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# US Hydrogen Policy

## Paving the Way for Energy Independence, Technology Leadership and Decarbonization

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# Summary

The U.S. is a leading actor in today's hydrogen economy and possesses significant geo-economic potential to lead in the global clean hydrogen economy. The U.S. hydrogen strategy has been shaped by the strive to balance a) energy independence b) the fight against climate change, and c) expanding technology leadership. The recent landmark legislative packages of the Bipartisan Infrastructure Law and the Inflation Reduction Act reflect these priorities and include large-scale investments and financial incentives to promote the supply of clean hydrogen at lower costs, to strengthen innovation, and domestic value chains. The U.S. has been pioneering policy instruments for scaling up domestic clean hydrogen production and use cases across multiple sectors, which raised significant interest among policymakers and industrial actors worldwide.

The international dimension of the U.S. hydrogen strategy has received much less attention in the U.S. policy debate and is less defined. This is apparent in comparison with other actors, such as a much more outward-oriented European Union, which reached out to numerous countries as potential trading partners for much-needed hydrogen imports. In contrast, the United States currently focuses much more on building up domestic hydrogen value chains, enabled by a favorable resource endowment. Nevertheless, the U.S. has fostered bilateral partnerships on hydrogen and strengthened its hydrogen-related engagement in international organizations and multilateral initiatives in the past five years. Emerging priorities for the United States' international collaboration on hydrogen include international demand creation and management, upscaling investments, international research collaborations, and joint efforts on regulation, standards, and certification. These efforts can be seen as the first steps towards the U.S. long-term goal to export hydrogen and related technologies to regional and global partners from the 2030s onwards.

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Federal Foreign Office

# Contents

# 1. Introduction

The United States (U.S.) is the second largest producer of hydrogen today, after China. The U.S. possesses significant geo-economic potential to lead in the global clean hydrogen economy. The U.S. benefits from vast resources for green hydrogen production, namely a high potential for renewable energy generation especially in the coastal areas but also sufficient freshwater resources. Additionally, related economic activities led to high technological capacity and a skilled labor force, which might foster innovation and enable technological leadership (Eicke & De Blasio, 2022). Furthermore, the U.S. has been pioneering policy instruments for scaling up domestic clean hydrogen production and use cases across multiple sectors, which raised significant interest among policymakers and industrial actors worldwide.

Hydrogen has been promoted by Democratic and Republican administrations alike - in contrast to the strong shifts in climate policy throughout the past years, with President Obama signing the Paris Agreement, President Trump leaving and President Biden rejoining the international agreement. This continuity in support for the clean hydrogen economy benefited from differing political agendas and policy objectives that nevertheless aligned with the same goal. Relevant drivers include, among others a) energy independence b) the fight against climate change, and c) enhancing economic leadership based on export-oriented industrial competitiveness and innovation.

This report provides an overview of the policy landscape and its drivers, focusing particular attention on its external dimension. It elucidates how competing policy objectives have been guiding the U.S. hydrogen strategy. The report summarizes key domestic policy instruments to achieve these policy objectives. Building on this, it then assesses how foreign policies and international initiatives relate to these policy objectives and how the US positions itself in relation to other world regions regarding hydrogen trade and technological development. This review is based on publicly available U.S. hydrogen strategy and policy documents as well as interviews with stakeholders involved in the implementation of the United States' hydrogen strategy.

The review is structured as follows. The next section analyzes the role of hydrogen in the U.S. economy and the future potential for clean hydrogen production. The third section analyses the three overarching policy objectives guiding the U.S. hydrogen policy. The fourth section describes the regulatory landscape governing hydrogen in the United States. The fifth section assesses the most important policy instruments employed domestically, whereas the sixth section elucidates how the United States approaches hydrogen-related foreign policy. The seventh section concludes.

# 2. The role of hydrogen in the U.S. economy

The U.S. is a leading actor in today's hydrogen economy. According to the Hydrogen Council, the U.S. had an installed hydrogen production capacity of around 10 million metric tons per year in 2021, only surpassed by China (Department of Energy, 2023d). Over 95% of hydrogen produced in the U.S. is labeled as "grey"; it is produced through steam methane reformation of natural gas. However, the number of projects producing green hydrogen, by splitting water molecules into hydrogen and oxygen using renewable electricity, has been increasing recently; over the past five years, 11 projects became operational and 13 more are currently under construction across the country, mostly in coastal areas (see Figure 1) (IEA, 2023a).

