Hydrogen: Hype or a Glide Path to Decarbonizing Natural Gas?

Thomas N. Russo

Existing technologies that produce blue hydrogen with carbon capture, use, and storage (CCUS) could be a bridge to widespread production of green H_2, which is produced with renewable energy without carbon dioxide (CO_2) emissions. By incenting and encouraging higher production of blue H_2, which primarily uses natural gas, and green H_2, the transportation sector could be decarbonized to combat the adverse effects of climate change. Such a program would require tax incentives for blue H_2 production and help decarbonize natural gas by blending it with H_2 for use in the heating and power sectors. Tax incentives on green H_2 production would also encourage more companies to use and improve alkaline and proton exchange membrane electrolyzers. One of the advantages of such an approach is that residential and industrial consumers in various countries could be given a choice in selecting an electric vehicle (EV) with H_2-powered fuel cells or battery-powered EVs.

Thomas N. Russo (tom@russoonenergy.com) is an energy and environmental expert with unique regulatory knowledge of energy infrastructure, environmental impact assessment, markets, and physical/cybersecurity. Prior to starting Russo on Energy LLC, he worked for over 30 years as a manager and senior energy industry analyst at the Federal Energy Regulatory Commission. There, he gained experience in hydropower licensing, National Environmental Policy Act environmental impact assessment of projects, business process reengineering, natural gas and crude oil market oversight, and applicable federal statutes.

HYDROGEN—YESTERDAY AND TODAY

Today, hydrogen is fast becoming an increasingly important part of the conversation surrounding the decarbonization of the natural gas, power, and transportation sectors. Hydrogen was always very popular with lawmakers and policy analysts who envisioned natural gas being used to run fuel cells in the power and transportation sectors. However, interest and research budgets surrounding the use of H_2 peaked in 2008 and declined rapidly as technology and cost challenges arose.

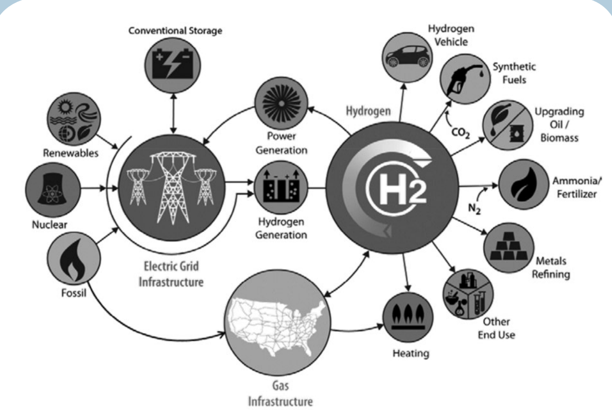
Now, H_2 once again is being touted by US policymakers, natural gas transmission operators in the European Union, and governments and industries in Japan, China, and South Korea as an attractive alternative to using natural gas and gasoline/diesel fuel. The goal of these supporters is to provide consumers an alternative to battery-powered EVs and trucks and other industrial uses. Other advocates dream of creating a hydrogen economy as envisioned in **Figure 1**. However, the economic, technical, safety, and infrastructure challenges to achieve this goal are formidable. Competition from electrification advocates is significant across the power and transportation sectors, which are competing with natural gas as a fuel and H_2 as well.

Drawing largely from the latest report on H_2 prepared by the International Energy Agency (IEA) in June 2019 and earlier work by the Royal Society and CE Delft,[1] a critical analysis of

[1] Van Cappellen, L., Croezen, H., & Rooijers, F. (2018). *Feasibility study into blue hydrogen: Technical, economic and sustainability analysis.* Retrieved from https://www.cedelft.eu/en/publications/2149/feasibility-study-into-bleu-hydrogen.

 DOI 10.1002/gas.22180 /

Figure 1. The Hydrogen Economy as Envisioned by H2@scale



Source: US Department of Energy.

whether increased investment in H_2 is warranted. Total electrification of the transportation sector using lithium-ion batteries is the most popular current policy initiative but also has its drawbacks. The production of lithium-ion batteries does produce environmental impacts from the mining of lithium, cobalt, nickel, and graphite.[2] Also, the amount of CO_2 emissions associated with manufacturing and charging a lithium-ion battery depends upon the source of power used. If renewable energy is not used, then the CO_2 emissions are only displaced to the EV. Other competing policy initiatives, including renewable natural gas, pumped storage hydro, and biomass, all have environmental impacts, but they will, to varying degrees, decarbonize energy systems. These policies and H_2 policies may reduce costs associated with renewable energy and help to repurpose existing natural gas pipeline systems. In subsequent columns, this author will explore in greater detail what development and deployment advances in H_2 are underway within the heating, power, and transportation sectors.

