists in the world. The research program of my lab is broad ranging and includes climate effects on nutrient pollution in lakes and coastal ecosystems, nitrogen effects in coastal marine ecosystems, sources of methane from natural gas operations and agriculture, atmospheric ammonia pollution, alternative energy policies, and lifecycle assessments for hydrogen, liquefied natural gas, and renewable natural gas. I am one of 22 members of New York's Climate Action Council (by appointment of the Speaker of the NY Assembly, the Honorable Carl Heastie). The Council is charged with implementing the State's ambitious climate goals laid out in the Climate Leadership and Community Protection Act of 2019.

Today I will briefly discuss the greenhouse gas consequences of blue hydrogen.

Blue hydrogen is a new concept, an idea that came out of the marketing forces of the oil & gas industry and widely promoted through the Hydrogen Council, an organization established in 2017 by several big majors in the oil industry (BP, Total, Shell, etc). The Hydrogen Council and others in the oil and gas industry have often described blue hydrogen as having low or zero greenhouse gas emissions. This is simply not true. Emissions of both carbon dioxide and methane are high for blue hydrogen, as I discuss further below.

The basic technology to produce blue hydrogen is the same as used for well over 130 years for production of gray hydrogen: steam methane reforming (SMR). In this process, methane in natural gas is the chemical feedstock, and is decomposed into carbon dioxide and hydrogen under heat and pressure, with the addition of steam. The heat, pressure, and steam are made from burning yet more natural gas. For blue hydrogen, an effort is made to capture the carbon dioxide produced in the SMR process.

In August of 2021, Mark Jacobson (an engineer at Stanford University) and I published a peer-reviewed analysis of the greenhouse gas footprint of blue hydrogen, the first effort to do so that included emissions of methane associated with the natural gas consumed to make the hydrogen. Our analysis was both transparent and conservative. Our conclusion is that while greenhouse gas emissions from blue hydrogen are somewhat less than those for the traditional gray hydrogen made from natural gas, they are substantially larger than if one were to simply burn natural gas instead. Why? Two reasons: 1) not all of the carbon dioxide is captured; and 2) yet more natural gas is consumed to power the attempt to capture carbon dioxide, with significant emissions of methane upstream in the shale-gas fields and processing plants that provide the methane to make blue hydrogen. It is important to note that so far, industry has only tried to capture carbon dioxide created in the SMR process. They have not attempted to capture the carbon dioxide in the exhaust flue gases made from burning natural gas that powers the process, which is far more challenging. Our paper is available online at https://onlinelibrary.wiley.com/doi/full/10.1002/ese3.956

Our conclusion is very robust, as we ran a series of sensitivity analyses around any reasonable values for methane emissions and for efficiency of carbon dioxide capture. Our fundamental conclusion held across all of these input values. Our conclusion is also conservative, for two reasons: 1) we did not include emissions from the transport and storage of captured carbon dioxide; this is unproven and untested territory with no track record with available data, and we simply gave the industry the benefit of the doubt; and 2) we did not include the consequences of hydrogen leaks on the climate; hydrogen leaks are inevitable and will likely be high, as hydrogen is the smallest molecule in the Universe; hydrogen itself is not a greenhouse gas, but adding more hydrogen to the atmosphere intensifies the warming effects of greenhouse gases such as methane; the science behind this has progressed remarkably quickly since our blue-hydrogen paper was published 28 months ago.

The bottom line is that blue hydrogen is a climate disaster. Greenhouse gas emissions are worse than from simply burning natural gas.

Following are slides I will present in the hearing, which have figures supporting the conclusions I have presented above.

Thank you for the opportunity to present this information.

The Methane Project at Cornell University

Greenhouse Gas Consequences of Blue Hydrogen

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Exploring the Impacts of Hydrogen in Pennsylvania
PA Senate Hearing

December 4, 2023

Currently, 96% of hydrogen globally comes from fossil fuels.

In North America & Europe, virtually all from natural gas.

- Natural gas is mostly methane, and this is the feed stock for hydrogen.
- Under high heat & pressure, methane plus steam (water vapor) is converted to hydrogen & CO_2 (steam methane reforming, or SMR).
- Natural gas also burned to provide the heat & pressure.
- Product is called "gray hydrogen."

$$CH_4 + 2\,H_2O \longrightarrow 4\,H_2 + CO_2$$

Methane feed stock from natural gas

Heat from burning natural gas

"Blue hydrogen" is traditional gray hydrogen from steam methane reforming of fossil natural gas combined with carbon capture and storage.

