NOTES
DE L'IFRI

JUNE
2022

Clean Hydrogen in the USA
The USA Doubles Down Efforts to Grasp Clean Hydrogen Leadership

Center for Energy
& Climate

Sylvie CORNOT-GANDOLPHE

The French Institute of International Relations (Ifri) is a research center and a forum for debate on major international political and economic issues. Headed by Thierry de Montbrial since its founding in 1979, Ifri is a non-governmental, non-profit foundation according to the decree of November 16, 2022. As an independent think tank, Ifri sets its own research agenda, publishing its findings regularly for a global audience.

Taking an interdisciplinary approach, Ifri brings together political and economic decision-makers, researchers and internationally renowned experts to animate its debate and research activities.

ISBN: 979-10-373-0726-2

How to quote this publication:

Sylvie Cornot-Gandolphe, "Clean Hydrogen in the USA: The USA Doubles Down Efforts to Grasp Clean Hydrogen Leadership", *Notes de l'Ifri*, Ifri, June 2023.

Ifri

27 rue de la Procession 75740 Paris Cedex 15 – FRANCE

Tel. : +33 (0)1 40 61 60 00 – Fax : +33 (0)1 40 61 60 60

Email: accueil@ifri.org

Website: Ifri.org

Author

Sylvie Cornot-Gandolphe is a consultant in energy, focusing on international issues. Since 2012, she has collaborated with the Center for Energy & Climate within the French Institute of International Relations (Ifri) as a research associate, with CyclOpe, the reference publication on commodities, and CEDIGAZ, the international center of information on natural gas of IFPEN.

Sylvie has a deep understanding of global gas and coal markets, gained during her career, first as General Secretary of CEDIGAZ, IFPEN, then Project Manager, Gas Centre, Economic Commission for Europe of the United Nations in Geneva, then Principal Administrator, Gas Expert, International Energy Agency and then Deputy Director of Business Development and Advisor to the Chairman on energy issues, ATIC SERVICES. She is the author of several reference publications on coal and gas markets. Sylvie is a graduate of École nationale supérieure du pétrole et des moteurs (ENSPM).

Abstract

Although late in adopting clean hydrogen (H2) and defining a national strategy–a draft was presented by the Department of Energy (DOE) in September 2022–, the United States (US) has strongly reinforced its support to clean hydrogen with the passage of the Inflation Reduction Act (IRA) in August 2022.

The IRA's support and technology-neutral approach has spurred investors' interest, accelerated clean hydrogen projects and driven investment in electrolyzers manufacturing capacity. There are now over 100 clean hydrogen production projects announced across the country, with a production capacity of 12 million tons (mt) of hydrogen per year (12 mtH2/y) in 2030.

The US is well on track to meet its medium-term objectives. Pathways for clean hydrogen to decarbonize applications have been informed by demand scenarios for 2030, 2040 and 2050, with strategic opportunities for 10 mtH2/y of clean hydrogen demand by 2030, before ramping up to 20 mtH2/y by 2040 and 50 mtH2/y by 2050, representing a cumulative investment opportunity of $85-215 billion through 2030, and $800–1,100 billion cumulative by 2050.

Several issues remain to be addressed–the most urgent one being the implementation guidance of the IRA's clean hydrogen tax credits.

The sheer scale of US support to clean hydrogen, combined with US assets, could make the nation one of the leading producers, consumers and exporters of clean hydrogen and its derivatives. Moreover, while the US missed the early opportunity to expand into electrolyzer production, the IRA has been a pivotal point, attracting US and European electrolyzer manufacturers to invest in manufacturing plants in the US and challenging China's and Europe's dominance. In April 2023, California-based EvolOH accounted for the largest share of projects planned to be operational in the world by 2030. The US could even become the cheapest producer globally and start exports of clean ammonia by 2027.

The strong business incentives for clean hydrogen have shaken up the global hydrogen industry and triggered new policy measures around the world.

Résumé

Malgré un retard dans l'adoption de l'hydrogène propre (H2) et l'élaboration d'une stratégie nationale – un projet a été présenté par le ministère américain de l'Énergie (DOE) en septembre 2022 –, les États-Unis ont considérablement renforcé leur soutien à l'hydrogène propre grâce à l'adoption de la loi sur la réduction de l'inflation (IRA) en août 2022. Le soutien de l'IRA, et son approche technologiquement neutre, a suscité l'intérêt des investisseurs, accéléré les projets d'hydrogène propre et encouragé les investissements dans la capacité de fabrication des électrolyseurs. Plus de 100 projets de production d'hydrogène propre ont été annoncés à travers le pays avec une capacité de production de 12 millions de tonnes d'hydrogène par an (12 mtH2/an) d'ici 2030.

Les États-Unis progressent favorablement vers l'atteinte de leurs objectifs à moyen terme. Des scénarios de demande pour 2030, 2040 et 2050 ont permis de tracer des voies pour l'utilisation de l'hydrogène propre dans la décarbonisation des applications. Des opportunités stratégiques se dessinent avec une demande estimée à 10 mtH2/an d'ici 2030, puis une augmentation à 20 mtH2/an d'ici 2040 et 50 mtH2/an d'ici 2050. Ces perspectives représentent une occasion d'investissements cumulés de 85 à 215 milliards de dollars d'ici 2030 et de 800 à 1 100 milliards de dollars d'ici 2050. Plusieurs questions restent à traiter, la plus urgente étant l'orientation de la mise en œuvre des crédits d'impôt pour l'hydrogène propre de l'IRA. L'ampleur du soutien accordé par les États-Unis à l'hydrogène propre, associée aux ressources du pays, pourrait positionner celui-ci comme l'un des principaux producteurs, consommateurs et exportateurs mondiaux d'hydrogène propre et de ses dérivés.