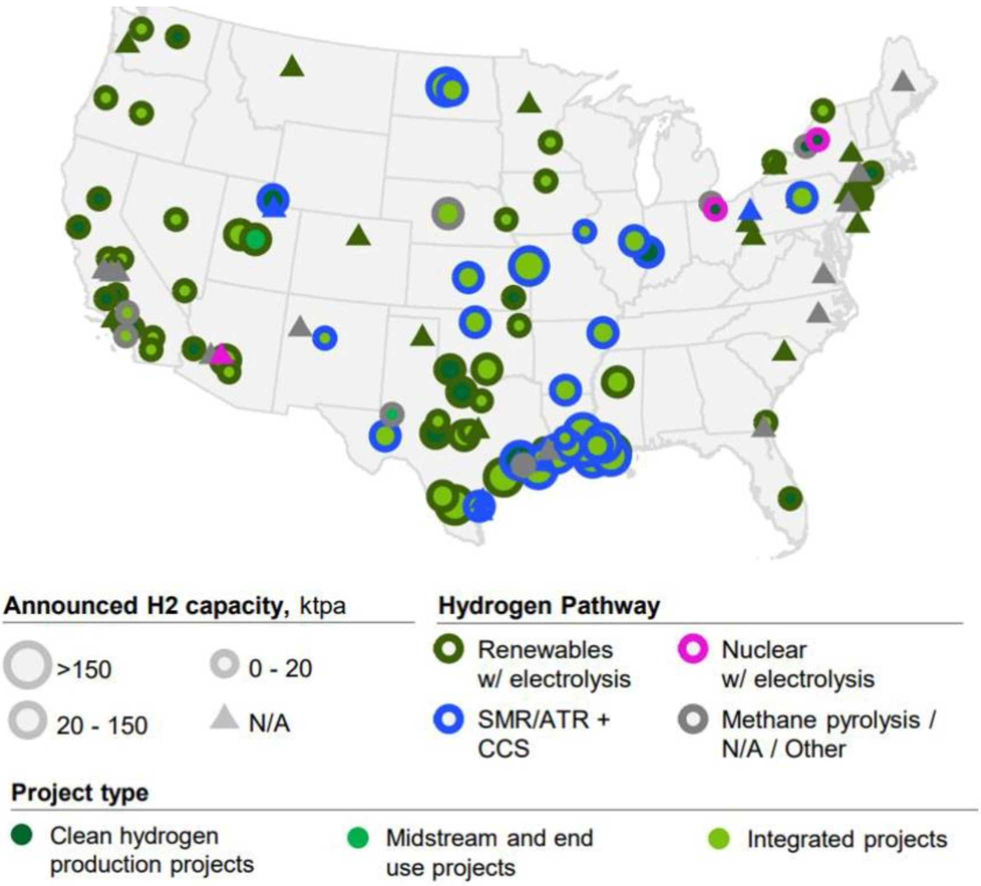


Figure 1: Currently publicly announced clean hydrogen production projects as of EOY 2022, with a total production potential of 12MMT/year (Department of Energy, 2023d)

The U.S. aims at scaling up the production of hydrogen based on various production processes. This includes green hydrogen (produced with renewable energy), blue hydrogen (produced from natural gas using carbon capture and storage), pink hydrogen (produced based on nuclear energy), and white hydrogen (based on energy from waste). Most policy documents refer to clean hydrogen, which can include all the above-mentioned sources.

For now, hydrogen is primarily used in industrial processes including petroleum refining, petrochemical manufacturing, glass purification, and fertilizer production. Furthermore, hydrogen is used in combination with fuel cells to power 16,000 cars, around 60,000 forklifts, and 80-150 buses and as storage for backup power, e.g. for telecommunications (Department of Energy, 2023d). The U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office estimates that hydrogen consumption in the U.S. is expected to grow from about 8 million metric tons per year in 2020 to around 20 million metric tons per year by 2040 and 50 million metric tons by 2050 (Department of Energy, 2023d).

According to the U.S. Department of Energy, the U.S. has the potential to produce over 50 million tons of clean hydrogen per year by 2050 and set an interim target of 10 million tons by 2030. The renewable energy potential as well as freshwater resources are large enough to meet the internal energy demand and enable the production of green hydrogen at scale for export (Eicke & De Blasio, 2022; Pflugmann & De Blasio, 2020). In 2021, renewable energy sources provided 19% of the countries' electricity production (EIA, 2022); the current targets foresee a share of 80% carbon emission-free electricity generation by 2030 and 100% by 2035 (The White House, 2021a).

The U.S. long-term strategy includes a leadership role in the export of clean hydrogen (Department of Energy, 2023d). The export of hydrogen could be facilitated by existing infrastructure, including pipelines, ports, and storage facilities. More than half of the global hydrogen infrastructure is currently located in the U.S., with pipelines of more than 2.600 km in length and the largest volume of hydrogen storage capacity worldwide (IEA, 2019). The country also has a well-established natural gas export industry, which can presumably be leveraged for hydrogen export. The U.S. National Renewable Energy Laboratory (NREL) estimates that by 2050, the U.S. could produce and export up to 4 million metric tons of hydrogen per year, based on the assumption that 20% of renewable energy generation is directed towards hydrogen production. The National Clean Hydrogen Strategy and Roadmap plans concrete actions for hydrogen exports in the time frame of 2030 through 2035 (Department of Energy, 2023d). However, the first projects aiming for regional and global clean hydrogen exports are already being built in Louisiana (Department of Energy, 2023d).

# 3. Policy objectives guiding U.S. hydrogen policy

U.S. hydrogen policy has been guided by three overarching policy objectives throughout the past decade: energy independence, the fight against climate change, and the promotion of industrial leadership. The quest for energy independence has represented a central pillar of U.S. energy policy since the first oil crisis in 1973. To reduce energy dependency, the U.S. started promoting renewable energy sources. In this context, the idea of a 'hydrogen economy' first received political support under Democratic President Carter (Piria et al., 2021). Green hydrogen was seen as an important piece in this endeavor because it can serve as a flexible source of power to compensate for fluctuations in renewable generation. In addition, it can be used as backup power for critical facilities, stationary power in remote areas, or medium and long-duration power storage. In the early 2000s, Republican President George W. Bush further supported R&D on hydrogen solutions in the mobility sector as a strategy to reduce oil imports (Romm, 2004). However, the U.S. quest for energy independence led to less pressure to act in subsequent years as the shale gas revolution led to a strong decline in oil and gas prices and turned the U.S. from an energy importer to a net exporter of energy in 2019 (Piria et al., 2021).

Climate policy has represented a second driver of the ambitious hydrogen policy. The interest in hydrogen renewed with the urge to address climate change when Democratic President Obama signed the Paris Agreement in 2016. The U.S. has pledged to reduce its carbon emissions by 50 - 52% relative to 2005 in its Nationally Determined Contribution to the UNFCCC (The United States of America, 2021). The DoE estimates that increasing the US clean hydrogen production and utilization by 500% by 2050 could reduce the country's total GHG emissions by approximately 10 percent relative to 2005 levels (Department of Energy, 2023d).

The promotion of industrial leadership is a third driver of hydrogen support policies. The presidency of the Republican Trump resulted in a backlash against policies aimed at the decarbonization of the U.S. economy. The federal programs on the hydrogen economy were continued but realigned with Trump's vision to 'make America great again'. In this context, hydrogen has been framed as a new sector in which the United States can become leading in terms of technology development and energy exports (Department of Energy, 2020, 2023d). Accordingly, domestic hydrogen production was seen as an enabler to increase domestic manufacturing jobs (Department of Energy, 2023d).