This column will attempt to provide answers to the following critical questions in an effort to determine whether H_2 can play a significant role in the US and global transition toward cleaner energy:

1. What's different this time, and is hydrogen really a viable way to decarbonize the natural gas, electric power, heating, and transportation fuel sectors by 2050?
2. What strategies and actions will be needed in terms of reducing the costs of various H_2 production technologies without increasing carbon emissions?
3. What investments are the private and public sector making in actually building out the H_2 supply chain?
4. What are the regulatory incentives or mandates needed to expedite the adoption of H_2 in various sectors?

HYDROGEN'S ROLE IN THE GLOBAL ECONOMY

Demand for H_2 has grown by almost four times from 1975 to 2018 (**Figure 2a**). For decades, H_2 has been an integral part of the oil refining and ammonia industries. Most of the H_2 produced is used by refineries to lower the sulfur content of diesel fuel and gasoline. The growing demand for pure H_2 comes primarily from refineries and ammonia plants, although demand from methanol facilities and direct reduced iron steel production is also increasing (**Figure 2b**). Global demand for hydrogen has been increasing steadily as the demand for diesel fuel has risen in the United States and internationally.[3] In 2018, refineries used 38 metric tons (Mt) of pure H_2. The demand for pure H_2 by refineries will likely increase to meet the demand for low-sulfur bunker fuels for ships needed to meet the new sulfur cap regulations enacted by the International Maritime Organization on January 1, 2020.

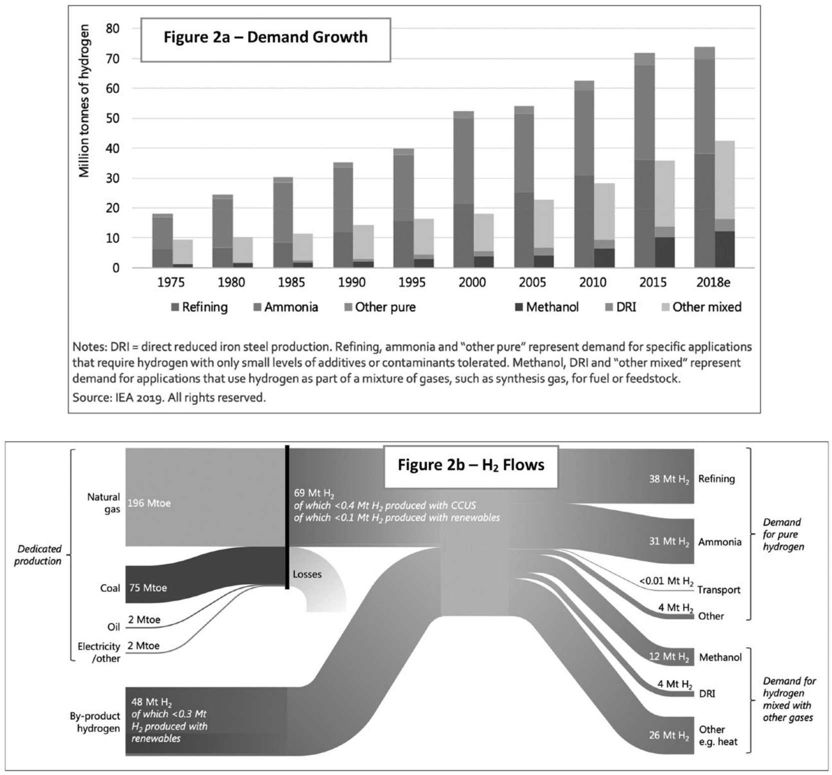
Since 1975, demand for pure H_2 by ammonia plants has also seen an annual increase. In 2018, the industry used 31 Mt of H_2. Approximately 80 percent of the ammonia produced by industry is used in the agricultural sector as fertilizer. Ammonia is also used as a refrigerant gas, for purification of water supplies, and in the manufacturing of plastics, explosives, textiles, pesticides, dyes, and other chemicals. Another 48 Mt of

[2] Russo, T. N., & Kim, M. (2019). Is electric battery storage overrated as a clean technology? *Natural Gas & Electricity, 36*(4), 24–27.

