Global Hydrogen Policy and Regulatory Review

October 2022

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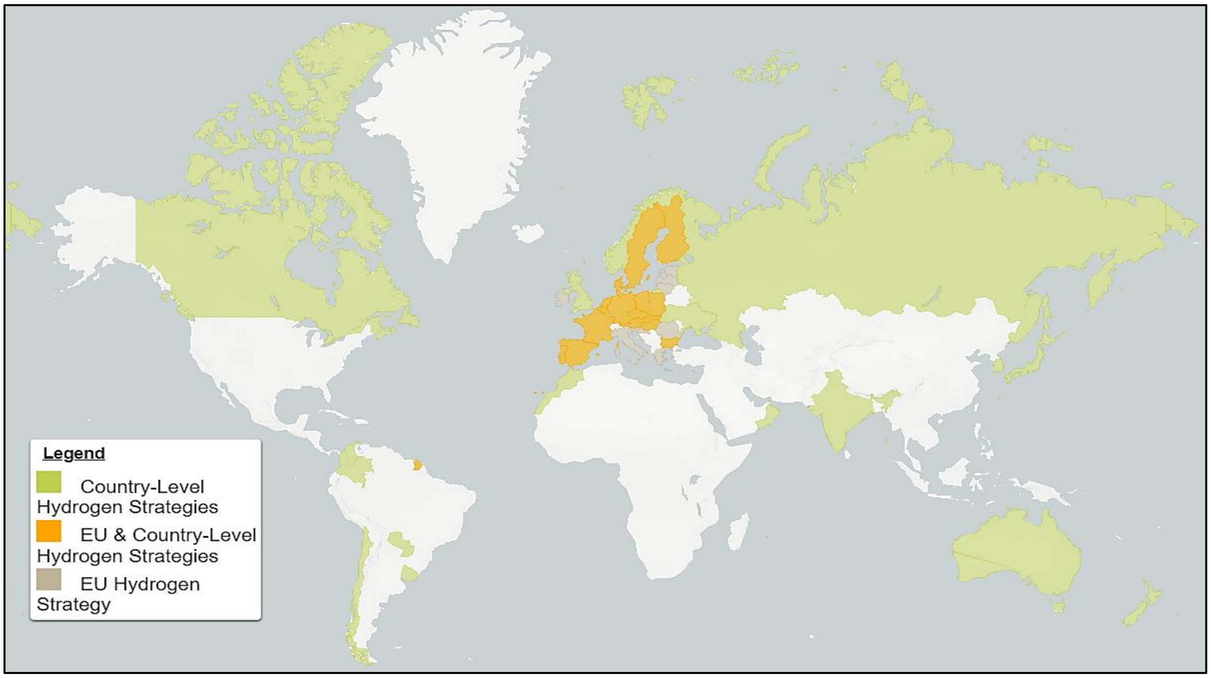
Introduction

As countries grapple with decarbonization commitments, more than 25 governments have released strategies for accelerating hydrogen market development through 2050 (see Appendix). These strategies include a variety of priorities, such as carbon intensity standards (See figure 1) for hydrogen production, durable supply chains, investment portfolios, policy incentives, workforce transition, international collaboration, gas standards, infrastructure, repurposing, and production targets. A key thread across most of the strategies is the need for consistency in regulatory and other policies to support the development of a global hydrogen market. Another important component of these strategies is acknowledging the need for alignment on what “clean” hydrogen production is,[1] a concept interpreted differently depending on the country or region.

Figure 1. *More than 25 governments have determined a strategy for hydrogen according to IEA and many of those governments are within the European Union (EU), which has its own hydrogen strategy*



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[1] The Department of Energy (DOE) defines clean hydrogen as having a carbon intensity of 2 kg or less of carbon-dioxide equivalent (CO_2e) produced at the site of production per kg of hydrogen produced. However, the recently signed Inflation Reduction Act of 2022 (IRA) provides tax incentives for clean hydrogen production to projects with less than 4 kg CO_2e/1 kg H_2 lifecycle emissions, which includes scope 1 and 2 emissions.