Today, Joe Biden's hydrogen policy combines the three above-mentioned policy objectives. The U.S. rejoined the Paris Agreement in 2021 and returned the fight against climate change to its policy agenda. The government announced the decarbonization of the electricity sector by 2035 and aims for climate neutrality by 2050. In this context, the Biden Administration frames clean hydrogen as a key factor in enabling decarbonization goals (The White House, 2021a). In addition, the Biden Administration continues to push for clean hydrogen in the context of an industrial strategy to strengthen the U.S. as a clean technology exporter (The White House, 2021a). The strategic framing of hydrogen regulations to strengthen domestic manufacturing and local job creation has been key to passing investment packages such as the Inflation Reduction Act (IRA) (see section 5) (Jackson & Hellmich, 2022). This framing was seen as necessary to unify all Democrats in a situation in which the Biden Administration depended on a majority by one vote in the Senate before the Midterms in 2022. Additionally, President Biden depends on the support of labor unions, which have formed a strong alliance with climate advocates over the last decade (Jackson & Hellmich, 2022). These developments led to a strategic linking of policy objectives, promising that hydrogen can simultaneously serve the objectives of climate protection and economic competitiveness. Furthermore, the goals of industrial leadership and energy independence became increasingly interlinked. The rise of China as the primary supplier of many renewable energy technologies and the dependency on Chinese imports of critical raw materials has raised concerns among Democrats and Republicans alike. This “overreliance” on Chinese imports has increasingly been framed as a threat to national security (Jackson & Hellmich, 2022). Thus, strengthening domestic hydrogen technology supply chains is framed as a measure to enhance industrial leadership and independence from foreign suppliers (The White House, 2021a).

# 4. Governing hydrogen

Public and private actors have been collaborating to scale up hydrogen production and use in the United States. The Energy Policy Act of 2005 established the Department of Energy (DOE) as the federal lead agency for directing and integrating activities on hydrogen. Within DOE, the Hydrogen and Fuel Cell Technologies Office coordinates research and development activities and aligns the activities of the four relevant DOE offices (Office of Energy Efficiency and Renewable Energy, Office of Fossil Energy, Office of Nuclear Energy, and Office of Science). DOE also collaborates with stakeholders, including industry, academia, local and tribal communities, and civil society groups, on hydrogen regulation. This inclusive strategy aims to address potential environmental and social justice concerns (Department of Energy, 2023e).

State-level agencies have also taken the initiative to promote the development and use of hydrogen (in all states but in Kansas), mostly with a focus on promoting hydrogen in the mobility sector (Department of Energy, 2023c). California is the most progressive with more than 50 laws and incentives related to the use of hydrogen. It introduced a low carbon fuel standard to foster growth in the fuel cell electric vehicle market as well as incentives such as carbon credit allowances. An executive order requires all vehicles sold by 2035 to release zero emissions. Furthermore, the state provides funding for R&D, as well as the deployment of hydrogen fueling infrastructure.

The following section concentrates on the federal government's policy instruments to foster the development of a hydrogen economy. Table 1 provides an overview of federal legislative acts and policies that significantly guided and supported the production and use of hydrogen in the United States. In addition, several programs, plans, and roadmaps describe in more detail how policy instruments should contribute to the guiding visions for a U.S. hydrogen economy. The most relevant plans include the Hydrogen Posture Plan (published in 2006), the Hydrogen and Fuel Cells Program Plan (published in 2011), the Hydrogen Program Plan (2020), the Energy Earth Shots Initiative, which includes plans for the Hydrogen Shot (2021) and the National Clean Hydrogen Strategy and Roadmap (2023).

**Table 1. Key legislative acts and policies on hydrogen**

| Year | Policies and Acts | Description |
|---|---|---|
| 1992 | Energy Policy Act | The Act initiated an R&D program for fuel cells and related transportation system applications. |
| 2005 | Energy Policy Act | The Act set the basis for an R&D program on technologies related to hydrogen production, purification, distribution, storage, and use, focusing on fuel cells. |
| 2007 | Energy Independence and Security Act | The Act creates incentives for R&D on hydrogen production, storage, distribution, and utilization. |
| 2022 | Infrastructure Investment and Jobs Act | The Act is also known as the Bipartisan Infrastructure Law (BIL). The BIL comprises $62 billion of which $8 billion is dedicated to regional clean hydrogen hubs, $1 billion to a clean hydrogen electrolysis program, and $500 million to incentivize clean hydrogen manufacturing and recycling. |
| 2022 | Inflation Reduction Act (IRA) | The Inflation Reduction Act (IRA) is the single largest investment package to combat climate change in the history of the United States with an estimated volume of $369 billion and fosters the production of hydrogen via tax credits. |
| 2022 | Clean Hydrogen Production Standard (CHPS) | The draft CHPS gives guidance on hydrogen production standards and associated emission levels, in accordance with the BIL. |

The following section provides an overview of the policy instruments included in these legislative packages and described in the plans. The main focus of these instruments lies on measures to bring down the costs of clean hydrogen several policy instruments aim to leverage economies of scale in clean hydrogen production and to foster R&D and innovation. These measures are partly combined with policies strengthening domestic manufacturing capacity to localize clean hydrogen supply chains, which are described thereafter. Lastly, policy instruments focusing on the decarbonization of high-impact end uses are described.

## 3.1 Scaling up hydrogen production

The initiative H2@scale was launched by the Hydrogen and Fuel Cell Technologies Office in 2016 to enhance hydrogen cost reductions by promoting economies of scale (Department of Energy, 2023b). The initiative brings together diverse stakeholders and channels funding for projects advancing the scale-up of hydrogen production (Department of Energy, 2023b).

The Bipartisan Infrastructure Law (BIL) provides more than $7 billion in direct grant funding for scaling up hydrogen applications in seven regional clean hydrogen hubs across the country. These hubs aim to create synergies via the creation of networks between hydrogen producers, consumers, and local connective infrastructure, which might further facilitate information exchange and innovation (The White House, 2023a).