De plus, bien que les États-Unis aient manqué l'opportunité précoce de se développer dans la production d'électrolyseurs, l'IRA a constitué un tournant en incitant les fabricants d'électrolyseurs américains et européens à investir dans des usines de production aux États-Unis, remettant ainsi en question la domination de la Chine et de l'Europe. En avril 2023, l'entreprise californienne EvolOH était en tête des projets prévus pour être opérationnels dans le monde d'ici 2030. Les États-Unis pourraient même devenir le producteur mondial le moins cher et commencer à exporter de l'ammoniac propre dès 2027. Les incitations commerciales considérables en faveur de l'hydrogène propre ont perturbé l'industrie mondiale de l'hydrogène et déclenché de nouvelles mesures politiques à l'échelle internationale.

Table of Contents

Introduction

The US is determined to make clean hydrogen an affordable alternative to fossil fuels in the US and around the world, and to lead the race in the global clean hydrogen market. Clean hydrogen is seen by US policymakers as one of the major tools for decarbonizing the US economy, particularly hard-to-electrify industrial sectors and heavy-duty transportation, while providing economic growth, industrial competitiveness, export and skilled jobs opportunities, promoting energy security, resilience, and advancing environmental and social justice. The IRA's support for clean hydrogen production is unprecedented and could be a game changer for the US and global industry.

This note analyses the development of US policy on clean hydrogen, what has been achieved since the passage of the IRA, and the challenges still to be addressed by US policymakers. It finally lays out broader implications of the IRA for other regions.

Strong policy support could make US clean hydrogen the cheapest in the world

US policy support to clean hydrogen

The IRA–a landmark legislation that earmarks around $369 billion for energy security and climate change initiatives–provides unprecedented support to clean hydrogen through tax credits. The IRA introduces a clean hydrogen production tax credit (PTC), known as the 45V tax credit, and extends the existing investment tax credit (ITC) to hydrogen projects and standalone hydrogen storage technology. The 45V PTC provides credits of up to $3/kgH2 to producers of clean hydrogen over 10 years, after the date of commissioning of the facility. The magnitude of the credit depends on the level of Greenhouse Gas (GHG) emissions (Table 1) and the fulfillment of IRA's labor and wage requirements.

Table 1. Clean Hydrogen Production Tax Credit (45V)

Carbon intensity ($kgCO_2e/kgH_2$)	Max. Tax Credit ($\$/kgH_2$)
4-2.5	0.60
2.5-1.5	0.75
1.5-0.45	1.00
0.45-0	3.00

Source: IRA

Only projects that start construction before 2033 would qualify. All forms of clean hydrogen production are potentially eligible for the 45V tax credits. For the purposes of these tax credits, the IRA defined clean hydrogen as hydrogen produced through a process that results in lifecycle GHG emissions (well to gate) of up to 4 kgCO2e/kgH2.

The IRA also provides significant support to carbon capture, utilization and storage (CCUS). For projects that meet the IRA's labor and wage requirements, it increases the existing tax credit (known as 45Q) to $85/t (from $50) for CO2 captured and geologically sequestered and to $60/t (from $35) for utilized carbon, such as for enhanced oil recovery. According to Resources for the Future, the $85/t tax credit is comparable to a subsidy of around $1/kgH2.[1]

The IRA also extends the existing renewable energy PTC, which is valued at $30/MWh. Green hydrogen projects would be allowed to receive the renewable energy tax credits in addition to the hydrogen ones. But blue hydrogen projects would be ineligible for hydrogen tax credits if they already receive federal tax credits for CCUS. Clean hydrogen producers are therefore expected to take advantage of either the 45V tax credits or the 45Q tax credit to improve near-term project economics.

These tax credits have the potential to make US clean hydrogen one of the cheapest in the world. In the case of blue hydrogen, the increased value of the 45Q tax credit already makes natural gas reforming plus CCS competitive with grey hydrogen, whose current production cost varies from $1 to $1.50/kgH2.[2] In the case of green hydrogen, the full $3/kgH2 PTC could make best-in-class projects (e.g. those with access to high capacity factor renewables) cost-competitive within around 3-5 years in several industrial and transport applications, particularly if midstream and downstream investments are realized.[3] These best-in-class project could see their production costs reach zero by 2030 after applying the full PTC and taking account of cost learning.

The IRA is not the only policy support to clean hydrogen. In November 2021, the US passed the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL).[4] The BIL, a $1.2 trillion commitment of funding for the country's physical infrastructure, includes provisions to accelerate research, development, demonstration, and deployment (RDD&D) of clean hydrogen production, transportation and use across of the US. The BIL provides significant support to clean hydrogen: $9.5 billion of federal funding is allocated for DOE programs between 2022 and 2026, including $8 billion for the creation of at least four regional hubs, $1 billion for a DOE clean hydrogen electrolysis program to reduce the production cost of hydrogen, and $500 million for clean hydrogen manufacturing and recycling RDD&D activities. This effort will also support American manufacturing of clean hydrogen equipment,

1. "Incentives for Clean Hydrogen Production in the Inflation Reduction Act", Resources for the Future, 2022, available at: www.rff.org.
2. "Policy Implementation and Infrastructure Building are Key to US Hydrogen Development", ING Think, 2023, available at: www.think.ing.com.
3. "Pathways to Commercial Liftoff - Clean Hydrogen", Department of Energy, available at: www.energy.gov. Considering that the 45V PTC is for the first 10 years, while hydrogen projects are for 20 years or so, about 60 to 65% of the PTC would reflect in LCOH (Levelized Cost of Hydrogen). So, a $3/kg tax credit will lower LCOH by approximately $1.9/kg. "The Inflation Reduction Act – a Turning Point for the Global Green Hydrogen Market", EY, 2022, available at: www.ey.com.
4. "Infrastructure Investment and Jobs Act, Library of Congress, 2021, Text H.R 3684- 117th Congress", US Congress, 2021-2022, available at: www.congress.gov.

including projects that improve efficiency and cost-effectiveness and support domestic supply chains for key components.