[3] Hydrogen for refineries is increasingly provided by industrial suppliers; see https://www.eia.gov/todayinenergy/detail.php?id=24612.

  / DOI 10.1002/gas

Figure 2. Hydrogen Demand Growth by End-User and Flows in 2018



by-product hydrogen that is mixed with other gas is used for heating, methanol plants and direct reduced iron steel production (Figure 2b).

Approximately 76 percent of global pure H_2 production is from natural gas; the remaining is made with coal in China. The annual global amount of H_2 produced requires 6 percent of global natural gas use and 2 percent of global coal use. As a consequence, global H_2 production today is responsible for 830 Mt CO_2/year—corresponding to the annual CO_2 emissions of Indonesia and the United Kingdom combined.[4]

GREY, BLUE, AND GREEN HYDROGEN

Energy analysts and policymakers categorize hydrogen into three types—grey, blue, and green. Each type of H_2 is distinguished by how the gas is produced (**Figure 3**). Approximately 95 percent of all H_2 produced is grey and blue H_2, which uses fossil fuels. Due to government mandates and subsidies to reduce CO_2, many blue H_2 production facilities use CCUS technologies to reduce CO_2 emissions. In contrast, green H_2 production in 2018 using renewables only accounted for 0.30 Mt of the 48 Mt of by-product H_2 production (Figure 2b). For example, the use of H_2 and fuel cells to operate forklifts in warehouses is increasing in the industrial sector according to Plug Power Inc.[5] The company is serving Amazon, BMW, the Southern Company, Carrefour, and Walmart.[6]

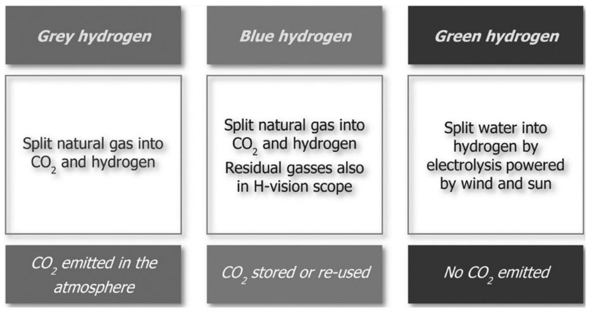
[4] International Energy Agency. (2019, June). *The future of hydrogen—Seizing today's opportunities.* Report prepared for the G20, Japan. Retrieved from https://www.iea.org/reports/the-future-of-hydrogen.

[5] Statements by Andy Marsh, president and chief executive officer, Plug Power–Reuters Webinar on the Global Hydrogen Economy—Fueling a Low-Carbon Future, May 7, 2020.

[6] Plug Power Inc. (2020, May 7). *Plug Power announces 2020 first quarter results.* Press release. Retrieved from https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Announces-2020-First-Quarter-Results/default.aspx.

 DOI 10.1002/gas / © 2020 Wiley Periodicals LLC

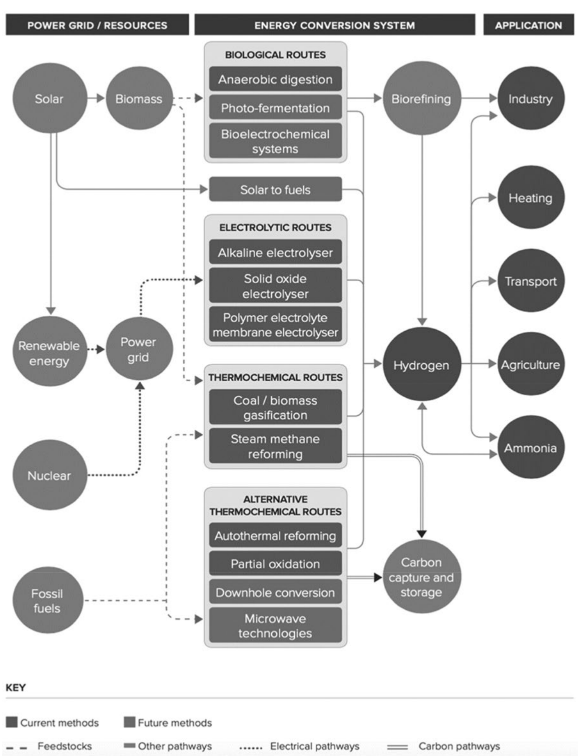
Figure 3. Hydrogen Types and Production



Source: CertifHy Canada.