Additionally, the Inflation Reduction Act (IRA) is a landmark legislation providing approximately $369 billion to combat climate change. The IRA provides large-scale investment to foster the upscaling of clean hydrogen production in the United States. However, what is defined as clean hydrogen remains under discussion. Whilst the BIL defines clean hydrogen as hydrogen that has been produced with less than 2KgCO2e/kg H2 at the site of production, hydrogen with lifecycle emissions below 2KgCO2e/kg H2 is supported as "clean hydrogen" in the IRA. In September 2022, DOE released a draft for the Clean Hydrogen Production Standard (Department of Energy, 2022b). The Clean Hydrogen Production Standard is not a regulatory standard but is intended to guide (not necessarily determine) DOE's funding decisions. The draft proposes to define clean hydrogen as hydrogen produced with a carbon intensity equal to or less than 4 kg of carbon dioxide-equivalent emissions per kilogram of hydrogen during its lifecycle. According to this definition, all the above-introduced types of hydrogen would be considered "clean" (Department of Energy, 2022b) based on a comparison with the carbon intensity of today's predominantly used grey hydrogen of around 10kg CO2e/kg H2 (Yan et al., 2022). However, the support mechanisms in the IRA do not treat all clean hydrogen equally but provide increasing tax incentives with lower life cycle emissions (see Table 2). The U.S. Congress has entitled the U.S. Treasury Department to decide upon the detailed rules for accounting emissions from hydrogen production, which will be essential for determining the volume of granted tax credits under the IRA. Similar to EU-level regulation, requirements for the additionality of clean electricity, its deliverability, and time matching are planned to ensure actual emission reductions in comparison to grey hydrogen production, but are not yet finalized (Esposito et al., 2023).

**Table 2. IRA tax credits based on carbon emissions**

| Kg CO2/kg of hydrogen | Production tax credit per kg of H2 | Investment tax credit in % |
|---|---|---|
| < 0.45 | $3.00 | 30% |
| < 1.5 | $1.00 | 10% |
| < 2.5 | $0.75 | 7.5% |
| < 4.0 | $0.6 | 6% |

The IRA allows hydrogen producers in the United States to choose between a production tax credit (granting a fixed credit per kilogram of produced hydrogen) or an investment tax credit (granted for a fraction of their capital expenses). These tax credits are granted from 2023 through 2033 and can be combined with additional credits for renewable energy investments in the case of green hydrogen production and with additional credits for carbon sequestration for blue hydrogen (The White House, 2023b). Instead of pricing the emission of carbon-intensive energy, the subsidies reduce the price difference- between clean hydrogen and grey hydrogen. They are sufficient to achieve cost-competitiveness with grey hydrogen in current applications and are expected to make green hydrogen the lowest-cost hydrogen production type in the United States by 2025 (see Figure 2) (Nationaler Wasserstoffrat, 2022). Cost estimates suggest that clean hydrogen production in the United States will be among the most economically viable worldwide and might foster an industrial leadership role for the US in the sector (Nationaler Wasserstoffrat, 2022).

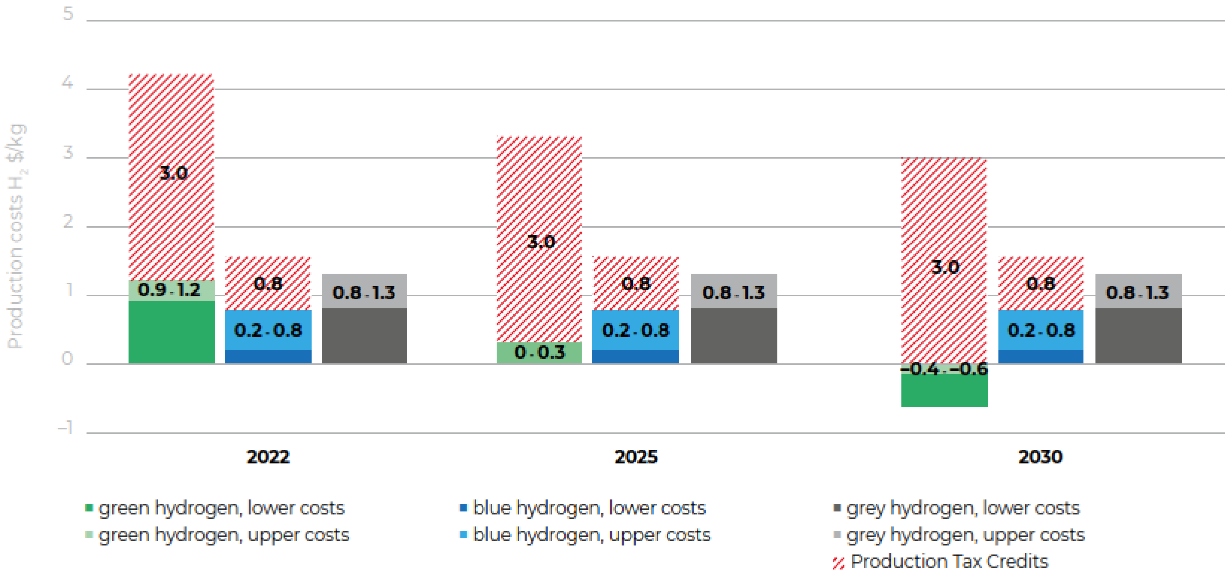


Figure 2. The IRA’s effect on hydrogen production costs (Nationaler Wasserstoffrat, 2022)

In comparison to these supply-side measures, measures targeting hydrogen use are still at a relatively early stage. A recent White House briefing note has acknowledged the need for further demand-side policies, given the low number of offtake contracts so far (The White House, 2023c). A recent notice of intent from the Department of Energy announces investments in additional measures of up to 1 billion USD to further stimulate demand for clean hydrogen through the Regional Hydrogen Hubs Program financed through the BIL (Department of Energy, 2023a). The DoE will decide upon demand-side policies and their design based on public input from diverse stakeholders, which is still being collected. Potential policies include “pay-for-delivery contracts, offtake backstops, feasibility funding to support analysis for off-takers” to increase revenue certainty for Hydrogen Hubs (Department of Energy, 2023a).