The BIL also contains the single largest appropriation of money for CCUS in the history of the technology. It provides $12 billion over 5 years in CCUS demonstration and networks, of which $3.5 billion for carbon capture demonstration projects and large-scale pilot projects, $2.1 billion for a new loan program for carbon transportation and $2.5 billion for carbon storage.

The DOE's Loan Programs Office (LPO) has also $40 billion in available debt capital financing to enable deployment at scale. So far, LPO has announced loan guarantees for two clean hydrogen projects: $1.04 billion for the first-ever commercial-scale project to deploy methane pyrolysis technology (Monolith, Nebraska); and $504 million for large-scale hydrogen energy storage, 220 MW electrolysis and turbine (Advanced Clean Energy Storage, Utah).

Implementation of the clean hydrogen PTC: a trade-off between cost reduction and growing emissions?

The IRA directed the Internal Revenue Service (IRS) of the US Department of Treasury to publish guidance for the implementation of the 45V tax credits within a year of enactment. The forthcoming rules will provide crucial information to investors, project developers, and end-users as they will determine which types of projects can qualify for the tax credits. They will have massive implications for clean hydrogen competitiveness, and therefore the pace of growth of clean hydrogen production in the coming years, climate goals, and global hydrogen trade.

The guidance rules will define how to measure GHG emissions from clean hydrogen, and particularly emissions from grid-connected electrolyzers. Similar to what occurred in Europe, this definition has triggered a hot debate among US stakeholders on additionality, temporal matching and deliverability. On the one hand, some stakeholders have asked the Treasury to adopt strict emissions accounting rules that require hydrogen producers to match their consumption of electricity from the grid with clean electricity production on an hourly basis, and only using production that has been recently installed nearby the hydrogen facility. That approach would ensure hydrogen would not increase GHG emissions from the power grid. On the other hand, opponents argue that these strict rules would reduce the electrolyzer capacity factor, which would result in an increase of production costs and finally delay the scale-up of green hydrogen. This would not enable the rapid deployment of electrolyzers needed to establish a domestic industry and drive down costs, therefore limiting the future role of green hydrogen in deep decarbonization. Also, the hourly matching would be challenging in the US as a nationwide system tracking clean electricity generation and consumption on an hourly basis is not available today. These stakeholders argue that the longer-term reductions from faster and cheaper electrolyzer penetration could more than offset any near-term increases in emissions from the current electricity grid.

As the ultimate goal of the IRA is to dramatically accelerate the deployment of clean energy solutions to achieve net zero by mid-century, a trade-off is likely to arise between near-term emissions reductions and the volume of electrolysis deployment. As occurred in Europe, the IRS is likely to define a phased approach over time to restrictive rules, thus allowing the early development of a clean hydrogen industry that ultimately adheres to strict rules within a clear timeframe and can play a meaningful role in deep decarbonization.

The US clean hydrogen strategy and roadmap: three key objectives

To activate the hydrogen economy, in September 2022, the DOE released a draft National Clean Hydrogen Strategy and Roadmap (NCHSR).[5] According to the DOE, developed at scale, clean hydrogen can reduce US GHG emissions by approximately 10% by 2050 relative to 2005.

The NCHSR covers all forms of clean hydrogen production, including green, blue and pink hydrogen (electrolyzers powered by nuclear power). It sets out DOE hydrogen program targets (but no quantitative targets for installed electrolyzers) and milestones for 2022-2036 for the clean hydrogen value chain and outlines the national actions that are needed to support and develop the clean hydrogen industry in the near, middle, and long term. It outlines the challenges to scaling up the hydrogen economy, including the cost of clean hydrogen, the lack of hydrogen infrastructure, the lack of manufacturing at scale, and durability, reliability, and availability challenges in the supply base across the entire value chain. The DOE develops three key strategies to address those challenges: (1) target strategic, high-impact end uses; (2) reduce the cost of clean hydrogen; and (3) focus on regional networks. These strategies are detailed hereunder.

DOE targets strategic, high-impact uses

The DOE will target strategic, high-impact uses of clean hydrogen, where limited deep decarbonization alternatives exist. In the short and medium term, specific markets include hard-to-electrify industrial applications, heavy-duty transportation, and long-duration energy storage (LDES) to enable a clean grid. Based on two key factors–estimated break-even cost and the relative attractiveness of hydrogen as a decarbonization solution–, the NCHSR outlines a phased development of the clean hydrogen market: (1) catalyze clean hydrogen use in existing industries (ammonia, refineries)[6]

5. "DOE National Clean Hydrogen Strategy and Roadmap (Draft): DOE Hydrogen Program", United States Department of Energy, 2022, available at: www.hydrogen.energy.gov; "DOE Releases Draft Clean Hydrogen Production Standard, Draft Roadmap, and Hydrogen Hub Funding Opportunity", Latham & Watkins, 2022, available at: www.lw.com.

6. Today, the US is the second-largest producer of hydrogen, with 13 Mt produced in 2021, representing 14% of global production. Almost all of this hydrogen is produced through methane reforming or as a by-product of petroleum refining. This hydrogen is mainly used in refining (55%) and in the chemicals industry (ammonia and methanol, 35%).