There are four main routes to produce blue H_2 with low-carbon by-products; several of these methodolgies are widely used for commerical H_2 production, while others are still in the early stages of development (**Figure 4**). Among the biological routes, anerobic digestion is currently used, while electrolytic routes contain three existing methods that use power from the existing electric grid and electrolysis to produce blue H_2. When renewable energy is used with electrolytic routes, only green H_2 is produced. Among the thermochemical routes, steam methane and autothermal reforming with carbon capture are two of the most prominent existing technologies that produce H_2.

Figure 4. Existing and Potential Routes to Produce Blue Hydrogen



Source: Van Cappellen, L., Croezen, H., & Rooijers, F. (2018). *Feasibility study into blue hydrogen: Technical, economic and sustainability analysis.* Retrieved from https://www.cedelft.eu/en/publications/2149/feasibility-study-into-bleu-hydrogen.

The two primary technologies used to produce blue H_2 use a steam methane reforming (SMR) technology and autothermal reforming (ATR) using natural gas almost exclusively as the feedstock. Refineries, industrial gas producers, and other chemical manufacturers all use the same SMR technology, which is 90 percent efficient in producing blue H_2. The SMR and ATR processes commonly employ CCUS to reduce CO_2 emissions. Less than 0.01 Mt H_2 was actually used in the transportation sector in 2018 (**Figure 2b**) despite growing interest in using H_2 to decarbonize the transportation sector with fuel cell–powered EVs.

Proponents of green H_2 and a hydrogen economy envision significant growth of wind and solar energy both on- and off-shore, with the belief this "inexpensive power" would be used with electrolyzers to produce green hydrogen. Even though accelerating growth rates of wind and solar generation may provide the power used in electrolytic methods for green H_2, the technology readiness levels (TRLs)[7] of electrolyzers are lower than SMR and ATR processes (**Figure 5**).[8] However, alkaline electrolyzers are a mature technology with TRLs comparable to SMR. Further, the TRLs of proton electron membrane electrolysis are between 5 and 7 and somewhat competitive to SMR and ATR. The abundance and low price of US shale gas currently at $1.70 per million Btu (MMBtu) has been a large factor in the selection of SMR and ATR by US refineries and ammonia plants. The supply surplus of liquefied natural gas (LNG) that currently exists in Asia and

[7] Technology readiness levels are a method for estimating the maturity of technologies during the acquisition phase of a program, developed at NASA during the 1970s.

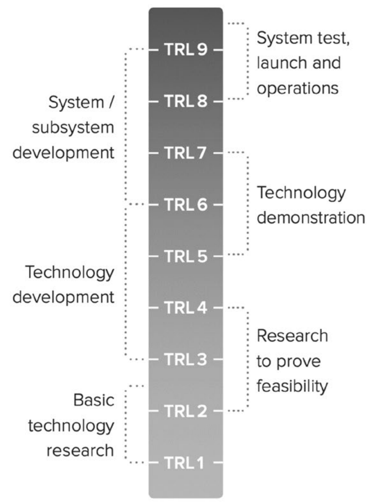
[8] The Royal Society. (2018). Options for producing low-carbon hydrogen at scale. Retrieved from http://www.royalsociety.org/low-carbon-energy-programme.

  / DOI 10.1002/gas

Figure 5. Comparison of Technology Readiness Levels of Various Methods Used to Produce Hydrogen

Technology readiness levels (TRL).

System	Technology readiness level (TRL)[47]
Steam methane reforming with carbon capture and storage	8
Autothermal reforming	High TRL
Coal gasification with carbon capture and storage	7
Alkaline electrolysers	Mature
Polymer electrolyte membrane electrolysis	5 – 7
Biomass gasification with carbon capture and storage	4
Solid oxide electrolysers	3 – 5
Biological methods	1 – 3
Solar to Fuels	1 – 3



Source: The Royal Society. (2018). Options for producing low-carbon hydrogen at scale. Retrieved from http://www.royalsociety.org/low-carbon-energy-programme.

Europe, with prices ranging from \$1.95 to \$2.10 per MMBtu, may increase blue H_2 production at refineries and ammonia plants in those regions.

In contrast, the cost of green H_2 may decline as the European Union implements its Green Energy Plan and renewable energy generation becomes a large percentage of the power produced in Germany and Western Europe. Even now, at certain times of the year and day, there is a surplus of renewable energy and prices go negative[9] due to lack of demand. The combination of increasing levels and frequency of renewable energy at low or negative prices could incent H_2 producers to invest in alkaline and proton electron membrane electrolyzers to produce green H_2.

