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# Blue Hydrogen Has Extremely Limited Future in U.S. Energy Market

## *Time Working Against Blue Hydrogen as Projects May Be Obsolete Before Launch*

A global shift has occurred in energy decision-making. Climate risk factors affect the decisions of governments, corporations, institutions, banks, private investors and end-use customers. Multiple cancellations of fossil fuel projects have occurred across the United States in recent years.[1] Moody's credit rating service acknowledges the risks of rising popular opposition. In 2020, it took the momentous step of declaring it would remain skeptical of new oil or gas pipeline investments and will not offer an unqualified opinion on such projects until they have achieved commercial operation for a reasonable period.[2] The International Energy Agency (IEA) pivoted in 2021, declaring that getting to net-zero greenhouse gas (GHG) emissions by 2050 means no new oil, gas or coal developments should be allowed.[3]

A proposed plant's outlook can rise or fall, based on emerging market trends. Blue hydrogen projects take several years to develop.[4] The full carbon footprint of blue hydrogen makes it difficult to justify as an energy strategy when feasible and prudent alternatives exist.[5] Even if public objections do not stop a blue hydrogen project, strong opposition can delay it. Meanwhile, cleaner competitors are moving fast to take up market share. While renewable energy projects take time to be developed, they are already established as effective technologies and profitable enterprises on a commercial scale. Carbon capture and storage (CCS) is not there yet, and time is not on blue hydrogen's side.

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[1] IEEFA. Rapidly changing investment climate challenges planned PJM gas plants: Renewables, falling capacity payments, flat demand undercut plans for new gas capacity. November 2021. Also see: Global Energy Institute. Infrastructure Lost: Why America Cannot Afford to Keep It In the Ground. December 2018. Also see: IEEFA. IEEFA Response to the U.S. Chamber of Commerce Analysis of the "Keep it in the Ground" Movement. February 2019.
[2] Moody's Investor Services. Shifting environmental agendas raise long term credit risk for natural gas investments. September 30, 2020 (Proprietary License).
[3] International Energy Agency. Net-Zero by 2050. May 2021, p. 20-21.
[4] The lead time from conception to operation for a CCS project can be up to ten years, depending in part on the location. Global CCS Institute. Global Status of CCS 2021. 2021, p.15.
[5] IEEFA. Blue Hydrogen Has Weak Case When It Comes to Emission Reductions. February 2022.

Assessing the potential of blue hydrogen requires a hard look at existing markets and market trends. The National Renewable Energy Laboratory (NREL) produced an analysis of the technical and economic potential for boosting hydrogen's role in the energy economy. It reported that if one did not consider economics at all, hydrogen could achieve a consumption rate of 106 million metric tons per year (MMT/yr), about 11 times larger than the 2020 market. But the NREL warned that "most of that potential demand would be for applications that are currently served by energy sources other than hydrogen."[6] Taking into account economic factors, the NREL estimated hydrogen's market potential to be 22 MMT/yr to 41 MMT/year in the contiguous United States, which would be only about two to four times larger than the current market.[7]

**The full carbon footprint of blue hydrogen makes it difficult to justify as an energy strategy when feasible and prudent alternatives exist.**

In other words, serious limits already exist on the need for blue hydrogen infrastructure. And this does not even factor in the growing threat from renewables-based green hydrogen.

The NREL report concluded all of hydrogen's estimated 106 MMT/yr of serviceable consumption potential could be supplied by only 2.1 percent of the annual technical potential of U.S.-based solar, or 15 percent of wind, or 22 percent of geothermal energy.[8] This does not include the potential for increased energy efficiency in the various uses. Also, the NREL analysis does not fully evaluate the social, political and technological trends that now drive and likely will continue to drive the energy markets.

While states will seek to access funding from the federal Infrastructure Investment and Jobs Act (IIJA) to diversify their energy base, expand local jobs and grow economic opportunities, a realistic assessment of the unfavorable market forces for blue hydrogen should lead them away from such poor investments and toward enterprises like wind, solar power and battery storage that have a brighter future.