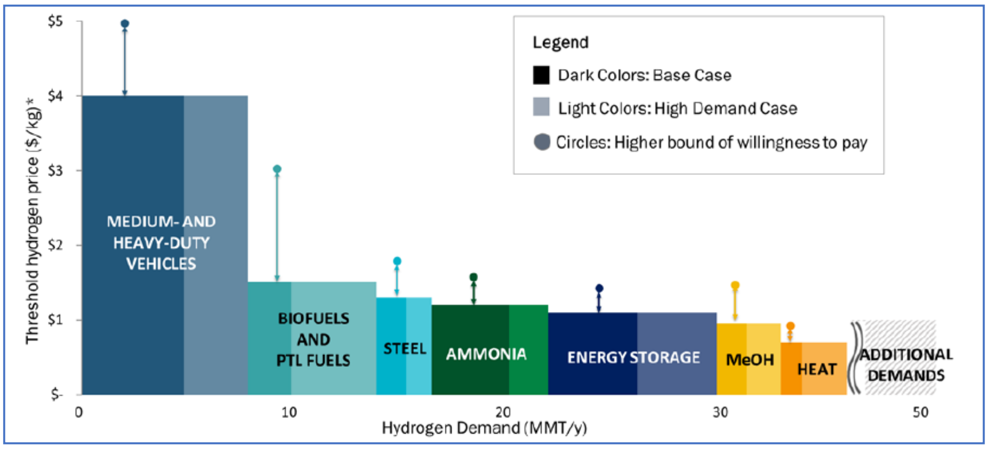
with an emphasis on industrial clusters to help drive down costs, create the infrastructure and initiate new uses; (2) scale up for use cases where clean hydrogen offers a "growing economic value proposition" (e.g. transportation use cases, LDES, greater use of industrial fuel and feedstock); and (3) as clean hydrogen production scales up, costs decline and infrastructure becomes available, market expansion to applications becoming competitive (e.g. backup power, stationary power, methanol, container ships, cement and blending into natural gas networks).[7]

Pathways for clean hydrogen to decarbonize applications have been informed by demand scenarios for 2030, 2040 and 2050, with strategic opportunities for 10 mtH2/y of clean hydrogen demand by 2030, before ramping up to 20 mtH2/y by 2040 and 50 mtH2/y by 2050 (Graph 1), representing a cumulative investment opportunity of \$85-215 billion through 2030, and \$800–1,100 billion cumulative by 2050.

The transportation and industrial segments are expected to make up more than 90% of total hydrogen demand by 2050–with clean ammonia, methanol, biofuels, fuel cell-based road transportation and sustainable aviation fuels (SAF) driving the majority of this volume.

The initial focus on existing uses will enable to rapidly kick off the market but remains limited in terms of climate benefits. Current hydrogen production emits around 100 MtCO2e annually or just under 2% of US net GHG emissions. The biggest emissions benefits from clean hydrogen materialize when its use is expanded to future applications. Notably, diversification of uses to heavy-duty transportation (e.g. road, SAF, maritime fuels) is crucial for hydrogen climate benefits, enabling the creation of a large market driving economies of scale and cost reductions.

Graph 1. Potential clean hydrogen demand by 2050



Assuming hydrogen is available at the corresponding threshold cost. Source: DOE

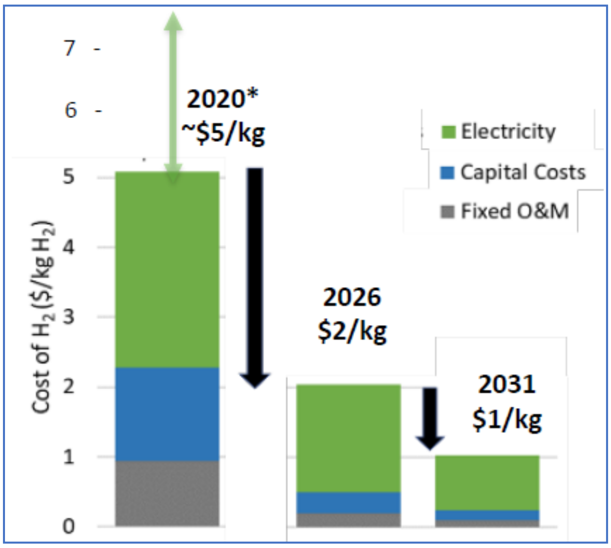
7. "DOE National Clean Hydrogen Strategy and Roadmap (Draft): DOE Hydrogen Program", *op. cit.*

Clean hydrogen at $1 per 1 kilogram in one decade

The NCHSR acknowledges that reducing the cost of clean hydrogen is key to adoption across the wide range of potential end uses that are hard to electrify. The DOE is advancing RDD&D efforts to reduce clean hydrogen production costs for multiple production processes (electrolysis, large-scale natural gas reforming, and innovative approaches such as photoelectrochemical processes). The DOE targets a reduction of production cost to $2/kgH2 by 2026 (from an average of $5 in 2020) for hydrogen from electrolysis (Graph 2). The DOE launched the Hydrogen Shot in 2021, which seeks to reduce the cost of green hydrogen by 80% to $1 per 1 kilogram in one decade ("1 1 1").[8] Several factors are expected to reduce the cost of green hydrogen, such as reducing the capital cost (CAPEX) of electrolyzers by more than 80%; improving energy efficiency and lifetime of electrolyzers; increasing electrolyzer capacity factors; and above all reducing electricity cost (the biggest cost driver) from $50/MWh in 2020 to $20/MWh in 2030. The US is developing large-scale renewable power to reach that specific target by 2030, while the IRA will significantly reduce the costs of clean power.

In March 2023, the DOE announced $750 million in funding, from the $1.5 billion allocated by the BIL, for electrolysis, manufacturing, and recycling to drive RDD&D efforts to dramatically reduce the cost of clean hydrogen.