HYDROGEN PRODUCTION COSTS

Two issues stand out when one looks at actual production and costs of grey, blue, and green H_2. The first is that the cost to produce green H_2 today is prohibitive; green H_2 costs range from two to three times the cost to produce blue H_2 (**Figure 6**). The range of green H_2 production costs is between \$3.00 and \$7.50 per kg of H_2 depending on the electrolyzer used and the cost of renewable electricity.

Currently, the combined effects of the oil price war between Saudi Arabia and Russia coupled with the COVID-19 pandemic have adversely affected the oil and natural gas industry. H_2 production by refineries and ammonia plants will decline since people are not driving or flying. Consumption of industrial and consumer goods is also down as a result of the economic recession that most countries are experiencing.

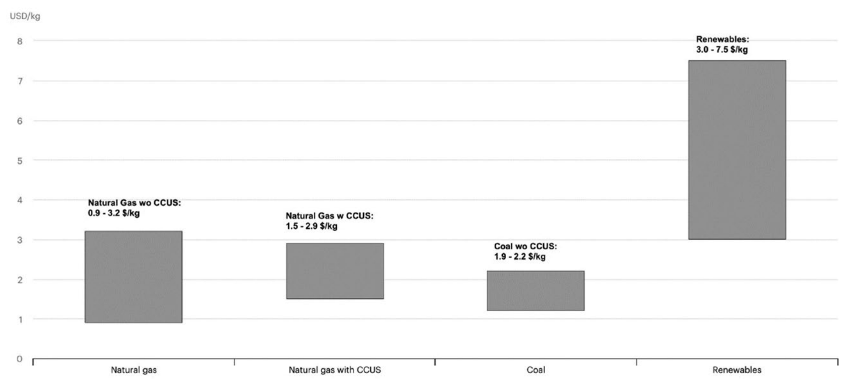
The natural gas industry has not suffered as much as oil from COVID-19, due to the fact natural gas is used primarily to heat homes and businesses and for power production. Natural gas production may decline by 5 percent.[10] Cooler or warmer winters and summers will affect natural gas demand and market prices globally. As of this writing, natural gas prices are \$1.646/MMBtu in the United States,[11] \$1.721/

[9] Negative prices mean that the renewable power producers will pay consumers to use the power.

[10] Cocklin, J. (2020, May 13). LNG Q&A: Scholar discusses the role of natural gas in a world changed by COVID-19, *Natural Gas Intelligence*. Retrieved from https://www.naturalgasintel.com/articles/121979-lng-qa-scholar-discusses-the-role-of-natural-gas-in-a-world-changed-by-covid-19.

DOI 10.1002/gas / © 2020 Wiley Periodicals LLC

Figure 6. Cost of Hydrogen in 2018 by Production Source in United States ($/kg)



Source: International Energy Agency.

MMBu in Europe, and $2.105/MMBtu in Asia. If prices of natural gas and LNG remain low and the global economy improves, blue H_2 producers may find the abundance of natural gas and low prices too good to pass up and decide not to switch to green H_2 production.

GREEN H_2 SUFFERS FROM A CHICKEN-AND-EGG PROBLEM

Abundant and inexpensive renewable power is a necessity in ushering in a new hydrogen economy primarily supplied by green H_2. However, based on this author's preliminary analysis, most programs promoting green H_2 will not gain traction if production from any source does not make signifcant progress in penetrating the transportation sector. Improving the TRLs, reducing costs, and improving the efficiency of electrolyzers are also necessary. This appears to be a chicken-and-egg problem. For example, even companies willing to produce green H_2 may not do so because of the intermittancy of renewable power or high prices. Other companies who have access to a reliable supply of renewable energy may not be willing to accept the higher costs and lower efficencies of existing electrolyzers. Aside from this issue, abundant and inexpensive natural gas prices are a significant disincentive from switching from SMR and ATR, which produce blue H_2, to electrolyzers producing green H_2.

In the latter case, governments may use subsidies to incent blue to green H_2 production switching in the United States and the European Union as a part of the New Green Deal[12] and Green Deal, respectively. Government bans, especially at the local and state levels, carbon taxes, and increased delays, or actually prohibiting construction of natural gas pipelines and gas processing facilities, could also increase the price of natural gas and increase blue H_2 production costs. While these are taking place, they will not discourage blue H_2 producers to increase or switch to green H_2 production.