## 3.2 R&D and innovation

Hydrogen R&D is seen as a key enabler for further cost reductions along the supply chain. The Hydrogen Shot initiative aims to reduce the costs of clean hydrogen from currently $5 to $1 per kilogram in a decade (Department of Energy, 2021). Strategic R&D funding is supposed to lead to a global leadership role concerning technology development, e.g., via the funding of first-of-its-kind projects. Funding for hydrogen-related R&D is channeled via a consortium under the H2@scale initiative, which includes various stakeholders. The consortium aims to identify promising hydrogen applications by reviewing and comparing proposed approaches based on their technical and economic viability, scalability, and value. The consortium supports the development of promising early-stage hydrogen applications by leveraging funding based on partnerships with national labs and the provision of data from industry-led demonstrations. Furthermore, the consortium disseminates information on the progress of these projects (Department of Energy, 2023b).

## 3.3 Building domestic manufacturing capacity

Several policy instruments strengthen the buildup of local supply chains for hydrogen technologies. The IRA is expected to create more than 9 million jobs related to clean energy (Ellerbeck, 2023). To achieve this, it includes several forms of local content requirements. Whilst they are not directly linked to electrolyzers, there are still several local content provisions that can be relevant for clean hydrogen projects. These include provisions in the new "Advanced Manufacturing Production Credit", that refer to the domestic production and sale of qualifying solar, wind, inverter, and battery components that are relevant for green hydrogen production. The provisions set a minimum requirement of domestic content, e.g., 20% for offshore wind facilities or 50% for battery components. The required shares of domestic production increase over time. Exceptions are granted if the quantity or quality of local production does not suffice or would increase the total construction costs by more than 25%.

Another example is the provision of "bonus" tax credits: if a clean energy project uses 100% domestically manufactured iron and steel, it is granted a bonus of 10% on top of the original tax credit value. Furthermore, the IRA includes provisions to increase the domestic supply of critical minerals for battery components and electric vehicles but also proton exchange membrane (PEM) electrolyzers and PEM fuel cells (Klevstrand, 2022). One instrument is the exclusion of projects from tax credits if battery components or critical minerals are sourced from a "foreign entity of concern"[1] (The White House, 2023b). Due to the free trade agreement with Canada and Mexico, the local content requirements on hydrogen technologies in the IRA can, for example, also be met via production in these two neighboring countries (The White House, 2023b).

Furthermore, the BIL entails domestic content procurement guidelines for all federal infrastructure project funding, based on a provision named "Build America, Buy America" (BABA). Accordingly, all infrastructure projects receiving financial assistance are required to source domestically produced iron, steel, and construction materials (EPA, 2021). This might also be relevant for the build-up of hydrogen infrastructure. In turn, the BIL includes $500 million to support the buildup of local Clean Hydrogen equipment manufacturing and recycling (Department of Energy, 2023d). These provisions aim to create good-paying union jobs and target disadvantaged communities in particular (Department of Energy, 2023d).

## 3.4 Decarbonization of high-impact end-uses

The U.S. clean hydrogen strategy focuses on the decarbonization of high-impact end uses of hydrogen, foremost in industry, transport, and the power sector. Multiple initiatives focus on the decarbonization of the industrial sector. The Regional Clean Hydrogen Hubs Program is a key instrument of the BIL to create networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the decarbonization of heavy industries. Up to date, seven potential hubs have been selected for award negotiations for funding of up to $1 billion for each hydrogen hub. The pre-selected hydrogen hub projects are dispersed across multiple regions of the United States and target diverse high-impact end uses, including ammonia and fertilizer production, refineries, marine and aviation fuel production as well as glass and steel production (Department of Energy, 2023c).
Additionally, the DOE's Advanced Manufacturing Office and Hydrogen and Fuel Cell Technologies Office have organized several stakeholder workshops to identify key challenges and opportunities for the decarbonization of the steel sector. To jumpstart the use of hydrogen in steel production, the DOE initiated two projects that optimize the use of clean hydrogen to produce 5,000 tons of steel per day. Targeting the chemical sector, the DOE supported the analysis of cost and life cycle emissions for hydrogen derivatives, including methanol, ammonia, and methylcyclohexane. Furthermore, it provides funding for innovation in ammonia production, e.g. based on modular, scalable solutions (Department of Energy, 2023d).

[1] The exact definition of a foreign entity of concern is still under discussion. The latest proposal **(**March 21st, 2023) from the US Department of Commerce would deem **any entity—including a U.S. based or incorporated entity—of which a Chinese person/company directly or indirectly holds at least a 25% voting interest a foreign entity of concern; it might further refer to** entities that are "owned by, controlled by, or subject to the jurisdiction of North Korea, Russia, and Iran (Lovells & LaFianza, 2023).

**Transport**. To reduce emissions in the transport sector, the DOE and other federal agencies collaborate with industry and academia through the 21st-century Truck Partnership. The partnership fosters exchange among stakeholders. Furthermore, the DOE initiated the Million Mile Fuel Cell Truck Consortium (M2FCT) in 2020, which also brings together partners from industry and academia, with a focus on the durability and costs of fuel cells for the decarbonization of long-haul heavy-duty trucks. Additionally, the Super Truck Program focuses on demonstration projects under real-world operating conditions. Furthermore, the DOE and the Federal Transit Administration jointly support fuel cell buses by collecting and evaluating deployment data to strategically identify transport corridors in the United States to guide infrastructure development of fueling stations and storage. To fully decarbonize aviation fuel demand by 2050, medium- and long-term goals for the hydrogen demand in the sector are set to facilitate planning and strategic investment for private actors. In collaboration with an industrial partner and the U.S. DRIVE partnership, a Net Zero Tech team compares and analyses the costs and emissions of different technology pathways to identify high-potential fuels among different biofuel and power-to-liquid fuels. Additionally, the DOE initiates stakeholder workshops to identify key challenges and potential solutions. Furthermore, the DOE supports demonstration projects exploring the direct use of hydrogen in uncrewed aerial vehicles (Department of Energy, 2023d).