Graph 2. Targeted cost reductions for hydrogen from electrolysis



**2020 Baseline: PEM low volume capital cost ~$1,500/kW, electricity at $50/MWh. Source: DOE*

8. "Hydrogen and Fuel Cell Technologies Office", Hydrogen Shot, Overview 2021-2022, available at: www.energy.gov.

Focusing on clean hydrogen hubs

The third key strategic objective is to focus on regional networks of hydrogen producers and consumers that are linked by connective infrastructure to enable critical mass infrastructure, drive scale, and facilitate market lift-off. Ultimately, they will form the foundation of a national clean hydrogen network that will contribute substantially to decarbonizing multiple sectors of the economy and creating jobs.

In September 2022, the DOE opened a $7 billion funding opportunity–from the $8 billion funding allocated by the BIL–to create 6 to 10 clean hydrogen hubs across the country (DOE's H2Hubs program). Each successful applicant could expect federal funding of up to $1.25 billion per hub over 8 to 12 years, with applicants funding at least 50% of the project cost from third-party and other non-federal sources. The funding opportunity received tremendous interest: the DOE received 79 pre-submissions requesting nearly $60 billion in federal funding—roughly eight times the size of DOE's solicitation, and including, in aggregate, more than $150 billion of own capital. The DOE encouraged 33 projects to submit formal applications by April 2023. Although a full list of submissions is not available, at least 20 groups from across the US submitted final applications, according to a survey conducted by S&P Global Commodity Insights.[9] A final funding decision on up to 10 hubs is expected in fall 2023. It is unclear at this stage how many hub proposals that do not get DOE funding will proceed regardless.

The proposed hubs focus on a diverse array of feedstocks and diversified end-use applications. The BIL included several requirements for the selection of the regional hubs, including diversity in feedstock, end use and geography. At least one of the hydrogen hubs should use fossil fuels plus CCUS as a feedstock. Another must produce its hydrogen from renewable energy. A third must use nuclear power. Two of the hubs must be sited in natural gas-producing regions. The DOE is also required to select at least one hub that demonstrates hydrogen's consumption within the power sector, one in heavy industry, one in residential and commercial heating, and one in transportation.

Different strategies have emerged among hub applicants based on the diversity of regional natural assets in the US.[10] States with large existing refining operations and petrochemicals production (e.g. the Gulf Coast), which currently produce extensive hydrogen through methane reforming, look to exploit their existing infrastructure to create blue hydrogen. For

9. "At least 20 hubs submitted final applications for US hydrogen hub funding", S&P Global Commodity Insights, 2023, available at: www.spglobal.com.

10. S. Cornot-Gandolphe and S. Cedigaz, "The United States of America Enters the Global Clean Hydrogen Race", Cedigaz, 2022, available at: www.cedigaz.com.

instance, leveraging existing assets in the US Gulf Coast area has the potential to bring substantial volumes of blue hydrogen and its derivatives to new markets rapidly and at scale, enabling the emergence of a leading global clean hydrogen hub (e.g. HyVelocity hub).[11] Blue hydrogen projects will need a high level of capture (above 95%) and upstream and midstream methane emissions will need to be minimized. The IRA will charge methane emitters $900/t of methane in 2024, before increasing to $1,200 and $1,500 in the following two years. Another pathway emerges in California, where the HyBuild Los Angeles[12] initiative to create the first national large-scale hub for green hydrogen envisages the use of green hydrogen in the power sector as the anchor sector for upscaling hydrogen production and reducing production costs. This would enable the adoption of green hydrogen by other heavily polluting sectors in the area, such as heavy-duty trucking, refining and shipping/aviation.

11. "Rapidly Scaling Clean Hydrogen Supply and Demand", HyVelocity Hub, available at: www.hyvelocithub.us.
12. "About the Hy Build initiative", Green hydrogen coalition, HyBuild Los Angeles, available at: www.ghcoalition.com.

Despite some remaining challenges, the industry is growing rapidly

The number of clean hydrogen projects is growing at an impressive speed

The industry has responded to recent policy support and announcements of new projects to produce clean hydrogen, ammonia and hydrogen-based fuels are growing at a very impressive speed. Over 100 clean hydrogen production projects totaling around 12 mtH2/y in production capacity by 2030 have been announced across the US as of end of 2022, exceeding the 10 mt-target set by the DOE.[13]

The US appears to be moving towards green hydrogen. The 45V tax credits have spurred a jump in green hydrogen investors' interest, with around 70% of new projects announced in 2022 involving green hydrogen production. The first giga-scale green hydrogen projects were announced with GHI announcing Hydrogen City, Texas, an integrated green hydrogen production, storage, and transport hub growing to 60 GW in size and producing over 3 mtH2/y and SoCalGas announcing Angeles Link, a proposed green hydrogen pipeline system to deliver clean hydrogen to the Los Angeles region from 10-20 GW of electrolyzers.