[6] NREL. The Technical and Economic Potential of the H2@Scale Concept Within the United States. October 2020, p. 110.
[7] *Ibid.*
[8] *Ibid.*

## A. Green Hydrogen Is Predicted to Surpass Blue Hydrogen in Cost-Competitiveness

To the extent that hydrogen finds niches in the energy or industrial economy, blue hydrogen is not likely to be the preferred option. Unlike green hydrogen, it relies on a fuel known to suffer from price volatility. The need to install carbon capture adds production as well as downstream carbon management costs and complexities.[9] An analysis comparing the costs of blue and green hydrogen saw a better opportunity for cost reduction in the green method:

> "While the cost of producing hydrogen via electrolysis [green hydrogen] is expected to fall, fossil fuel and carbon capture options are mature technologies. Likewise, it is unlikely that there will be significant reductions in the cost of carbon transport and storage as improvements from economies of scale will be limited. The inclusion of realistic $CO_2$ transport, storage and monitoring costs would lead to higher costs than currently projected."[10]

The European Commission reported in July 2020 that green hydrogen costs between $3 per kilogram (kg) and $6.55/kg, and blue hydrogen costs about $2.40/kg.[11] This scenario, however, is changing quickly.

- BloombergNEF predicts green hydrogen will be cheaper than blue hydrogen by 2030.[12]
- Petroliam Nasional Bhd (Petronas), a Malaysian oil and gas company, said in 2021 that it plans to be able to produce green hydrogen at $1/kg to $2/kg, and electrolyzer manufacturer Nel Asa of Norway declared it would do so at $1.50/kg by 2025.[13]
- MIT Energy Initiative research scientist Dharik Mallapragada attributed green hydrogen cost declines to the substantial cost decreases that have already occurred and continue to occur in wind and solar power generation. He also points to the declining cost of electrolyzer technology.[14]
- The cost of alkaline electrolyzers fell 40 percent from 2015 to 2019 and is projected to drop between 20 percent and 39 percent by 2030.[15]

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[9] IEEFA. Costs of Blue Hydrogen Production Too High Without Fiscal Life Support. February 2022.
[10] T. Longden, *et al.* 'Clean hydrogen? – Comparing the emissions and costs of fossil fuel versus renewable electricity-based hydrogen. Applied Energy.206: 1181-45. 2021, p. 5.
[11] S&P Market Intelligence. Experts explain why green hydrogen costs are falling and will keep falling. March 5, 2021. Fossil-based hydrogen costs about $1.80/kg.
[12] BloombergNEF. Hydrogen—10 predictions for 2022. January 21, 2022.
[13] S&P Market Intelligence, *op. cit.*
[14] *Ibid*.
[15] T. Longden, *op cit.*, p. 6.

While government dollars are available for blue hydrogen development, green hydrogen is also receiving financial support for research and new development. The U.S. Department of Energy (DOE) has an existing program to reduce green hydrogen's cost to $1/kg by 2030. The DOE tackled a similar cost reduction project with solar power starting in 2011; its "SunShot Initiative" reached the target of a 75 percent cost reduction in 2017, three years earlier than expected.[16] The two efforts are not identical, but blue hydrogen developers clearly face a competitive risk from the accelerating decline in green hydrogen costs.

**Blue hydrogen developers clearly face a competitive risk from the accelerating decline in green hydrogen costs.**

Given that no new blue hydrogen projects are expected to commence operations until at least 2024, the cost comparison is likely to provide blue hydrogen plants with a short-lived competitive edge, at best.

Finally, the NREL makes the observation that blue hydrogen may be limited by physical constraints for carbon storage in some locations. It states:

> "If carbon sequestration is desired, impacts on efficiency and availability of geologic formations suitable for carbon sequestration could constrain natural gas use and thus reduce potential hydrogen production from the natural gas resource. Further analysis would be needed to quantify that impact."[17]

Researchers have warned:

> "As CCS and fossil fuel-based facilities have long lifetimes, early investment in fossil fuel-based hydrogen production creates a risk of lock-in. Tightening carbon constraints combined with decreases in the cost of hydrogen from electrolysis will raise the possibility that natural gas- and coal-based hydrogen production assets could become stranded."[18]

By the time a new blue hydrogen project commences operations, its market potential will likely be weak, and the condition can reasonably be expected to worsen over the next few years.

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[16] DOE. The SunShot Initiative. Accessed January 18, 2022. Also see: Climate Scorecard. The SunShot Initiative in the U.S. April 17, 2021.
[17] NREL, *op. cit.*, p. ix.
[18] T. Longden, *op. cit.*, p. 9.