In addition to the over 25 countries that have announced hydrogen goals, there are at least 20 additional governments with plans to release formal strategies in the next two years. As more countries gain interest in hydrogen as an energy commodity, establishing a rule-based market system that leverages the unique policy levers of different countries will be paramount for driving down costs and fostering international trade.

The Middle East and North Africa (MENA) region has several ongoing hydrogen projects but, like many other countries, has no guiding regulatory framework. The global need for deep decarbonization, an abundance of renewable energy capacity, and strategic geography offers an important opportunity to diversify away from oil and gas exports. There is a further opportunity to build a regional clean hydrogen economy and create a new export market as regional and global hydrogen demand grows.

The MENA region is well positioned to develop hydrogen markets for both green and blue hydrogen by utilizing natural gas reserves, deploying renewables, and leveraging existing knowledge of energy export markets.[i] OPEC Member Countries in MENA together have around 80 trillion cubic meters of proven gas reserves, which represents about 43 percent of global totals.[ii] Additionally, MENA is geographically well positioned to deploy renewables at scale, which could be used to produce green hydrogen via electrolysis of water. Both blue and green hydrogen, have a role to play in the low-carbon hydrogen economy of the future. MENA countries can leverage both production pathways to deliver clean hydrogen to industrialized countries with aggressive decarbonization targets.

The MENA region can become a valuable exporter of clean hydrogen by 2030, helping importing countries meet their ambitious targets. For example, Saudi Arabia and Germany have already signed a green hydrogen agreement to help Germany supply 90 to 110 TWh of energy by 2030.[iii,iv] Other countries, such as Japan, France, South Korea, and Germany that are constrained by limited resources, may look to MENA as a reliable exporter of hydrogen to meet their own ambitious energy targets. This paper is a summary of current reporting on the opportunities and challenges; and, is meant to set the stage for discussion on question areas facing traditional energy-producing nations as they aim to become a frontrunner in the nascent global hydrogen market.[v] Subsequently, investment in the full value chain will play a significant role in shaping country strategies.

Figure 2.

Key Terms

Clean Hydrogen: As defined by the U.S. Department of Energy, is hydrogen produced with a carbon intensity of 2 kg or less of carbon-dioxide equivalent produced at the site of production per kg of hydrogen produced. (https://afdc.energy.gov/fuels/laws/HY?state=US) However, the Inflation Reduction Act (IRA) and other countries have different definitions for low-carbon hydrogen, which account for lifecycle emissions.