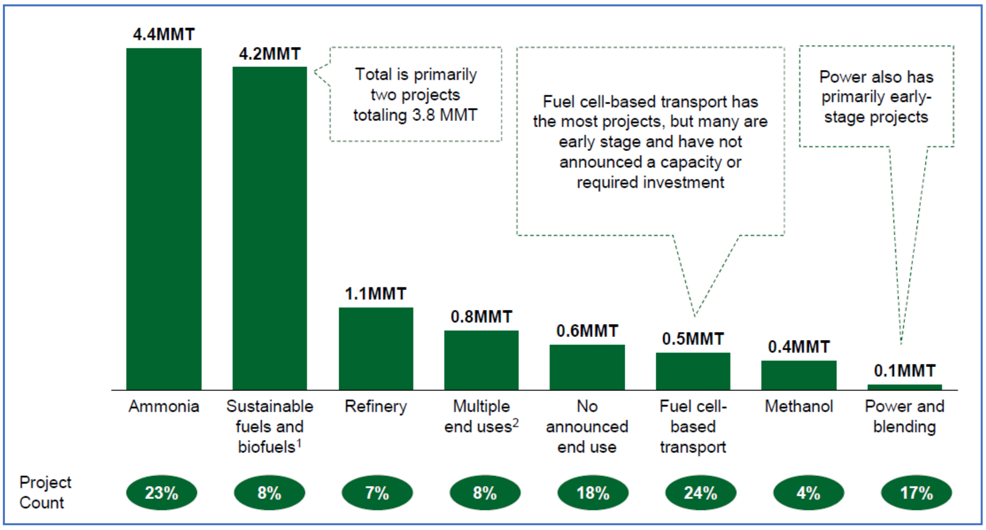
But blue hydrogen projects are very large-scale and still dominate production capacity (56% of the capacity planned by 2030, or almost 7 mtH2/y). Most of these projects target the export market (mostly in the form of blue ammonia, see below). Due to limited midstream infrastructure, announced hydrogen production projects focus on co-located off-takers as well as off-takers that already use carbon-intensive hydrogen.

Only 1.5 Mt of the announced capacity as of end 2022 has reached final investment decision (FID). The lack of contracted offtake and limited transport and storage infrastructure are key reasons, but a major factor is the uncertainty regarding the implementation rules of the 45V tax credit. Thus, most committed projects today relate to blue hydrogen. The increased 45Q tax credit has provided a path to sustainability for traditional

13. Department of Energy, op. cit. (after McKinsey Hydrogen Insights P&I tracker & Electrolyzer supply tracker), 2023.

hydrogen end uses, such as refining and ammonia production. For instance, Air Products has committed $4.5 billion to build a hydrogen-focused complex in Ascension Parish, Louisiana, that by 2026 will start producing 675 ktH2/y of blue hydrogen.

Graph 3. Announced clean hydrogen production projects by end uses, as of end 2022



1 Includes sustainable fuels and biofuels and fuel-cell-based transport

2 Represents production capacity that is targeting more than one of the other end-use sectors

Source: DOE after McKinsey Hydrogen Insights P&I tracker & Electrolyzer supply tracker

Infrastructure and market uptake challenges

Even with large-scale supply-side support and a willing investor and business community, progress towards a hydrogen economy will stagnate if the infrastructure needed to connect clean hydrogen supply to users is unavailable. Outside of the Gulf Coast, few regions of the US have pipelines that are ready to transport hydrogen or facilities where hydrogen could be stored. Investments of only $3 billion in hydrogen infrastructure projects until 2030 have been announced so far.[14] A lack of connective infrastructure could make it harder to reduce the cost of clean hydrogen to levels that would match potential offtakers' interest. A rapid ramp-up is needed to enable an extended pipeline network and unlock hydrogen demand where production/offtake are not co-located. This also requires developing safety protocols to mitigate safety risks.

The US has no binding targets for clean hydrogen in selected end-use applications, such as the EU binding targets for the use of renewable fuels

14. "Hydrogen Insights 2023", Hydrogen Council, McKinsey & Company, 2023, available at: www.hydrogencouncil.com.

of non-biological origin in industry and transportation. Favorable supply-side dynamics will be insufficient to scale the market, unless end-use applications are also addressed. Even when hydrogen production costs are low, midstream and downstream costs can more than double the price of hydrogen. Green hydrogen at \$2/kgH2–which is equivalent to above \$11/MBtu[15]–is much more expensive than the price of natural gas it could substitute, for instance in industrial heat applications. This is partly addressed by the IRA, which includes funding for R&D related to advanced clean manufacturing, federal procurement of construction projects that use clean steel and cement, subsidies for the purchase of fuel cell electric vehicles, and funding for a green bank. However, regulations, incentives or standards for lower carbon-intensity products are required to create long-term demand for clean hydrogen.

The DOE has recently addressed the demand issue. In May 2023, the DOE launched the Clean Fuels & Products Shot[16] to develop sustainable feedstocks and conversion technologies necessary to produce crucial clean fuels, materials, and carbon-based products. The Clean Fuels & Products Shot aims to meet projected 2050 net-zero emissions demands for 100% of aviation fuel; 50% of maritime, rail, and off-road fuel; and 50% of carbon-based chemicals by using sustainable carbon resources.

The US is grasping a leading position in electrolyzer manufacturing capacity

Low-cost electrolyzers are essential for gaining hydrogen manufacturing competitiveness. China and Europe have been early adopters of this nascent clean energy technology. The US missed this early opportunity. But the IRA has been a pivotal point, generating more orders for electrolyzers from a wider range of customers. The IRA has attracted US and European electrolyzer manufacturers to invest in manufacturing plants in the US, so that China's and Europe's dominance is being challenged. According to Aurora Energy Research, California-based EvolOH now accounts for the largest share of projects planned to be operational by 2030, at 22%.[17]

Major US fuel cell markers, Bloom Energy and Plug Power, as well as manufacturers of power generation products, like Cummins, have expanded into electrolyzer manufacturing, making use of their expertise in the manufacturing of several common components. In November 2022, Bloom

15. "Alternative Fuels Data Center: Fuel Properties Comparison", Department of Energy, Clean cities US department for Energy, 2021, available at: www.energy.gov.
16. "DOE Launches New Energy Earthshot to Decarbonize Transportation and Industrial Sectors", Department of Energy, 2023, available at: www.afdc.energy.gov.
17. "Global hydrogen pipeline surpasses 1 TW as European dominance challenged", Aurora Energy Research, 2023, available at: www.auroraer.com.