## B. As a Blending or Replacement Fuel at Natural Gas-Fired Electric Power Plants, Blue Hydrogen Faces Technical Complications as Well as a Strong Market Challenge From Renewable Energy

For new power supply facilities, wind and solar energy prices are already cost-competitive with natural gas, and prices are falling.[19] With increased development of wind and solar resources, the U.S. Energy Information Administration (EIA) projects the share of natural gas to drop three more percentage points from 2021 over the next two years, to 34 percent. It reports:

> "One of the most significant shifts in the mix of U.S. electricity generation over the past 10 years has been the rapid expansion of renewable energy resource, especially solar and wind. The amount of solar power generating capacity operated by the U.S. electric power sector at the end of 2021 is 20 times more than it was at the end of 2011, and U.S. wind power capacity is more than twice what it was 10 years ago."[20]

The IEA concludes that most of the growth in U.S. electricity generation in 2022 and 2023 will come from new renewable energy sources.[21]

Plans to achieve 100 percent hydrogen power plants at utility scale, typically with an operation start-up target of around 2030,[22] may be eclipsed by market forces. Hydrogen-based power plants will face substantial competition from renewable energy sources. BloombergNEF states:

> "The dominance of low-cost renewables leaves relatively little space for hydrogen, CCS and small modular nuclear reactors in power generation…. By 2030, zero-carbon sources provide at least three quarters of electricity in each of our scenarios, and by 2035 they account for 90% or more."[23]

Investing in a technology that is likely to have little or no market share in less than a decade does not make sense.

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[19] Lazard. Levelized Cost of Energy, Levelized Cost of Storage, and Levelized Cost of Hydrogen. October 28, 2021.
[20] Energy Information Administration. New renewable power plants are reducing U.S. electricity generation from natural gas. January 18, 2022.
[21] *Ibid.*
[22] See: Euractiv. GE eyes 100 hydrogen fueled power plants by 2030. May 20, 2021.
[23] Bloomberg NEF. New Energy Outlook 2021. July 2021, p. 6.

For existing natural gas plants, the temptation to blend hydrogen should be tempered with a realistic view of its limitations. Promises of starting up at a 20 percent or 30 percent blend but increasing to 100 percent are just that—promises. No utility-scale power plant is currently capable of operating at 100 percent hydrogen.[24] Despite certain companies' desires to produce new gas turbines capable of burning 100 percent hydrogen,[25] or retrofitting existing natural gas turbines to do so, the practical feasibility is questionable.

**Promises of starting up at a 20 percent or 30 percent blend but increasing to 100 percent are just that—promises.**

Martin O'Neill, vice president of GE Gas Power, asserts that the company has "a 50% hydrogen capability for combustion in our largest baseload gas turbines," and that many of its existing gas turbines already have the capacity to ingest significant quantities of hydrogen.[26] Although many small turbines have employed 50 percent or higher blends,[27] such high percentage blends are not actually being used at utility scale today.

In a recent decision that rejected the notion that a promise of increasing blends of hydrogen into a natural gas plant would justify issuing a permit for the plant, the New York Department of Environmental Conservation said:

> "While existing combustion turbines are generally capable of firing mixtures of hydrogen and natural gas, these fuel blends raise other concerns. When compared to natural gas, hydrogen has a higher explosive potential, a higher leak potential, a lower volumetric heating value, and a higher flame temperature. A lower volumetric heating value means that more fuel needs to be fired to achieve the same output. The additional volume of fuel fired, combined with the higher flame temperature when firing hydrogen, is expected to cause higher emissions of NOx without the installation of additional NOx controls. An existing combustion turbine facility may be required to modify its fuel feed system, fuel firing system, and/or emission control system to facilitate hydrogen firing in the combustion turbine while maintaining compliance with its permitted emission limits. Further, if a blend of hydrogen and natural gas is combusted, some amount of GHG emissions would still be generated from the natural gas."[28]

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[24] A small 40 MW turbine at a Samsung General Chemicals facility in South Korea has operated at about 90% hydrogen for some 20 years. See: Bloomberg. Green hydrogen could price gas out of power markets by 2050. January 14, 2020 (hereafter, Bloomberg on green hydrogen costs).
[25] Forbes. Eager to become hydrogen ready, power plants turn to dual fuel turbines. July 30, 2021.
[26] Euractiv, *op. cit*.
[27] Bloomberg on green hydrogen costs, *op. cit.*
[28] New York Department of Environmental Conservation. Notice of Denial of Title V Air Permit, DEC ID: 2-6301-00190/00014. October 27, 2021.