**Power sector**. Hydrogen applications in the power sector are meant to ensure a secure and stable supply of energy and are funded via the Regional Clean Hydrogen Hubs Program (Department of Energy, 2023c). Furthermore, DOE is funding RDD&D and actively collaborates with industrial partners to quantify the economic benefits that hydrogen storage might provide under specific grid conditions given high shares of renewable energy sources. To this end, DOE has established test facilities in national laboratories to demonstrate the integration of electrolyzers in the power grid with electric and thermal sources as well as nuclear power plants to support grid stability. Another instrument is the provision of loan guarantees for first-of-its-kind hydrogen applications, such as a clean hydrogen production and storage facility which might provide long-term seasonal energy storage in a salt cavern in Utah. Such pilot schemes aim at de-risking technological development to facilitate additional private sector investment and to foster the commercialization and market adoption of new hydrogen applications. Furthermore, DOE funded the deployment of hundreds of fuel cell applications as backup power (Department of Energy, 2023d).

# 4. International cooperation on hydrogen

Besides the promotion of domestic clean hydrogen production, the U.S. engages in bilateral and multilateral cooperation on hydrogen. However, the international dimension of the U.S. hydrogen strategy has received much less attention in the policy debate and is therefore less defined. Accordingly, the national roadmap for hydrogen-related actions includes no references to international actions in the near future until 2026. Whilst the United States aims to export hydrogen and related technologies to regional and global partners, this vision is defined as a long-term goal (Department of Energy, 2023d). Thus, the national roadmap includes more references to international actions in later periods. The U.S. plans to focus more on the international harmonization of codes and standards related to hydrogen technologies in the period between 2026 and 2029. The development of market structures and regulatory guidance for clean hydrogen exports is foreseen for the period between 2030 and 2035 (Department of Energy, 2023d).

Emerging priorities for the United States' international collaboration on hydrogen are outlined in the draft for the national clean hydrogen strategy (Department of Energy, 2020). The priorities include a) demand creation and management, b) finance and investment, c) research and innovation, and d) regulation, standard, and certification. The following section provides an overview of hydrogen-related U.S. foreign policy activities concerning these priority areas.

## 4.1 Demand creation and management

The United States aims to strengthen the coordination with other countries and private actors to increase the scale and visibility of hydrogen demand signals. Ensuring off-takers for potential hydrogen exports is important for infrastructure investments, building investor confidence, and avoiding supply chain risks and stranded assets.

So far, the United States has collaborated with partners in several world regions on hydrogen demand creation and management. All bilateral partnerships focusing on hydrogen-related collaboration cover foreseen activities related to scaling up hydrogen deployment and related infrastructure. Partnering countries include future hydrogen importers, such as Germany or Japan as well as potential future hydrogen export competitors, such as Australia, Saudi Arabia, or the United Arab Emirates. The partner countries are all high- or middle-income countries. Table 2 delivers an overview of partner countries, formats, and joint hydrogen-related activities (see Table 2).

Furthermore, the US engages in multilateral initiatives engaging in demand creation and management. The closest collaboration exists within North America where the U.S. collaborates with Canada and Mexico to establish a joint hydrogen market. The United States-Mexico-Canada Agreement (USMCA) includes provisions related to the cross-border trade of hydrogen and hydrogen-related technologies. The strong existing trade relations have enabled Canada and Mexico to benefit from U.S. policy instruments for establishing economic leadership. As mentioned above, the local content requirements on hydrogen technologies in the IRA can also be met via production in these two neighboring countries (The White House, 2023b).
The U.S. collaborates with the EU Commission on accelerating the deployment of clean hydrogen in a joint task force on energy security, which includes dialogue on scaling up the production of clean

hydrogen (The White House, 2022h). Moreover, energy trade between the U.S. and the EU has intensified since the Russian war in Ukraine started in 2022. Newly built infrastructure for additional LNG imports from the United States is meant to be adjustable for future clean hydrogen imports (EU Commission, 2022b).

However, several policy measures to increase hydrogen demand while strengthening local industries have created tensions between both regions. To reduce the economic disadvantage of more expensive clean hydrogen-based industrial production compared to fossil-based production, the EU employs carbon pricing. To guarantee a level playing field between European industries and their international competitors, the EU will apply import taxes based on carbon content (CBAM). In turn, the U.S. focuses on tax credits for clean production within the country, which are often paired with local content requirements, for example in the IRA. Both measures are criticized as harmful to free trade and fair competition and might result in conflicts within the WTO (Jackson & Hellmich, 2022).To ease these tensions, the EU-U.S. Task Force on the Inflation Reduction Act was launched in October 2022. The task force addresses concerns on both sides; the first success of these negotiations has been granting access to IRA subsidies for commercial clean vehicles for EU companies (EU Commission, 2022a). Despite differences, there has been a recent convergence between EU and U.S. policy approaches. the production subsidies included in the U.S. IRA have been an important driver for the EU Net Zero Industry Act, whilst E.U. approaches, such as auctions launched by the European Hydrogen Bank, have inspired the U.S. to advance demand side support policies (The White House, 2023c).

## 4.2 Finance and investment

The scope of investments in clean hydrogen is too small in relation to the needs for a global hydrogen economy, especially in developing countries. The United States aims to increase international coordination and visibility to scale up investments in hydrogen worldwide.

The U.S. bilaterally partners with several countries on scaling up investments in hydrogen worldwide (see Table 2). In a joint "Strategic Clean Energy Partnership" with India, the U.S. works on leveraging investments in clean energies and clean hydrogen in particular (Office of International Affairs, 2022b). The "Partnership for Accelerating Clean Energy (PACE)" with the United Arab Emirates aims to mobilize $100 billion in investments and other support to deploy 100GW of clean energy worldwide, of which parts are foreseen to finance hydrogen production (The White House, 2022g).