Energy became the world's largest electrolyzer maker (at that time), after inaugurating a new 1-GW production line at its plant in Newark, Delaware, bringing its manufacturing capacity to 2-GW/y. Cummins is building its first US proton exchange membrane (PEM) electrolyzer manufacturing plant in Fridley, Minnesota. The production will begin at 500-MW capacity and could scale up to 1 GW, while Plug Power launched a gigafactory in Rochester, New York, in 2021 (500 MW of PEM stacks for fuel cells and electrolyzers). Once fully online, the gigafactory will have a production capacity of over 2.5 GW/y.

Attracted by the IRA tax credits, European manufacturers are investing in the US. Among recent announcements, Danish electrolyzer manufacturer Topsoe plans to spend $300 million on a new factory of 500 MW to produce solid-oxide electrolyzers in the US—with the potential to eventually scale it up to 5 GW/y (FID expected by end 2023). Norwegian Nel has announced its plans to build a new gigawatt electrolyzer manufacturing facility in Michigan. When fully developed (4 GW/y of alkaline and PEM electrolyzers), the facility will be among the largest plants in the world. Norwegian manufacturer HydrogenPro will build 500-MW high-pressure alkaline electrolyzers annually at a new factory in Texas that could later be scaled up to several gigawatts.

US start-ups are also developing new technologies/concepts to produce innovative and low-cost electrolyzers. EvolOH has announced a new facility to open in 2025 in Massachusetts, consisting of a single production line of 3.75-GW/y to produce anion-exchange membrane electrolyzers. EvolOH said that it would be a quarter the cost and size of a comparable PEM or alkaline electrolyzer plant. EvolOH will add three identical production lines, raising the total annual capacity to 15 GW after 2026. Electric Hydrogen (EH2) will start building 100-MW electrolyzers–so far the world's largest–at a new 1.2-GW/y gigafactory in Massachusetts. Wisconsin-based Advanced Ionics has developed an electrolyzer, which requires only 35 kWh/kgH2 of electricity. Los Angeles-based start-up H2U Technologies has demonstrated a new PEM electrolyzer stack that replaces the standard iridium catalyst with "inexpensive and abundant catalyst materials".[18] The development of alternative catalysts is significant as highly constrained sources of platinum group metal materials, such as iridium, a mainstay PEM electrolyzer catalyst, could lead to supply chain shortages and price increases.

18. "Cheaper hydrogen? | US start-up demonstrates iridium-free PEM stack that will 'nearly halve' cost of electrolysers", Hydrogen Insight, 2023, available at: www.hydrogeninsight.com.

A leading exporter of clean ammonia on the horizon

Hydrogen trade is at a nascent stage but could see huge growth this decade. The International Energy Agency estimates that by 2030, more than 12 MtH_2/y of clean hydrogen (and its derivatives, such as clean ammonia) will be exported.[19] And the export market is expected to grow rapidly in the coming decades. The Hydrogen Council assesses international trade at about 190 MtH_2/y by 2050.[20] However, challenges involving transportation and cost still need to be addressed.

With its unique assets to produce clean hydrogen from an array of national energy resources, its low energy prices relative to other regions, its strong and innovative technology capability, its hydrogen hubs and ports in coastal states, its world-class geological means to store CO_2, and its strong policy support to clean hydrogen, the US is well positioned to become a leading exporting country of clean hydrogen and its derivatives. The NCHSR sets a long-term goal (from 2030) to establish US leadership in the global energy transition by exporting clean hydrogen and enabling energy security for US allies. But the strategy does not give a specific target for hydrogen trade.

The US could start exporting clean hydrogen in the form of ammonia already in 2027 and could become one of the largest exporters by 2030. Several project promoters have announced clean ammonia projects, targeting domestic and export markets. The US Gulf Coast, which holds key assets to become a global clean hydrogen exporter, leads announced projects. While the initial exports are looking to be blue ammonia because of the abundant access to natural gas, green ammonia exports are also contemplated by project promoters. This would give the US the ability to serve different markets with different low-carbon intensity requirements. Exports of green and blue methanol, e-fuels and blue hydrogen (at LNG export terminals) are also considered by project promoters.

Europe and Japan/greater Asia are the main targeted markets. Several US-based corporations have signed memoranda of understanding with potential importers (such as JERA, Mitsubishi, Mitsui, Lotte Fine Chemical, Uniper, RWE, Port of Rotterdam). For instance, Yara International and CF

19. "Global Hydrogen Review 2022", *IEA Analysis*, International Energy Agency, 2022, available at: www.iea.org.
20. "Global Hydrogen Flows", Hydrogen Council, October 2022, available at: www.hydrogencouncil.com.

Industries were selected by JERA in its tenders seeking to import up to 500,000 t/y of clean ammonia from long-term contracts starting in the fiscal year 2027-2028. Both companies are considering separately to develop blue ammonia facilities in the US Gulf Coast. CF Industries, together with Mitsui, has commenced a Front End Engineering Design study to construct a greenfield blue ammonia facility in Ascension Parish, Louisiana (0.8-1 mt/y in 2027). Similarly, Yara and Enbridge have signed a letter of intent for the joint development of a blue ammonia production facility (1.2-1.4 mt/y in 2027/2028) in Corpus Christi, Texas. JERA and ConocoPhillips have plans to build a 2 mt/y clean ammonia plant in the US Gulf Coast, with expansion potential up to 8 mt/y. Europe is the primary initial export market, with Uniper targeting about 1 mt/y of green ammonia by the end of the decade. RWE, Lotte Chemical and Mitsubishi are working together to develop a large-scale clean ammonia production and export project in the Port of Corpus Christi, exporting to both Europe and Asia. Chevron and Uniper together with Air Liquide and LyondellBasell have also plans for clean ammonia facilities in the US Gulf Coast, while OCI NV has started construction of a 1.1 mt/y blue ammonia facility in Beaumont, Texas, and Canada's Nutrient has announced plans for a $2 billion, 1.2 mt/y blue ammonia production facility in Geismar, Louisiana.