Term first used by Air Liquide in 2015, highly promoted since 2017 by the oil & gas industry, particularly by the Hydrogen Council (a group established by BP, Shell, Total, & other oil & gas companies in 2017).

As of a year ago, only two commercial blue hydrogen facilities globally (Texas in the US and Alberta in Canada).

BLUE HYDROGEN

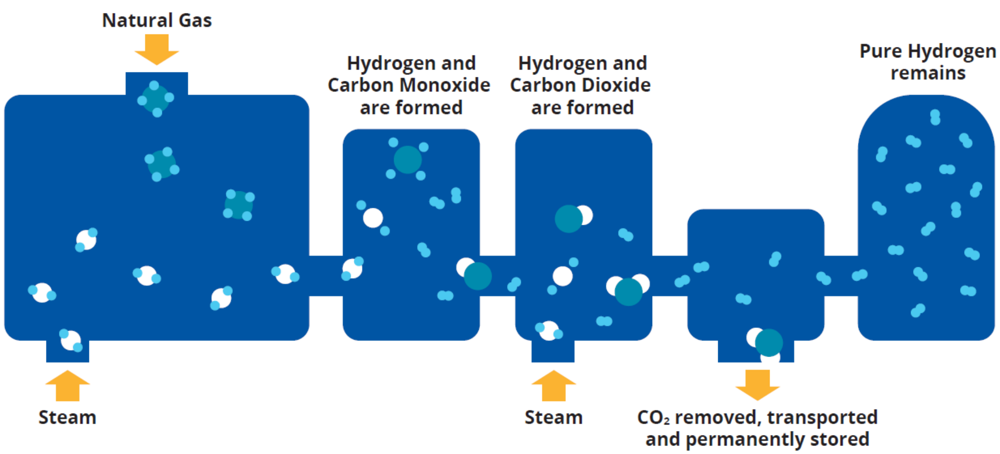
Blue hydrogen is derived from natural gas through the process of steam methane reforming (SMR). SMR mixes natural gas with very hot steam, in the presence of a catalyst, where a chemical reaction creates hydrogen and carbon monoxide. Additional water is added to the mixture converting the carbon monoxide to carbon dioxide and creating more hydrogen.

The carbon dioxide emissions produced are then captured and stored underground using Carbon Capture, Utilization and Storage (CCUS) technology leaving nearly pure hydrogen.

Blue H_2 facts:

- The most common and economical way to produce hydrogen
- When used with CCUS, blue hydrogen produces nearly zero emissions
- Alberta has the infrastructure to produce blue hydrogen cheaper than any other jurisdiction in the world

"nearly zero emissions"



ATCO

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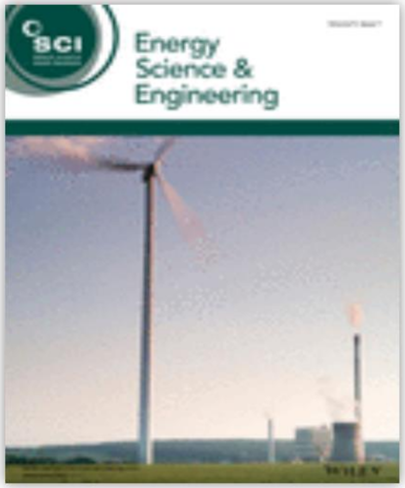

August 2021

Received: 28 April 2021 | Revised: 16 July 2021 | Accepted: 26 July 2021

DOI: 10.1002/ese3.956

Energy Science & Engineering Open Access

MODELLING AND ANALYSIS

How green is blue hydrogen?

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Funding information
Funding was provided by the Park Foundation and by Cornell University

Abstract

Hydrogen is often viewed as an important energy carrier in a future decarbonized world. Currently, most hydrogen is produced by steam reforming of methane in natural gas ("gray hydrogen"), with high carbon dioxide emissions. Increasingly, many propose using carbon capture and storage to reduce these emissions, producing so-called "blue hydrogen," frequently promoted as low emissions. We undertake the first effort in a peer-reviewed paper to examine the lifecycle greenhouse gas emissions of blue hydrogen accounting for emissions of both carbon dioxide and unburned fugitive methane. Far from being low carbon, greenhouse gas emissions from the production of blue hydrogen are quite high, particularly due to the release of fugitive methane. For our default assumptions (3.5% emission rate of methane from natural gas and a 20-year global warming potential), total carbon dioxide equivalent emissions for blue hydrogen are only 9%-12% less than for gray hydrogen. While carbon dioxide emissions are lower, fugitive methane emissions for blue hydrogen are higher than for gray hydrogen because of an increased use of natural gas to power the carbon capture. Perhaps surprisingly, the greenhouse gas footprint of blue hydrogen is more than 20% greater than burning natural gas or coal for heat and some 60% greater than burning diesel oil for heat, again with our default assumptions. In a

One of very few peer-reviewed analyses of greenhouse gas footprint of either gray or blue hydrogen.