Additionally, the United States provides foreign aid and investment to other countries to support the development of hydrogen projects and associated infrastructure. Several initiatives focus on Africa. The programs "U.S-Africa Partnership in Supporting Conservation", "Climate Adaptation", and "Just Energy Transition" foster investments in the deployment of hydrogen in African countries (The White House, 2022d). The "U.S.-Africa Clean Energy Finance initiative" aims at mobilizing private sector investment in clean energy projects in Africa, including hydrogen projects. The "Global Partnership for Climate-Smart Infrastructure" supports the development of hydrogen projects in emerging economies. It provides funding for feasibility studies and other project-planning activities (USTDA, 2021). While these activities are a contribution to energy security worldwide, they are also part of an export-oriented strategy aimed at enhancing economic leadership in global hydrogen markets. Accordingly, the Global Partnership for Climate-Smart Infrastructure also identifies market opportunities for U.S. companies by facilitating the deployment of transformative U.S.-made technologies and services in partner countries (USTDA, 2022). Consistently, the Export-Import Bank of the United States provides financing and insurance for U.S. companies exporting hydrogen and hydrogen-related technologies (EXIM, 2010).

## 4.3 Research and innovation

The United States aims to accelerate innovation in hydrogen technologies by strengthening international cooperation on research and development and including more countries in existing collaborative approaches. A focus of international R&D collaboration is diverse and scalable pilot and demonstration projects.

All its bilateral partnerships on hydrogen include initiatives to foster joint hydrogen-related R&D (see Table 2). The U.S. further cooperates on hydrogen-related R&D with its Northern American trading partners Canada and Mexico (Valero de Urquia, 2023).

Furthermore, the U.S. has been fostering international research and innovation projects in several multilateral forums. The U.S. acts as co-lead for the hydrogen initiatives under the auspices of both the Clean Energy Ministerial and Mission Innovation (Clean Energy Ministerial, 2023; Mission Innovation, 2023). Being a founding member of the International Energy Agency (IEA), the United States has engaged in collaborative hydrogen research and development since 1977 in a specialized Technology Collaboration Program (Hydrogen TCP). Current projects focus on underground hydrogen storage or conversion technologies. The United States has supported these joint research activities by holding the Chairmen position in the Executive Committee of the Hydrogen TCP from 1995 through 2002 and by hosting numerous Committee meetings (IEA, 2023b).

## 4.4 Regulation, standards, and certification

Internationally accepted and implemented standards and certification schemes are seen as essential enablers for international trade along hydrogen value chains. However, definitions of clean hydrogen currently vary internationally, concerning the emission thresholds and system boundaries considered in the calculation of emissions. The U.S. supports clean hydrogen, with lifecycle emissions of less than 4kgCO2e/Kg H2, including upstream methane emissions but not distribution to end users. The European Union's Renewable Energy Directive sets a lower lifecycle emission target of approximately 3.4 kgCO2e/kgH2 for clean hydrogen and  targets less than 3.0 kgCO2e/kgH2 under its Taxonomy Regulation on sustainable investment and also considers emissions from distribution to end users (Collins, 2023b; Department of Energy, 2022b), which makes an international comparison difficult. Therefore the U.S. aims to increase the coordination of existing workstreams across different countries and international initiatives on the topic, to identify and address potential challenges and to increase the inclusion of stakeholders.

Several bilateral hydrogen partnerships include workstreams on hydrogen regulation, standards and certification, including partnerships with Australia, Japan, and the Netherlands. The U.S. also works closely on this topic with Canada and Mexico, as joint regulation, standards, and certification are crucial for the foreseen North American hydrogen market. The U.S. works with the EU Commission on a joint methodology for tracking emissions embedded in carbon-intensive steel and aluminum products, which will be key to quantifying potential emission reductions due to clean hydrogen applications in the sector (EU Commission, 2021). Furthermore, the U.S. and the EU are currently negotiating a Global Arrangement on Sustainable Steel and Aluminum (GASSA) until 2024. The GASSA might rebuild trust after recent disputes about tariffs and build an equal level playing field for steel and aluminum producers on both sides of the Atlantic as they tackle timely challenges related to overcapacity and accelerate the decarbonization of these sectors, potentially also via the definition of shared standards (Office of the US Trade Representative, 2023).

Furthermore, the U.S. works on regulation, standards, and certification within the International Partnership for Hydrogen and Fuel Cells in the Economy" (IPHE). The United States has been a founding member of IPHE in 2003 and served as chair of the IPHE steering committee from 2003 through 2007 and from 2018 through 2021. Currently, the country serves as vice-chair of the steering committee and takes an active part in two working groups on Regulations, Codes, Standards, and Safety, and on Education and Outreach, as well as in the Hydrogen Production and Analysis (H2PA) task force, which is developing joint methods of lifecycle analysis for hydrogen production (Department of Energy, 2023d). As of 2023, the partnership has assembled 22 countries, including several European countries, Australia, Brazil, Canada, Chile, China, Costa Rica, India, Japan, Korea, Russia, and South Africa (IPHE, 2022).