GLOBAL H_2 DEPLOYMENT POLICIES FOCUS ON TRANSPORTATION, NOT POWER OR HEATING

Japan, South Korea, China, the European Union, and the United States all have H_2 deployment and research and development (R&D) programs. In addition, the Hydrogen Council, a global CEO-led initiative of 60 leading energy, transport, and industry companies, also has a united and long-term vision to develop the hydrogen economy by reducing costs and educating consumers. However, these H_2

[11] Natural gas prices are settled prices on May 15, 2020, at the Nymex Natural Gas Futures for U.S., Title Transfer Facility for Europe, and Japan-Korea Marker in Asia.

[12] The New Green Deal is aspirational at this time. Future movement on this proposal depends on the results of the US presidential election.

  / DOI 10.1002/gas

policies are largely targeting the transportation sector, which might partially explain why the power and heating sectors have not taken decarbonization via H_2 seriously. Undoubtedly, low natural gas prices in both the United States and globally will discourage blue or green H_2 production for the power and heating sectors unless state and federal regulators encourage decarbonization of natural gas. Most states are promoting electrification of the power and heating sectors, and some, like California, New York, and New Jersey, envision very limited need for natural gas by 2050 or earlier.

BLUE H_2 SHOULD BE A BRIDGE FOR GREEN H_2

The chances of realizing a hydrogen economy or at least increasing use of H_2 with fuel cells in the transportation sector are very low. Government R&D funding and incentives for green H_2 production may be difficult to obtain in the current COVID-19 environment and related economic recession. However, blue H_2 production could be increased due to record-low US and global LNG prices. If the goal is to increase significant H_2 production for use by fuel cell–powered EVs, the viable alternative is to increase blue H_2 production significantly above levels used by refinery ammonia and petrochemical industries. To achieve this would require a reliance on and to incent more blue H_2 production as well as green H_2. The earlier example of Plug Power's penetration of the electric forklift market may be instructional here. To penetrate that market, the company had to ensure its customers that it had a reliable supply of fuel cells and H_2 in its supply chain that is probably blue H_2.

Advocates of a hydrogen economy or its use in fuel cell–powered EVs could jumpstart their vision by embracing blue H_2 with CCUS and viewing these technologies as a transitional bridge to green hydrogen. This approach may be untenable for many H_2 advocates who see no place for natural gas as a feedstock or embracing CCUS. Today, the most popular market for CO_2 is enhanced oil recovery. That use and others are subsidized under the US Treasury Department's Tax Credit for Carbon Sequestration (Section 45Q) regulations. The new regulations were designed to provide tax credits to companies that sequestered and/or used CO_2 in new products. Without the 45(g) incentives, few companies would employ CCUS technologies.

In addition to using the 45(g) incentives, H_2 advocates could lobby Congress and regulators for similar incentives to produce green H_2, as is done with renewable energy production tax credits, which were successful in increasing wind energy generation. They could also advocate for subsidies to encourage natural gas producers, gatherers, processors, and pipeline companies to prevent methane leaks and discourage flaring. Self-enforcement of such regulations by the natural gas indusry and strong monitoring and enforcement through fines and penalties by the US Environmental Protection Agency or Pipeline Hazardous Materials and Safety Administration could help decarbonize natural gas and encourage mitigation and monitoring of fugitive gas emissions and flaring.

CONCLUSIONS

Blue H_2 production already serves the refinery, ammonia, and petrochemical industries with increasing supplies of H_2. Abundant and inexpensive natural gas prices are a disincentive for H_2 producers to switch to green H_2, which relies on abundant and low-cost renewable energy. Despite promoting the use of H_2 in fuel cell–powered EVs, there are insufficient quantities of green H_2 produced by renewables, and very little H_2 from all sources is available in the transportation sector. As a preliminary step, H_2 advocates should discuss incenting increased production of blue H_2 with CCUS for use in the transportation sector using tax incentives for CCUS and separate incentives for green H_2. The combined effect of these incentives would provide more H_2 for use in fuel cell–powered EVs and help to further decarbonize the natural gas industry.

Further analysis on initiatives the United States and other countries should take to invest in H_2 and fuel cell R&D and subsidize H_2 as part of decarbonizing the power and heating sectors is needed. Future columns by this author will include recommendations on the ability to blend H_2 with natural gas for heating and power generation as well as safety and technical challenges in the potential storing and transporting of H_2.

DOI 10.1002/gas / © 2020 Wiley Periodicals LLC