One set of researchers observed:

> "Several technical and economic limitations have held back hydrogen, including its explosiveness, low energy density per volume, ability to cause embrittlement in metals and, accordingly, costly infrastructure for production, storage, and distribution."[29]

More specifically, challenges of high percentage hydrogen fuel mixes include:

- Hydrogen emits higher amounts of nitrogen oxides (NOx), which is a regulated air pollutant and reacts with hydrocarbons in the air to form photochemical smog (ground-level ozone).

- Its low density and low calorific (heat) value means that gas velocities in pipelines and gas installations will need to be "up to three times higher,"[30] and some piping and valves would have to be larger to accommodate the higher gas volumes needed to produce the same energy content.[31] A testing program will be needed to ensure that the many control and pressure reduction installations in the network are suitable for hydrogen use or are modified as needed.[32]

**Interest in blue hydrogen for power plant use exists but is underwhelming.**

- Storage and transport of hydrogen presents challenges. The Congressional Research Service noted that the small molecular size of hydrogen gas makes it difficult to contain, which makes its storage or transportation more challenging.[33]

- Pipeline construction could present high capital costs. Although about 1,600 miles of hydrogen pipelines operate in the United States, the DOE reports they are located where large hydrogen users, such as petroleum refineries and chemical plants, are concentrated such as the Gulf Coast region.[34] It also notes that although existing natural gas pipelines may be able to transport low-level hydrogen blends with modifications, higher level or 100 percent hydrogen transport would require "more substantial modifications," given

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[29] T. Van de Graaf, *et al.* The new oil? The geopolitics and international governance of hydrogen. Energy Res Soc Sci. December 2020.
[30] Gas Processing News. Gas and the Energy Transition—repurposing the system with hydrogen [reporting on DNV GL's 2018 Energy Transition Outlook. 2019.
[31] Congressional Research Service. Hydrogen in Electricity's Future. June 30, 2020.
[32] Gas Processing News, *op. cit.*
[33] Congressional Research Service, *op. cit.*
[34] U.S. Department of Energy, Office of Fuel Cell Technologies. Hydrogen Pipelines. Accessed February 2, 2021.

the potential for hydrogen to embrittle the steel and welds of pipelines not made with fiber reinforced polymer material.[35]

- Finally, blending hydrogen/natural gas fuel in power plants has a lower benefit than the stated percentage may imply. Since hydrogen has a lower density than methane, a 20 percent blend by volume would correlate with only a 7 percent blend by energy value.[36]

In the private sector, interest in blue hydrogen for power plant use exists but is underwhelming. The Monolith Nebraska LLC, which plans to use an energy-intensive pyrolysis process powered by renewable energy but using natural gas feedstock to produce hydrogen, decided to market the hydrogen for ammonia rather than power plant use.

Monolith communications director Dan Levy said the company and its utility partner decided "after several years and millions of dollars invested in engineering studies … that there were better and higher impact uses for our clean hydrogen."[37]

To the extent that hydrogen-blending or hydrogen-generated electricity are considered, blue hydrogen will face substantial competition from green hydrogen. Green hydrogen is already making headway in the power sector. For example, the Intermountain Power Agency (IPA) already plans to use green hydrogen as part of its decision to retire coal units in Utah and replace 47 percent of the capacity with a 30 percent blend of hydrogen and natural gas. When the 1,800 megawatts (MW) of coal-fueled capacity retires in 2025, only 840 MW of natural gas-fired capacity will replace it. The IPA already provides roughly 300 MW of wind energy and more renewable energy projects are planned. The IPA believes that the new natural gas project, consisting of two single-shaft combined-cycle units, will be capable of blending 30 percent hydrogen at start-up.[38] But no data on the operational effectiveness of the project will be available until at least 2025.

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[35] *Ibid.*
[36] I. Staffell, *et al.* The role of hydrogen and fuel cells in the global energy system. Energy Environ. Sci. 12:463-491, 474. 2019. Also see: U.S. Department of Energy. Hydrogen Storage. 2020.
[37] E&E News EnergyWire. DOE unveils $1B loan for hydrogen plant. But is it 'clean'? January 3, 2022.
[38] Intermountain Power Agency. 2021 Annual Report. 2021, p. 6. The IPA facility supplies power to cities in Nevada and California as well as Utah. Also see: Los Angeles Department of Water and Power. Intermountain Power Project and Green Hydrogen. July 2020. The plant is sited over a salt dome that will allow it to store hydrogen for peak power purposes (seasonal fluctuations). The Los Angeles Department of Water and Power operates the facility and is the largest buyer of its power. S&P Capital IQ. Intermountain Power Agency selects firm for coal plant's hydrogen conversion. June 3, 2020.