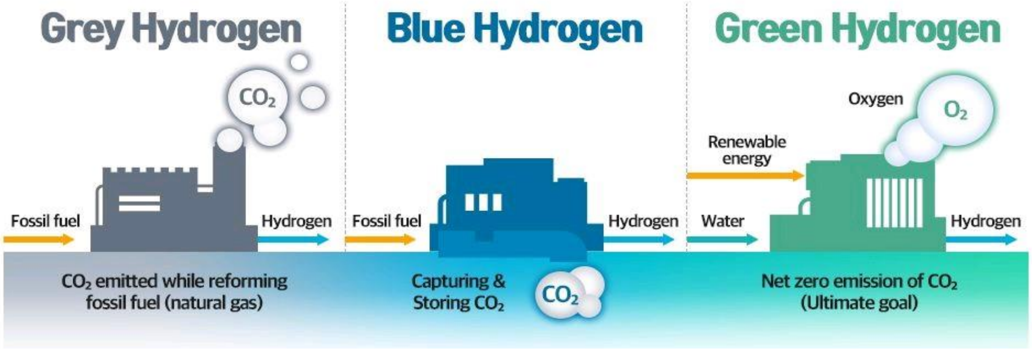

Table of Contents

1. Regulatory Framework

There is currently no global hydrogen market; supply, demand and prices for hydrogen are largely based on bilateral contracts for its use as a specialty chemical. While some countries have existing regulations associated with current forms of hydrogen production, consistency and, if necessary, further expansion to include new uses and technologies are needed. As such, there is no regional or global regulatory or pricing structure for managing hydrogen as an energy commodity. The ongoing need for a fuel for industry and for power generation absent breakthroughs in long-duration storage offers an incentive for governments, industry, and other interest groups to form consistent regulatory frameworks and clear definitions for safe handling (including shipping), clean hydrogen, product quality, storage requirements, pipeline regulations, and appropriate levels of blending with natural gas.

Safe Handling. To limit health and safety risks from hydrogen or a hydrogen carrier, hydrogen equipment must be inspected and routinely maintained. Especially for toxic substances, like ammonia or methanol, permissible exposure limits should be determined and communicated to those handling the substances. Some countries, including the United States, have already established such requirements; these could inform global practices.[vi]

The materials that hydrogen or hydrogen carriers are transported in should also be standardized to avoid premature embrittlement or losses in tensile strength, ductility, and fracture toughness, which could ultimately result in failing pressure containment. Thus, ubiquitous guidelines for using specific types of materials, such as aluminum alloys, copper alloys, or low-alloy ferritic steels, must apply globally. In the event of an accident, incidents should be investigated for causality and corrected accordingly by the appropriate international or national agency.[vii]

Clean Hydrogen. Countries planning to export hydrogen should develop carbon intensity benchmarks for domestic production to align with international buyers. Some nations, such as the United States, are opting for technology-neutral approaches[2] for hydrogen development and are focusing on carbon intensity benchmarks to develop clean hydrogen standards. More than 20 countries have been coordinating since 2019 to harmonize emissions analysis methodologies and boundary conditions for hydrogen pathways through the International Partnership for Hydrogen in the Economy's (IPHE's) Hydrogen Production Analysis Task Force (H2PA TF), which is co-led by the U.S.[viii] Similarly, Saudi Arabia has a technology-neutral approach reflective of the circular carbon economy framework it adopted in 2020[3]. Other countries have indicated that they would consider hydrogen clean only if it is produced by renewable electricity, e.g., solar and wind.

The definitions that countries and policies use is important, especially as a market develops. Several leading nations in hydrogen development have their own definitions for low-carbon hydrogen. Examples of this variation in standards can be seen in the United States (EPA, Infrastructure and Jobs Act), the United Kingdom, the European Union, Australia, China, and Japan.

Ensuring that producing countries, are producing hydrogen that is aligned with the GHG allowance of other countries will require clear articulation in commercial agreements such as – contracts, letters of intent, and memorandums of understanding.

Fuel Quality. Countries planning to produce hydrogen should develop fuel quality standards to ensure compatibility with international standards and end-use applications. As new end uses for hydrogen are commercialized, typical hydrogen quality[4] of 95-99 percent may no longer be sufficient. For example, fuel cell vehicles require high-quality hydrogen[5] with a purity level of 99.97 percent.[ix] Excessive impurities such as sulfides or particulate matter can degrade fuel cell performance or irreversibly damage fuel cell components. There are many

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[2] Technological neutrality means applying no constraints or prescriptions on choices of technology or equipment, within the bounds of compatibility and interference avoidance, in this case, the carbon intensity of the hydrogen produced.

[3] Saudi Arabia pioneered and adopted the Circular Carbon Economy Framework which was unveiled during Saudi Arabia's presidency of the G20 in 2020. The framework emphasizes a technology-neutral approach to addressing fugitive carbon emissions and highlights that emissions can be managed through any of the 4 mitigating options: “Reduce”, “Reuse”, “Recycle” and “Remove”.

