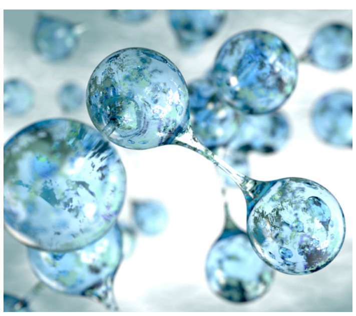
Stanford | Natural Gas Initiative
School of Earth, Energy & Environmental Sciences and Precourt Institute for Energy

NATURAL GAS *brief*

JANUARY 2021

Achieving ambitious climate targets to avoid catastrophic outcomes[1] essentially means getting to net-zero emissions by 2050. This is not going to be easy, given that the pathways to such deep decarbonization are not clear for many sectors, including transportation and industry. This is where hydrogen comes in.



The hydrogen opportunity

By Gireesh Shrimali, PhD; Precourt Scholar, Stanford University and Naomi Boness, PhD; Managing Director, Natural Gas Initiative, Stanford University

Hydrogen may play a role in decarbonizing many of the sectors that have historically been hard to decarbonize, such as long-distance/heavy duty transportation, shipping, district heating, seasonal energy storage, and heavy industry[2,3]. In addition, hydrogen can play a key role in accelerating renewable energy integration; distributing energy across sectors; and acting as resilience buffer[4].

The Hydrogen Council[4], IRENA[3] and IEA[5] estimate that green hydrogen could cut annual CO_2 emissions by 6 billion tonnes by 2050, equivalent to 18% of the necessary abatement to limit global warming to two degrees Celsius.

Hydrogen has been around as a fuel since the beginning of the universe; in fact, our very existence, which is enabled via the energy produced by the sun, is due to hydrogen converting to helium via nuclear fission. However, for human consumption, we need access to hydrogen at industrial scale that can be utilized as an efficient and clean energy source.

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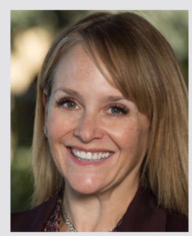
ABOUT THE AUTHORS

Gireesh Shrimali is a Precourt Scholar at the Sustainable Finance Initiative at Stanford University. Previously, he was the Director of Climate Policy Initiative's India Program, and a Research Fellow at the Steyer-Taylor Center at Stanford University. He has taught at the Middlebury Institute of International Studies, Monterrey as well as the Indian School of Business, Hyderabad. His research focus is on renewable energy finance and policy; in general, on the catalytic role of finance in getting to the 2°C target; and, in particular, on provision of low-cost, long-term capital for clean energy transition. He holds a PhD from Stanford University, an MS from the University of Minnesota, Minneapolis, and a BTech from the Indian Institute of Technology, New Delhi.



Naomi Boness Naomi Boness is the Managing Director of the Natural Gas Initiative at Stanford University, a leader of the Stanford Hydrogen Focus Group and a co-instructor of a graduate seminar class on the Hydrogen Economy. She is an experienced practitioner in the energy sector with a focus on natural gas, hydrogen and decarbonization in both the developed and the developing world. Prior to Stanford, she held a variety of technical and management positions at Chevron. Naomi is also a Director for a renewable fuels company and an advisor for a hydrogen startup. Naomi holds a Ph.D. in geophysics from Stanford University and a M.Sc. from Indiana University.

For more information

Gireesh Shrimali:
https://profiles.stanford.edu/gireesh-shrimali

Naomi Boness:
https://profiles.stanford.edu/naomi-boness

Natural Gas Briefs:
ngi.stanford.edu/briefs

Industrial hydrogen comes in many forms: gray, blue, and green (see Figure 1)[6]; where grey emits the most CO_2 and green emits the lowest. Gray hydrogen is generated from methane (typically to be used in various chemical processes) resulting in sometimes appreciable carbon emissions; blue hydrogen is essentially gray hydrogen with carbon capture and storage, to reduce emissions. Gray and blue hydrogen are typically produced through a process called steam methane reforming (SMR) which has been widely-used for many decades. Green hydrogen typically refers to hydrogen produced by using electricity to separate hydrogen and oxygen in water molecules (via a process called electrolysis). If the electricity is produced from renewable sources, it has the potential to result in extremely low emissions. An alternative path to green hydrogen is methane pyrolysis that results in carbon in solid form, thus avoiding CO_2 emissions. Despite the fact that these technologies have been well established for years, hydrogen has yet to become a key fuel for human consumption.

WHAT ARE THE KEY BARRIERS TO ADOPTION OF HYDROGEN AS A KEY FUEL SOURCE FOR HUMANS?