And the first to include methane in addition to CO_2.

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Primary input parameters for our blue hydrogen assessment:

- Upstream fugitive methane emission rate (**3.5%;** sensitivity analysis 1.54% to 4.3%)
- Time frame for comparing methane to CO_2 (**20 yrs, GWP= 86;** sensitivity analysis GWP_{100} of 34 to GWP_{20} of 105).
- CO_2 capture in SMR process (**85%;** sensitivity analysis 79% to 90%)
- CO_2 capture from gas burned to provide heat & pressure for SMR process (**0%** for current SMR plants; possible **65%** based on power plants; sensitivity analysis 55% to 90%)

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Color of hydrogen	Process to make hydrogen	Greenhouse gas emissions ($kg\ CO_2$-eq/$kg\ H_2$)
Gray hydrogen	Steam methane reforming (SMR) of natural gas to produce hydrogen and carbon dioxide	**25**
Blue hydrogen	Steam methane reforming (SMR) of natural gas to produce hydrogen and carbon dioxide, with some carbon dioxide capture	**23**
Green hydrogen	Electrolysis of water with renewable electricity to produce hydrogen & oxygen	**3**

Gray and blue hydrogen estimates from Howarth & Jacobson (2021) using GWP20 & default methane emissions. GWP20 for H2 = 33 (Ocko & Hamburg 2022); 10% emission = 3.3 kg CO2-e/kg H2); added to all of the above.

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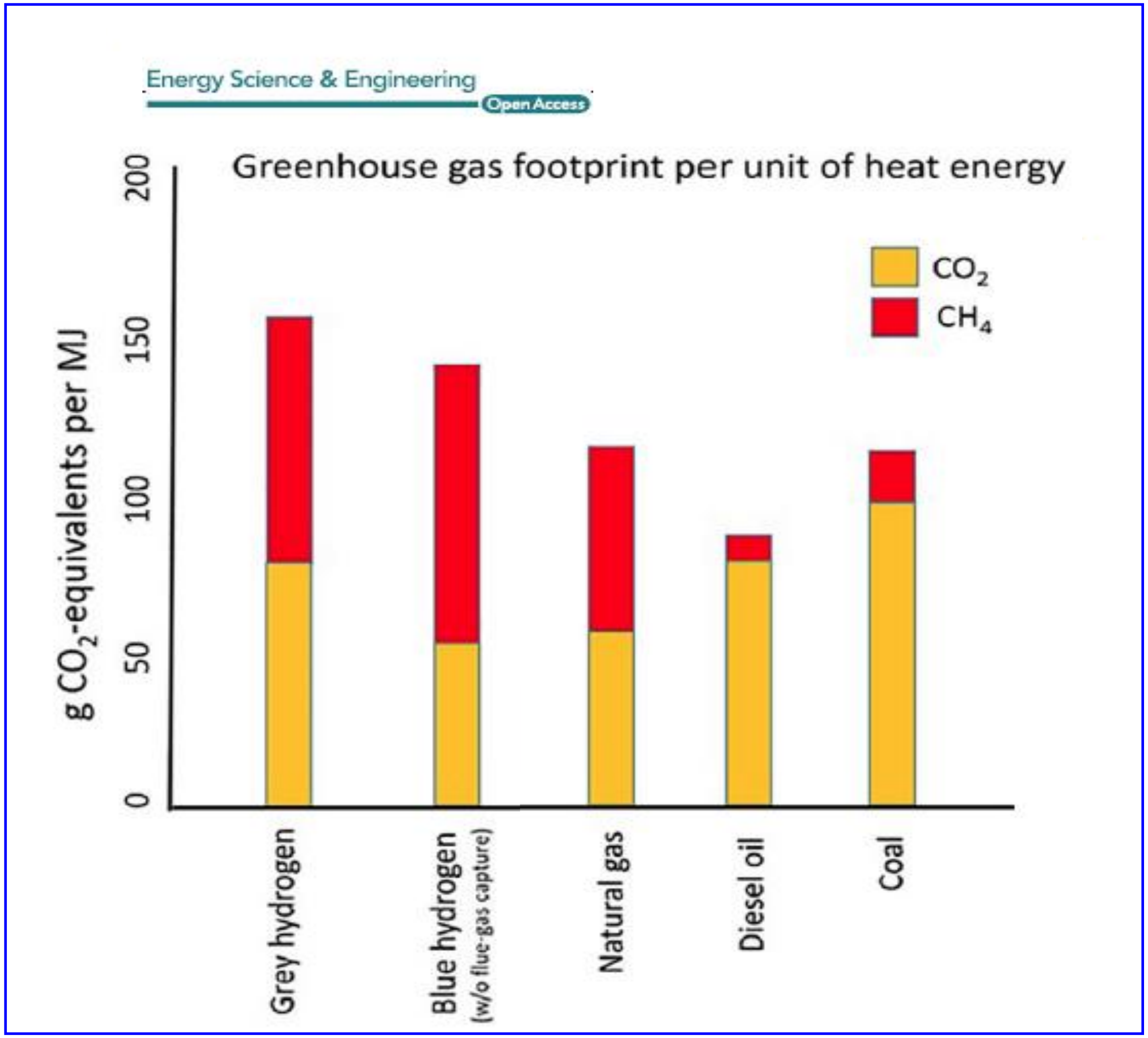