## C. As an “On Demand” Fuel to Meet Peak Demand Spikes for Electricity, Blue Hydrogen Faces a Strong and Growing Competitive Challenge From Battery Storage

To ensure that an existing electrical power system maintains reliability and addresses demand spikes, a combination of targeted grid support, consumer peak demand management incentives (rewarding customers who reduce their power load during hours of high demand), and energy storage may be needed. Hydrogen, however, is likely to be eclipsed by energy battery storage.

IEEFA has observed a positive trend of the declining cost of battery storage. The cost curve globally has plummeted from $1,100 per kilowatt-hour (kWh) in 2011 to $137/kWh in 2020 for a stand-alone lithium-ion battery system. It is projected to drop by roughly 55 percent to just $58/kWh by 2030.[39]

Investor interest is focused heavily on battery storage not only in the U.S. but also globally. For example, the Reliance Group, India’s large oil-to-telecommunications conglomerate, is partnering with the Bill Gates-owned investment management firm Paulson & Company to invest $142 million in Ambri, Inc., a U.S.-based battery development company researching alternatives for longer-duration battery storage systems.[40]

Some hydrogen projects may move forward. Siemens Energy announced it will provide two turbines for the Omaha Public Power District’s new Turtle Creek Station Peaking Plant in Papillion, Neb., with the ability to run as much as 30 percent hydrogen and biodiesel.[41] Also, if the hydrogen is used instead for fuel cells, it could provide power for a utility power station.[42] Ultimately, however, neither of these options is likely to be competitive with battery storage.

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[39] IEEFA. Battery Storage and Green Hydrogen: The next chapter in India’s clean energy story. October 2021.
[40] Reuters. Reliance joins Bill Gates, others to invest $144 million in U.S. energy storage co. August 10, 2021.
[41] Siemens Energy. Siemens Energy to provide hydrogen-capable turbines to back utility scale solar installation in Nebraska. June 17, 2021.
[42] U.S. Department of Energy, Energy Efficiency and Renewable Energy-Fuel Cell Technologies Office. Fuel Cells. Accessed February 2, 2021.

## D. As a Blending or Replacement Fuel for Direct Delivery to Homes and Buildings, Blue Hydrogen Has Technical Complications and Faces Strong and Growing Competition From Electrification

This is one of the least practical, most risky uses for hydrogen. Not surprisingly, blue hydrogen is already behind the curve. Electrification of home heating and cooking systems is moving quickly to capture market share.

Energy efficiency and demand response systems are playing an increasingly greater role in planning for home heating and cooking energy needs. BloombergNEF projects that the use of electricity-saving heat pumps (which may be air source or geothermal), along with electric heaters and clean electric cooking ranges, will account for nearly three-fourths (74 percent) of building emissions abatement to 2050 under two of its three scenarios, and just a slightly smaller share in its third scenario. It projects improved building efficiency in new construction and renovations would provide an additional 10 percent reduction in emissions by 2050.[43] When peak demand management methods are deployed, this also shaves more energy use from the scenario, since utilities plan their needs based on peak demand days, which occur only a few days out of the year.[44]

This does not leave an obvious need for new uses of natural gas or blue hydrogen in the home and building sector. Hydrogen blending cannot reasonably be used as a justification to expand natural gas infrastructure for home and building heating or cooking.

The primary challenge will be transitioning old heating systems. BloombergNEF assumes that hydrogen will play a substantial role, responsible for about 40 percent or more of greenhouse gas abatement in the sector during the transitional period. Actual implementation of hydrogen blending, however, is likely to run into substantial obstacles. Blue hydrogen would have trouble catching up to electrification because of the practical problems involved in increasing the blending ratio to 100 percent hydrogen for distribution.