The economic barriers to hydrogen as a fuel source for human consumption include the cost of production including capital and operating expenditures[7]; lower efficiencies of hydrogen fuel cells compared to electric batteries (40% compared to 80%)[2]; and storage and transportation capacity and costs[3]. According to the Hydrogen Council[4], other barriers to hydrogen include difficulties associated with transporting and storing hydrogen; risk-mitigation mechanisms of the initial large capital investments necessary to enable development and deployment; new technology support; industrial standards; and a lack of coordination across stakeholders.

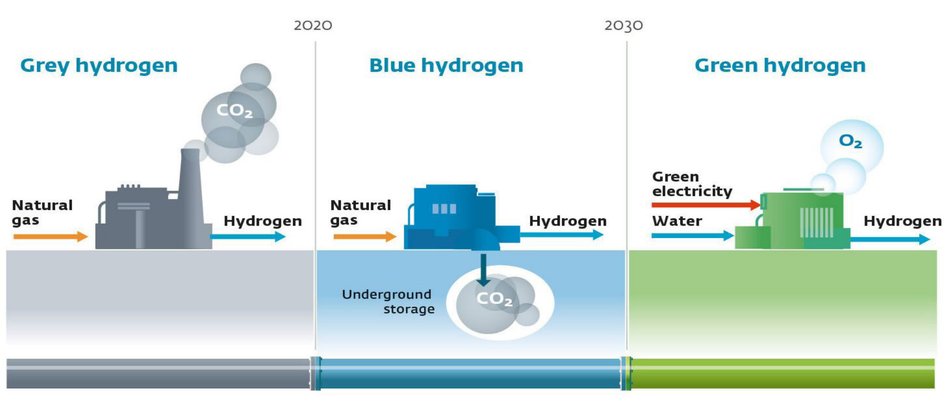
But the hydrogen landscape is finally changing, driven by ambitious climate targets and falling costs[3].

The adoption of hydrogen and the associated potential for carbon abatement in each potential application is hard to predict and will depend on policy decisions, technology development, societal acceptance and choices, and cost. Currently, hydrogen accounts for 1.5% of the global energy supply. Estimates of global hydrogen use in 2050 range from 1.5%[8] (IPCC, 2018) to a theoretical maximum of 30%[7]. In 2050, the IEA predicts hydrogen use will meet 7% of final energy demand in 2050, comprised of transport (44%), industry (28%), power (19%) and buildings (9%)[9].

The primary obstacle to widespread use of hydrogen is the production cost, especially from low-carbon energy sources.

Figure 1

Indications of Hydrogen



Source:
https://www.theworldofhydrogen.com/gasunie/what-is-hydrogen/

THE CRITICAL ROLE OF BLUE HYDROGEN IN BUILDING A HYDROGEN ECONOMY

While green hydrogen is the target long-term technology for net-zero trajectories, it is not likely to be cost-competitive in the short-to-mid-term. In this period, blue hydrogen, which is likely to become cost-competitive much earlier, can provide an interim solution that enables the development of the hydrogen economy that may be transitioned to green ▶

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hydrogen as and when it becomes cost-competitive. This ecosystem would consist of a buildup of (blue) hydrogen infrastructure supported by appropriate policies, business models, and financing mechanisms; for example, as laid out for California in the recent report by the Energy Futures Initiative and Stanford University[10].

Blue hydrogen essentially combines two well-established technologies, steam methane reforming (SMR) and carbon capture and storage (CCS). The abundant and cheap supply of natural gas along with the existing natural gas infrastructure ensures that SMR is cost-effective. CCS is the storage of carbon in geologic storage sites such as depleted oil and gas reservoirs or deep saline aquifers. CCS is a commercially-ready technology and there are currently 61 large-scale CCS facilities either operationally underway or in advanced stages of planning around the globe[10]. Oil and gas companies have established the knowledge and infrastructure that could be utilized to rapidly develop CCS projects. Currently, CCS is the only established technology that is able to scale up in the near term to mitigate the volumes of carbon necessary to limit global warming to the Paris accord threshold of 2°C.

Blue hydrogen is starting to become economically viable at $1.5-3.5/Kg[2,7], particularly in states like California that have low carbon fuel tax incentives[11] that may be coupled with the federal 45Q carbon sequestration tax credit[12].

In an often polarized energy landscape, the idea of blue hydrogen will not be appealing to all. However, blue hydrogen offers a cost-effective near-term solution that can be net-zero carbon and thus be an enabler of the energy transition. It can also pave the way for green hydrogen to be commercially viable, and it could significantly accelerate the impact of this promising solution on mitigating the climate crisis.

WHAT IS THE LIKELY COST TRAJECTORY OF GREEN HYDROGEN?