Howarth & Jacobson 2021

Sensitivity analyses for methane emissions rate & global warming potential

TABLE 2 Sensitivity analysis for total emissions of carbon dioxide and methane (g CO_2-equivalents per MJ of heat generated in combustion) for different upstream fugitive methane leakage rates and for either 20-year or 100-year global warming potentials (GWP20, GWP100)

	Gray H_2	Blue H_2 (w/o flue-gas capture)	Blue H_2 (w/flue-gas capture)	Natural gas
Fugitive CH_4 = 3.5%				
GWP20 = 86	153	139	135	111
GWP20 = 105	170	158	155	123
GWP100 = 34	106	86	77	76
Fugitive CH_4 = 4.3%				
GWP20 = 86	171	159	156	124
GWP20 = 105	192	182	181	139
GWP100 = 34	113	94	86	81
Fugitive CH_4 = 2.54%				
GWP20 = 86	133	115	109	95
GWP20 = 105	144	129	124	104
GWP100 = 34	98	76	67	70
Fugitive CH_4 = 1.54%				
GWP20 = 86	110	90	82	79
GWP20 = 105	117	98	91	84
GWP100 = 34	89	67	57	64

Baseline analysis

Worst case

Best case

Howarth & Jacobson 2021

Blue hydrogen is a terrible idea from a climate perspective… Yet increasingly promoted by oil & gas industry

- Note that in past, hydrogen use almost entirely as chemical feedstock (oil refineries, plastics, synthetic nitrogen fertilizer). NOT as fuel.
- Progressive energy planners have seen a role for **green** hydrogen as a fuel in the future for "hard to decarbonize" sectors (air travel, steel manufacturing). Also perhaps for storage of surplus electricity from wind and solar.
- Since 2017, blue hydrogen promoted by oil & gas industry (Hydrogen Council, etc.) to include blending with natural gas in pipelines, for use to heat homes, etc.
- Beginning in 2021, birth of "clean energy:" confusing green and blue hydrogen.

Is there a role for green hydrogen in our energy future?

Yes, for on-site storage from surplus wind & solar electricity, and hard to decarbonize needs, such as steel manufacturing and *perhaps* long-distance transportation (trucks trains, & planes).

But hydrogen should NEVER be used for heating homes & buildings (as is being promoted by oil & gas industry): far better to use electricity directly to power high-efficiency heat pumps.

The Methane Project at Cornell University

Blue hydrogen is not "green."

Far from having near zero or low emissions, greenhouse gas emissions are very high, worse than for just burning natural gas.

Questions?

Color of hydrogen	Process to make hydrogen	Greenhouse gas emissions (kg CO_2-eq/kg H_2)
Gray hydrogen	Steam methane reforming (SMR) of natural gas to produce hydrogen and carbon dioxide	**25**
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Green hydrogen	Electrolysis of water with renewable electricity to produce hydrogen & oxygen	**3**

The Methane Project at Cornell is funded by the Park Foundation and by an endowment given to Cornell by David R. Atkinson.

Further information available at Howarthlab.org