Also, blue hydrogen at levels ranging from 30 percent to 100 percent is likely to be less attractive to the public. A changeover to high-blend or 100 percent hydrogen would require refitting of appliances. NOx emissions from home-heating boilers might require pollution controls.[45] The potential for hydrogen leaks into the home cannot be ignored. Hydrogen is even more capable of leakage than natural gas. Even

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[43] Bloomberg NEF. New Energy Outlook 2021. July 2021, p. 8.
[44] See IEEFA. Proposed NESE Pipeline in New York: A bad bargain for ratepayers and taxpayers. April 17, 2020.
[45] I. Staffell, *op. cit.*, p. 470.

natural gas-fired kitchen ranges have recently been shown to be a greater indoor air pollution hazard than previously understood.[46]

Home safety is an issue as well. Graham Bennette, vice president of business development for GNV GL's UK and West Africa regions, and Andrew Williams, senior principal consultant at DNV GL – Oil & Gas in Loughborough, UK, expressed optimism that hydrogen has a role in a low-carbon future, but warned that "extensive work will be needed to prove that the introduction of H2 will not compromise the safety and integrity of gas networks and that there is no increase in risk to the public, either directly or indirectly."[47] For example, equipment used during maintenance must be suitable for atmospheres where hydrogen may be present, given the difference between its ignition and flow properties and those of natural gas.[48]

**Blue hydrogen would have trouble catching up to electrification because of the practical problems involved in increasing the blending ratio.**

Equally important, many states in which large areas depend on natural gas for home heating and cooking also have both political leaders and community-based organizations that strongly oppose the continued use of fossil fuel and are actively working against energy proposals that would prolong its use.

## E. For Ground Transportation, Blue Hydrogen Faces a Strong and Growing Competitive Challenge From Electric Vehicles

As with heating, blue hydrogen is already behind the curve in the transportation arena. The primary forces behind this trajectory are private investment and corporate decision-making.

- In 2021, the number of fuel cell vehicles reached only 3,341, while plug-in electric vehicle sales roughly doubled to 607,567.[49]
- Only 48 hydrogen fuel cell public charging stations exist, all in California. In contrast, at least 43,000 electric vehicle charging stations with 120,000

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[46] E. Lebel, *et al.* Methane and $NO_x$ emissions from natural gas stoves, cooktops, and ovens in residential homes. Environ. Sci. Technol. January 27, 2022.
[47] Gas Processing News. Gas and the energy transition—repurposing the system with hydrogen [reporting on DNV GL's 2018 Energy Transition Outlook]. 2019.
[48] *Ibid.*
[49] Argonne National Laboratory. Light duty electric drive vehicles monthly sales updates. December 2021.

> charging ports exist, with relatively heavier concentrations per capita in California, Colorado, Maine, Utah, Oregon, Vermont and Washington.[50] The electric chargers are in public stations—not homes and businesses, where vehicle charging is also occurring.

Substantially more electric vehicle charging infrastructure is on the way. The IIJA provides $5 billion in grants for states to deploy public EV chargers. The goal is to establish 500,000 charging ports, up from the 106,000 public charging ports (at about 46,000 stations) identified by NREL in 2020. The full cost will be much higher, but electric vehicle charging providers are employing private capital. For example, Electrify America plans to more than double its current electric vehicle (EV) charging infrastructure in the United States and Canada, with plans to have more than 1,800 fast charging stations and 10,000 individual chargers installed by the end of 2025.

Members of the Electric Highway Coalition (14 utilities in the Eastern and Southern United States), plus the Tennessee Valley Authority, and utilities in California and New York are investing in EV charging buildout.[51] In July 2021, Southern California Edison launched a $436 million Charge Ready program to add about 38,000 new electric car chargers in its service area over the next five years. The utility plans to locate half in disadvantaged communities that suffer most from air pollution.[52]

**Passenger cars and small trucks.** This ship has sailed. Electric vehicles have a strong advantage in the passenger car market. Their market share is growing and expected to continue to grow.

The private sector is well aware of the market. Automotive companies are investing in electric vehicles. General Motors recently dropped its opposition to California's vehicle emission standards[53]—a notable development—and pledged collaboration with charging infrastructure investment and other measures. Echoing a statement made by its CEO in 2020,[54] GM's website declares:

> "GM is on its way to an all-electric future, with a commitment to 30 new global electric vehicles by 2025. We are aggressively going after every aspect of what it takes to put everyone in an EV because we need millions of EVs on the road to make a meaningful impact toward building a zero-emissions future."[55]

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[50] Reuters. Factbox: Five facts on the state of the U.S. electric vehicle charging network. September 1, 2021.
[51] E&E News EnergyWire. Major US utilities plan coast-to-coast EV-charging network. December 2, 2021.
[52] PV Magazine. Sunrise Brief: SCE launches EV charging program. July 13, 2021.
[53] Reuters. GM recognizes California's authority to set vehicle emissions rules. January 9, 2022.
[54] Green Money. General Motors' Mary Barra on putting everyone in an electric vehicle. December 2020.
[55] General Motors. Our path to an all-electric future. Accessed January 10, 2022.