Green hydrogen is not cost-competitive yet at its current production cost of $4-8/Kg[13]. This cost would need to fall to $1-2/Kg to become competitive with other fuel sources[14].

It is expected that green hydrogen production costs will continue to drop and will reach $2/Kg by 2030[5] and $1/Kg by 2050[15], which would be cost competitive with natural gas. There are isolated cases where green hydrogen may be economically viable even earlier, such as generation from cheap wind in Texas that is predicted to be cost-competitive in two years[16].

The variation in cost estimates, is dependent on different cost of electricity scenarios[17] and the cost of electrolyzer components[18]. For non-transport applications, 90% of cost reductions are expected to be from supply chain scale-up; whereas for transport applications, 70% of cost reductions would be from manufacturing scale-up.

WHAT POLICIES MAY RESULT IN A MORE RAPID ADOPTION OF HYDROGEN?

Hydrogen is an opportunity for governments to think strategically and become global leaders (e.g., see Figure 2 for the US). Near-time opportunities for hydrogen deployment include the following[5]: industrial ports, natural gas pipelines, high mileage transport, and shipping. While following these opportunities, governments also may want to focus on promoting low-cost manufacturing of equipment for hydrogen production as well as production of low-cost renewable energy as a cheap fuel source for green hydrogen.

Policy can help. The development of a global hydrogen economy may require up to $150 billion in cumulative subsidies by 2030[7], including movement on seven interrelated signposts, as follows: (1) net-zero climate targets, (2) technical standards and ▶

regulatory barriers, (3) hydrogen targets with investment mechanisms, (4) transport emission standards, (5) mandates for low emission products and markets, (6) industrial decarbonization and incentives, and (7) hydrogen supply-chain. This is relatively minor compared to subsidies for renewables e.g., $30 billion in one year in one country—Germany.

In this context, it would be key to create a level playing field for hydrogen[18]. There are six ways governments can do so, via the following: (1) national strategies, (2) coordination among stakeholders, (3) regulation, (4) standardization, (5) infrastructure, and (6) incentives. Furthermore, five enablers for market creation would be: (1) reducing market uncertainty, (2) focusing on scaling applications, (3) seeking complementarities, (4) prioritizing increasing utilization, and (5) investing heavily.

Many countries are focused on supporting hydrogen technology development through policies and direct investment. Approximately 50 targets, mandates and policy incentives exist to encourage the use of hydrogen, particularly in the transportation sector[5].

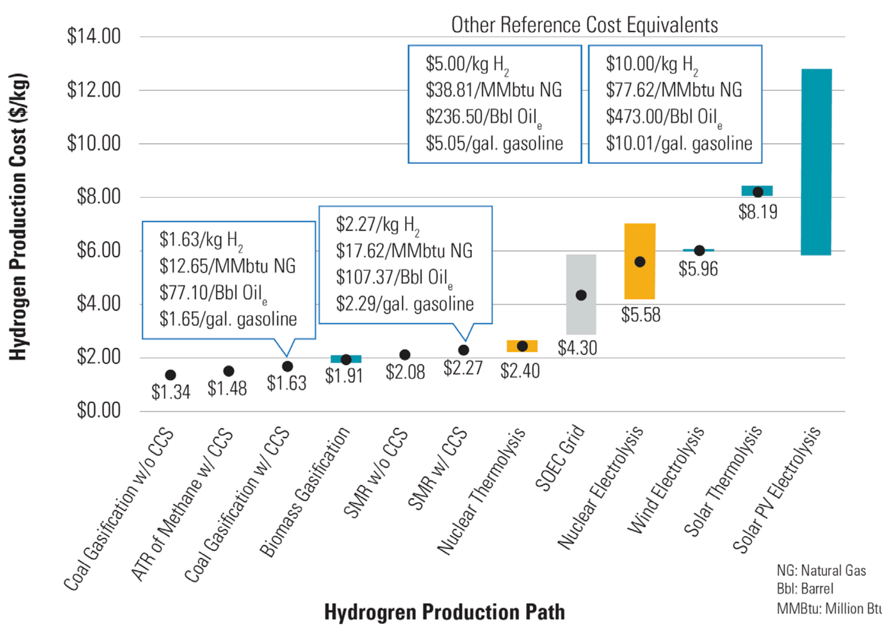
In 2020 the European Union released the EU Hydrogen Strategy[19] in an effort to support hydrogen technologies and exploit the economic opportunities associated with the coronavirus pandemic. The strategy is supported by a pledge from the European Commission to allocate part of a $825 billion coronavirus recovery fund to advance hydrogen innovation, research and project development. Individual EU countries are also budgeting for significant investment in the hydrogen economy, both for domestic projects and international partnerships, such as Germany (~10 billion)[20] and The Netherlands (~$39 million annually)[21].