Conclusion & Perspectives

The IRA is a landmark in advancing the US clean hydrogen economy and the decarbonization of hard-to-electrify sectors. The sizeable government support will accelerate the deployment of clean hydrogen allowing significant cost reductions through scale, learning, and innovation. This should advance the clean hydrogen cost gap by several years. Although uncertainties remain regarding the implementation rules of the 45V tax credits, the US is poised to become one the most–if not the most–lucrative market for the nascent clean hydrogen industry.

While the IRA will undoubtedly accelerate the ongoing transition to a net-zero US economy, it entails a string of protectionist measures that–though aiming mainly at China–might hurt other regions. This has stirred criticism in Europe and elsewhere (e.g. regarding electric vehicle battery production).[21] Also, the sheer scale and nature of the clean hydrogen PTC have raised concerns in other regions about the distortion of competition these incentives might cause in the global hydrogen industry and supply chains. In this context, the implementation of IRA provisions will be crucial to US and global clean hydrogen development, and the IRS guidance rules are scrutinized with great attention around the world. One of the issues is that the IRA does not place a cap on the amount of clean hydrogen production subsidies.[22] The European Commission (EC) and the US are tackling these issues through a dedicated US-EU Task Force. They recently launched the Clean Energy Incentives Dialogue to coordinate their respective incentive programs so that they are mutually reinforcing.[23] Both the US and the EU want to jump-start domestic green hydrogen production to reduce emissions. With the war in Ukraine and China's rise as a global competitor, the US and the EU have more incentives than ever to cooperate and deepen their partnership, particularly in the green hydrogen market where they have complementary strengths.

The IRA's clean hydrogen incentives have pushed other regions to respond with new measures to maintain competitiveness and not be left behind.

---

21. "Submission by the European Union on the Inflation Reduction Act", Internal Revenue Service, 2022, available at: www.regulation.gov; "No End in Sight: US and EU Continue Negotiations on Clean Car Deal", Electric Dive, 2023, available at: www.electrive.com.
22. The budget of $13.2 billion over 10 years estimated by the US Congressional Budget Office (CBO) for the clean hydrogen production subsidies is subject to considerable uncertainty.
23. "Joint Statement by President Biden and President von der Leyen | The White House", The White House, 2023, available at: www.whitehouse.gov.

In Europe, as part of the broader Net Zero Industry Act, proposed by the EC to increase EU industrial competitiveness,[24] the EC has launched the European Hydrogen Bank (EHB) to accelerate investment in renewable hydrogen by covering and lowering the cost gap between renewable hydrogen and fossil fuels for early projects.[25] Through the EHB, the EC is creating an auction facility for renewable hydrogen production that will award a subsidy to hydrogen producers in the form of a fixed premium per kg of hydrogen produced over ten years. A first pilot auction will be launched in fall 2023, backed by €800 million from the Innovation Fund.[26] It is expected that support for hydrogen production in the form of competitive auctions will become a permanent feature of the European market, in addition to other funding, such as the Important Projects of Common European Interest. Experience of auctions for renewable generation shows that they can contribute significantly to a rapid decline in the cost of supported technologies. Despite this positive development, challenges remain, including the need for substantial additional funding to accelerate the growth of EU green hydrogen production and the availability of such funds at the EU level.

In Canada, the federal government has announced new clean hydrogen incentives to accelerate Canada's competitiveness as a hydrogen-producing and exporting region.[27] The new incentives mirror those in the US. Canada has introduced an ITC of up to 40% for hydrogen production–based on the life cycle carbon intensity of the hydrogen produced and labor requirements, a 30% ITC for clean electricity generation systems, a 50% ITC for CCUS applicable to CCS equipment and a 30% ITC for clean technology manufacturing and processing. The majority of these credits are phased out by 2035. These incentives will complement Canada's existing carbon pricing and credit systems. Canada's recently introduced 2023 budget (A Made-In-Canada Plan) includes CAD17.7 billion ($12.6 billion) funding for the clean hydrogen ITC between 2023 and 2035.

Australia is also to revise its 2019 National Hydrogen Strategy in light of the IRA's introduction and will give more support to renewable energy investors to maximize the benefits of their investments, notably through the National Reconstruction Fund.[28]

24. "Net-Zero Industry Ac », European Commission, 2023, available at: www.europa.eu.
25. "Commission Outlines European Hydrogen Bank to Boost Renewable Hydrogen", European Commission, 2023, available at: www.europa.eu.
26. "More generous than US | Green hydrogen could fetch a 'fixed premium' subsidy of up to €4/kg in EU's first competitive auction", Hydrogen Insights, April 2023, available at: www.hydrogeninsight.com.
27. "News release: 2023 Federal Budget ushers in new era for Canadian renewables", Canadian Renewable Energy Association, 2023, available at: www.renewablesassociation.ca.
28. "Australia's National Reconstruction Fund to help renewables, hydrogen | S&P Global Commodity Insights 2023)", S&P Global Commodity Insights, available at: www.spglobal.com.

Given the early stages of the clean hydrogen technology, governments play a crucial role in supporting the growth of the sector. The main lesson from the US is that simple, predictable, and favorable policies, including sizeable incentives for early projects, no over-regulation and a business-minded approach are required to encourage investments and create a conducive environment for the expansion of the green hydrogen industry. Finally, any scheme needs to ensure that competition is not distorted, and that fair trade is not undermined. International cooperation and partnerships will be critical for advancing green hydrogen and its decarbonization potential.

french
institute
of international
relations

since
1979

27 rue de la Procession 75740 Paris Cedex 15 – France

Ifri.org