It backed up this policy in January 2022 with an announcement that it will invest almost $7 billion in two Michigan manufacturing sites, producing electric vehicles in Orion and battery cells in Lansing.[56]

**Buses and freight trucks.** The debate between hydrogen fuel cells and electric batteries for heavy vehicles continues to rage. At this point, hydrogen fuel cells appear to be lagging. The Wall Street Journal reported:

> "The use of hydrogen fuel cells in the biggest semi tractor-trailer trucks will lag behind battery electric trucks for up to a decade, says Greg Genette, senior research analyst in the U.S. commercial vehicle group at IHS Markit. By 2030, battery electric trucks will make up around 14% of U.S. new truck sales, compared with just 1% for hydrogen fuel cell vehicles, he says."[57]

As with passenger vehicles, the dearth of hydrogen filling stations is a problem for heavy vehicles. But in the long run, another expert cited by the Wall Street Journal predicts, hydrogen fuel cells "will become the better proposition for long-haul trucks because they will be more convenient to operate and run longer because of the short time to refill the tanks."

To the extent that hydrogen fuel cells gain a significant market share among heavy vehicles, green hydrogen would be a more likely candidate than blue hydrogen for the job. The Wall Street Journal noted:

> "Producing hydrogen now is such an energy-intensive process that it cancels out any climate benefits from a zero-emission vehicle, analysts say. That is why vehicle manufacturers are counting on so-called green hydrogen, the production of hydrogen using renewable energy sources such as hydroelectric or solar power."

**Marine shipping.** Assumptions about market potential for hydrogen in marine shipping need to take into account the consideration that the existing shipping fuel market is likely to shrink to a significant extent. Over the years, so little effort has been made at energy efficiency in shipping that Bloomberg NEF calculated that efficiency improvements will make up two-thirds of emissions reductions to 2030, and further reductions of about 45 percent will be made up to the year 2050. In two of three scenarios, it saw biofuels and ammonia produced from zero-carbon hydrogen each making up 18 percent to 35 percent of emissions reductions; in the third scenario, it assumed that biofuels become a major player, accounting for 46 percent of the final energy mix for shipping in 2050. Bloomberg NEF predicted only domestic and short-haul general cargo vessels, ferries, cruises and other light vessels will likely convert to electricity.[58]

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[56] General Motors. GM accelerates its drive to lead the EV industry with $7 billion investment in Michigan, creating 4,000 new jobs and retaining 1,000. January 25, 2022.
[57] The Wall Street Journal. The electric truck battle to come: Batteries versus hydrogen fuel cells. November 9, 2021.
[58] Bloomberg NEF, *op. cit.*, p. 8.

The marine shipping market, however, is likely to be slow-growing, given that most ships are equipped with fossil fuel systems and have long lifetimes.[59] As green hydrogen overtakes blue hydrogen on economic grounds, the potential market for blue hydrogen as a feedstock for ammonia fuel in ships is likely to diminish considerably.

**Aviation.** Aviation presents a fuel decarbonization challenge. Most aviation carbon emission impacts to date have been reduced only through carbon offsets. BloombergNEF concludes that only light aircraft operating on commuter routes, which make up just 5 percent of aviation fuel consumption, are likely to become electric.[60]

The use of hydrogen in aviation fuel production raises questions, however. One analysis reported the climate benefits of hydrogen for aviation "has been questioned because it produces more than double the water vapor emissions of kerosene." Water vapor at high altitudes, although short-lived in the atmosphere, "causes radiative forcing and thus contributes to net warming." It concluded that significant hydrogen deployment is thought unlikely before 2050 except perhaps for small or low-flying aircraft.[61]

**The use of hydrogen in aviation fuel production raises questions.**

**Competition with green hydrogen.** Even where hydrogen is used for transportation, blue hydrogen will again face competition from green hydrogen. Plug Power launched construction in October 2021 on a $290 million green hydrogen fuel production facility and electricity substation in New York's Genesee County. When completed, it will be North America's largest green hydrogen production facility, producing 45 metric tons of green liquid hydrogen daily. The plant is expected to provide transportation fuel at prices competitive with diesel.[62]

[59] I. Staffell, *op. cit.*, p. 468.
[60] Bloomberg NEF, *op. cit.*, p. 8.
[61] I. Staffell, *op. cit.*, p. 468.
[62] Office of New York Governor Kathy Hochul. Governor Hochul announces largest green hydrogen plant in North America. October 20, 2021.