In stark contrast, the U.S. lags behind the European Union as well as China and Japan in policy and the required infrastructure and research investments. In both Asia and the European Union, governments, in coordination with industry partners, are investing a total of $2 billion per year in hydrogen, while the U.S. Department of Energy funding for hydrogen and fuel cells has ranged from $100 million to $280 million per year over the last decade[22].

More recently, the U.S. has demonstrated its growing support for hydrogen technologies. The Moving Forward Act, a $1.5 trillion infrastructure package that was passed by the House of Representatives in July 2020, includes a number of hydrogen provisions. However, for the U.S. to be a global leader in energy transition and embrace the promise of hydrogen for clean energy and climate mitigation, a cohesive national hydrogen strategy is essential. ■ ▶

Figure 2

Current Hydrogen Production Cost Ranges and Averages by Technology and Equivavlent Prices for Fossil Sources With CO_2 Capture and Storage



Source:
https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

REFERENCES [WITH URL LINKS]

1 Business Ambition for 1.5°C. URL

2 Economist (2020). After many false starts, hydrogen power might now bear fruit. URL

3 International Renewable Energy Agency (2019). Hydrogen: A renewable energy perspective. URL

4 Hydrogen Council (2017). How hydrogen empowers the energy transition. URL

5 International Energy Agency (2019). The future of hydrogen. URL

6 Power Technology (2020). What colour is your hydrogen? A Power Technology jargon-buster. URL

7 Bloomberg New Energy Finance (2020). Hydrogen economy outlook: key messages. URL

8 IPCC (2020). Special report: global warming of 1.5°C. URL

9 International Energy Agency (2020). Energy technology perspectives 2020. URL

10 Energy Futures Initiative and Stanford University (2020), An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions. URL

11 California Air Resources Board low carbon fuel standard. URL

12 Congressional Research Service (2020). The Tax Credit for Carbon Sequestration (Section 45Q) URL

13 Forbes (2019). The hydrogen economy is within grasp and progressive energy companies know it. URL

14 US Department of Energy (2020). Hydrogen strategy enabling a low-carbon economy. URL

15 National Renewable Energy Laboratory (2020). The value of seasonal energy storage technologies for the integration of wind and solar power, Energy and Environmental Science, issue 7. URL

16 MIT Technology Review (2020). How falling solar costs have renewed clean hydrogen hopes. URL

17 Glenck and Reichelstein (2019). Economics of converting renewable power to hydrogen, Nature Energy, vol 4. URL

18 Hydrogen Council (2020). Path to hydrogen competitiveness: A cost perspective URL

19 European Commission (2020). Powering a climate neutral economy Comission sets out plans for the energy system of the future and clean hydrogen. URL

20 The German Federal Government (2020). The national hydrogen strategy. URL

21 The Netherlands Government (2020). Government strategy on hydrogen. URL

22 Fuel cell and hydrogen energy association (2020). Roadmap to a US hydrogen economy. URL

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THE NATURAL GAS INITIATIVE AT STANFORD

Major advances in natural gas production and growth of natural gas resources and infrastructure globally have fundamentally changed the energy outlook in the United States and much of the world. These changes have impacted U.S. and global energy markets, and influenced decisions about energy systems and the use of natural gas, coal, and other fuels. This natural gas revolution has led to beneficial outcomes, like falling U.S. carbon dioxide emissions as a result of coal to gas fuel switching in electrical generation, opportunities for lower-cost energy, rejuvenated manufacturing, and environmental benefits worldwide, but has also raised concerns about global energy, the world economy, and the environment.

The Natural Gas Initiative (NGI) at Stanford brings together the university's scientists, engineers, and social scientists to advance research, discussion, and understanding of natural gas. The initiative spans from the development of natural gas resources to the ultimate uses of natural gas, and includes focus on the environmental, climate, and social impacts of natural gas use and development, as well as work on energy markets, commercial structures, and policies that influence choices about natural gas.

The objective of the Stanford Natural Gas Initiative is to ensure that natural gas is developed and used in ways that are economically, environmentally, and socially optimal. In the context of Stanford's innovative and entrepreneurial culture, the initiative supports, improves, and extends the university's ongoing efforts related to energy and the environment.

Join NGI

The Stanford Natural Gas Initiative develops relationships with other organizations to ensure that the work of the university's researchers is focused on important problems and has immediate impact. Organizations that are interested in supporting the initiative and cooperating with Stanford University in this area are invited to join the corporate affiliates program of the Natural Gas Initiative or contact us to discuss other ways to become involved. More information about NGI is available at ngi.stanford.edu or by contacting the managing director of the initiative, Naomi Boness, Ph.D. at naomi.boness@stanford.edu.