**Table 3: U.S. partnerships and dialogues on hydrogen**

| Country | Year | Type of partnership and hydrogen-related activities |
|---|---|---|
| Australia | 2022 | The "Net-Zero Technology Acceleration Partnership" collaborates on clean hydrogen applications in heavy vehicles, in the mining sector, on certification, and CCUS. The U.S. "National Renewable Energy Laboratory" (NREL) partners with the Australian "Commonwealth Scientific, Research, and Industry Organization" (CSIRO) on hydrogen R&D (Department of Energy, 2022a). |
| Germany | 2021 | The "U.S.-Germany Energy Partnership" supports the development and deployment of clean energy technologies, including collaboration on scaling up the deployment of sustainable hydrogen (The White House, 2021b). |
| India | 2022 | The "Strategic Clean Energy Partnership" was launched in 2018; this partnership led to the creation of a joint public-private 'hydrogen taskforce' in 2022 to leverage clean energy investments and accelerate the deployment of hydrogen technologies (Office of International Affairs, 2022b). |
| Indonesia | 2022 | The U.S. and Indonesia have been collaborating in a strategic partnership since 2015. In 2022, the partnership was enhanced by new initiatives, covering collaboration on green hydrogen. Accordingly, the U.S. International Development Finance Corporation announced to invest in green hydrogen projects in Indonesia (The White House, 2022c). |
| Israel | 2022 | The U.S.-Israel "Strategic High-Level Dialogue on Technology" aims to establish a partnership on critical and emerging technologies, including joint R&D on clean and renewable hydrogen production, delivery, infrastructure, storage, fuel cells, and multiple ends uses as well as the support of the commercialization of hydrogen projects (The White House, 2022f). |
| Japan | 2022 | The U.S. and Japan created a "Climate Partnership" to foster clean hydrogen deployment for industrial decarbonization (The White House, 2022e). The joint "Clean Energy and Energy Security Initiative" (CEESI) focuses on energy supply with hydrogen and fosters innovation and marketization of related technologies, e.g. with joint safety standards (Office of International Affairs, 2022a; The White House, 2022a). |
| Netherlands | 2020 | The U.S. and the Netherlands collaborate on hydrogen R&D, the harmonization of safety codes, and standards in emerging areas like hydrogen and natural gas blending (Government of the Netherlands, 2020). |
| Saudi Arabia | 2022 | The "Bilateral Partnership Framework for Advancing Clean Energy" focuses, among others, on green hydrogen. The partnership aims to leverage public and private sector collaboration to enhance the deployment of green hydrogen and to accelerate R&D on innovative technologies (The White House, 2022b). |
| South Korea | 2021 | The U.S.-Korea "Energy Security Partnership" supports the development of clean energy technologies, including hydrogen; it fosters ministerial collaboration to support R&D on hydrogen storage (The White House, 2021c). |
| United Arab Emirates | 2022 | The U.S.-UAE "Partnership for Accelerating Clean Energy (PACE)" aims to mobilize investments to deploy clean energy worldwide. The joint work on hydrogen includes R&D on CCUS for blue hydrogen, and cooperation on nuclear energy for pink hydrogen production (The White House, 2022g). |

# 5. Conclusion

The U.S. is a leading actor in today's hydrogen economy. The U.S. hydrogen strategy aims to secure and expand this position in a global transition towards clean energy to prevent dangerous consequences of climate change. The U.S. has been pioneering hydrogen policy instruments which are driven by the strive for energy independence to meet the rising internal demand and to eventually export clean hydrogen in the next decade. A further key driver of US hydrogen has been to enhance economic leadership based on export-oriented industrial competitiveness and technology leadership via the promotion of R&D and localized supply chains. The recent landmark legislative packages BIL and IRA reflect these priorities and include large-scale investments and financial incentives to promote the supply of clean hydrogen at lower costs, to strengthen innovation, and domestic value chains. These policies are characterized by large scale investments to foster mission-oriented innovation (e.g. in the Hydrogen Shot Initiative) and share a strong focus on supply side instruments to scale up production of clean hydrogen. The focus on 'clean' instead of green hydrogen enables the support of certain types of blue hydrogen production despite the danger of creating path dependencies and carbon lock-in effects. The U.S. further aims to manifest this technological openness in international standards.

International policymakers and companies have observed these recent regulatory schemes closely, especially concerning the introduction of tax credits as subsidies for clean hydrogen production and their pairing with local content requirements to gain more independence from Chinese clean technology suppliers. Since the IRA was passed, several large European companies such as Enel, Volkswagen, BMW, NEL, and Freyr have announced their intentions to newly build or expand almost 20 clean energy manufacturing plants in the U.S. (Collins, 2023a; Wessner & Khemka, 2023). Partly in reaction to US developments, other governments have indicated that they plan to enhance subsidy schemes in their jurisdictions. For example, India has announced the development of its own subsidy schemes (Singh, 2023). Furthermore, the EU enhanced its Temporary Crisis and Transition Framework to allow for state aid and introduced subsidies in the form of carbon contracts for differences in green hydrogen in the Net Zero Industrial Act but despite these similarities generally focuses much more on demand side instruments, such as the introduction of mandatory minimum quota in certain industries (EU Commission, 2023). But whilst large economies such as China, the U.S. and EU have the capacities to compete for green leadership, most other countries will lack the resources to match the subsidy model put forward by the United States.

The international dimension of the U.S. hydrogen strategy has received much less attention in the U.S. policy debate and is therefore less defined. This is apparent in comparison with other actors, such as a much more outward-oriented European Union, which reached out to numerous countries as potential trading partners for much-needed hydrogen imports. In contrast, the United States currently focuses much more on building up domestic hydrogen value chains, enabled by a favorable resource endowment. Nevertheless, the U.S. has fostered bilateral partnerships on hydrogen and strengthened its hydrogen-related engagement in international organizations and multilateral initiatives in the past five years. Emerging priorities for the United States' international collaboration on hydrogen include international demand creation and management, upscaling investments, international research collaborations, and joint efforts on regulation, standards, and certification. These efforts can be seen as the first steps towards the U.S. long-term goal to export hydrogen and related technologies to regional and global partners from the 2030s onwards.

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The **Research Institute for Sustainability (RIFS)** conducts research with the aim of investigating, identifying, and advancing development pathways for transformation processes towards sustainability in Germany and abroad. The institute was founded in 2009 as the Institute for Advanced Sustainability Studies (IASS) and has been affiliated with the Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences under its new name since 1 January 2023 and is thus part of the Helmholtz Association. Its research approach is transdisciplinary, transformative, and co-creative. The Institute cooperates with partners in science, political and administrative institutions, the business community, and civil society to develop solutions for sustainability challenges that enjoy broad public support. Its central research topics include the energy transition, climate change and socio-technical transformations, as well as sustainable governance and participation. A strong network of national and international partners and a Fellow Programme supports the work of the Institute.

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