## F. For Marketing as Industrial or Fertilizer Feedstock, or as Fuel for Industry, Blue Hydrogen Faces Growing Competition From Green Hydrogen

**Ammonia and fertilizer.** The typical feedstock for industrial and agricultural ammonia currently is hydrogen produced from natural gas. The NREL reported in October 2020 that domestic ammonia production is growing because of low-cost natural gas,[63] a condition that was true for several years due in large part to over-production by hydrofracking but has since changed.[64] An additional cost factor is entering the picture as well: Almost all the ammonia production currently occurs without CCS, falling into the category of gray hydrogen-based processes. Adding CCS will increase the costs of ammonia production. An analysis of the size of the fertilizer market will need to take these factors into account in determining the size of the overall hydrogen market for ammonia production, and the point at which green hydrogen overtakes blue hydrogen in cost competitiveness.

Note that the benefits of adding CCS to natural gas-based ammonia production facilities can be overstated if CCS is only provided for the production process and not for an onsite natural gas combustion source powering the process.[65] This can become a liability, especially from the perspective of corporate responsibility and public perception.

**Industrial use.** Industrial use of hydrogen is predicted to rise in sectors where high-temperature heat is required, such as in the steel and cement industries. It may also find a market if the iron and steel industry begins to use it in the direct iron reduction steelmaking process.[66] Although these are market targets for blue hydrogen, turnover for industrial systems may be slow and the passage of time is likely to see green hydrogen become more cost competitive.[67]

Bloomberg NEF observes that hydrogen for heat production in cement rotary kilns is likely to make some headway, but fossil fuels are likely to "continue to dominate energy use in the cement sector all the way to 2030," when it expects hydrogen use for rotary kilns to become widespread.[68] Again, turnover will move slowly, and it is likely that green hydrogen will become cost-competitive.

Petrochemical production is an important sector to address with regard to energy use. A study of the sector observed:

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[63] NREL, *op. cit.*, p. 18.
[64] IEEFA. Booming U.S. natural gas exports fuel high prices. November 4, 2021.
[65] See IEEFA. Reality Check on CO2 Emissions Capture at Hydrogen-From-Gas Plants. February 2022.
[66] Gas Processing News, *op. cit.* Also see: Public Utilities Fortnightly Magazine. Green hydrogen: Dave Edwards [Air Liquide's director and advocate for hydrogen energy]. December 2021. Also see I. Staffell, *op. cit.*, p. 472.
[67] I. Staffell, *op. cit.*, p. 472.
[68] Bloomberg NEF, *op. cit.*, p. 10.

> "When compared to other chemical industries, plastic production is among the most energy-demanding. Most of the emitted $CO_2$ can be associated with energy consumption and heat generation, although direct industrial emissions occur during oil and gas cracking, hydrogen production, and feedstock manufacture."[69]

For petrochemicals, greater recycling is likely to make a substantial difference in the potential blue hydrogen market because it can be accomplished at a lower heat, facilitating electrification of the sector. For plastics newly manufactured from petroleum products, control of carbon emissions remains a problem. As public outcries against the environmental impacts of plastics manufacturing increase, blue hydrogen as a heat source is unlikely to be an attractive option.

[69] L. Pires de Mata Cpsta, *et al.* Capture and reuse of carbon dioxide ($CO_2$) for a plastics circular economy: A review. Processes. 9(759). April 26, 2021.

# About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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Tom Sanzillo, director of financial analysis for IEEFA, is the author of numerous studies on the oil, gas, petrochemical and coal sectors in the U.S. and internationally, including company and credit analyses, facility development, oil and gas reserves, stock and commodity market analysis and public and private financial structures. Sanzillo has experience in public policy and has testified as an expert witness, taught energy industry finance and is quoted frequently in the media. He has 17 years of experience with the City and the State of New York in senior financial and policy management positions. As the first deputy comptroller for the State of New York Sanzillo oversaw the finances of 1,300 units of local government, the annual management of 44,000 government contracts, and over $200 billion in state and local municipal bond programs as well as a $156 billion global pension fund.