[4] Hydrogen purity or hydrogen quality describes the presence of impurities in hydrogen when used as a fuel gas. Impurities in hydrogen can interfere with the proper functioning of equipment that stores, distributes, or uses hydrogen fuel.

[5] Hydrogen quality for FCEV and hydrogen refueling stations in the United States may be influenced by SAE J2719 Hydrogen Fuel Quality for Fuel Cell Vehicles and two international standards: ISO14687–2:2012 and ISO/DIS 19880-8.

technologies available to producers to remove different impurities, including pressure swing absorption (PSA), permeable membranes, and metal hydrides, but using just one type is often insufficient to achieve the purity needed and increases the cost of production.[x] Contaminants and hydrocarbon standards are part of what create the “grades” of pure hydrogen: pure hydrogen (hydrogen purity ≥ 99.99%), high pure hydrogen (hydrogen purity ≥ 99.999%), and ultrapure hydrogen (hydrogen purity ≥ 99.9999%).[xi]

Countries that are looking to export hydrogen should regulate domestic hydrogen production in line with the purity standards of the target countries. Like the carbon intensity benchmarks, hydrogen purity standards vary from country to country. In China, for example, the purity standards for hydrogen are no less than 99.97 percent, which is greater than that of industrial hydrogen but less than that of hydrogen for the electricity sector.[xii] Additionally, the UK’s Department of Business, Energy, and Industrial Strategy recommends a minimum hydrogen purity standard greater than 98 percent.[xiii] It is important to consider the target country and end-use application when identifying appropriate hydrogen quality standards.

Blending Levels. If hydrogen is integrated into existing natural gas systems, compatibility with pipeline materials and end-use systems must be determined to establish the appropriate blend ratios. In the United States, blending hydrogen into aging natural gas infrastructure carries serious risks of steel embrittlement and complications with compressor stations or gas meters even at low blend rates of five to 10 percent. Recent studies show that residential and commercial application limits are 20 percent hydrogen content, with limited benefits for emissions reductions.[6] Natural gas transmission and distribution systems, as well as intended end-use applications, should be analyzed on a case-by-case basis to determine the appropriate blend ratios that ensure safety for surrounding communities.[xiv]

Storage. Developing a regulatory framework for hydrogen storage requires careful consideration of a country’s natural resources and a cost-benefit analysis of transportation

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[6] Research conducted by Energy Innovation argues that blending hydrogen into natural gas pipelines is not a viable option for reducing greenhouse gas emissions or minimizing costs to consumers due to low blend percentages and incompatibility with end use systems.[6] Natural gas pipelines can only handle low hydrogen blends before imposing safety risks, and such blends max out on reducing GHG emissions by a mere 6 to 7 percent[6] as hydrogen has around a third of the calorific value of natural gas by volume.

methods. Hydrogen can be stored as a pressurized gas, cryo-compressed gas, or as a liquid.[xv] Cryo-compression and liquefaction deliver the highest energy density of hydrogen; these processes are, however, energy intensive, and hydrogen can be lost in transit due to boil-off.[7] Storage options for hydrogen include pressurized or cryogenic tanks or underground geographic formations such as salt caverns or empty oil and gas formations, which can hold much greater volumes.[xvi]

Leakage. Mitigation of hydrogen leakage throughout the value chain is critical if the greatest climate and economic benefits are to be realized through the creation of a hydrogen economy. There are concerns of leaky infrastructure due to the high leakage rate of methane throughout the natural gas value chain and hydrogen's high rate of permeability.[8] Additionally, the climate impact of modeled leak scenarios is not negligible as pure hydrogen is a greenhouse gas, albeit a short-lived GHG, and can contribute to global warming.[xvii,xviii,xix] When building out a hydrogen value chain, regulators should ensure that there are ample sensors and other leak detection safeguards in place.

As hydrogen regulation is in its nascent stage, countries seeking to contribute to a global hydrogen market should play an active role in developing governance and regulatory principles for hydrogen trade. Although countries are beginning to develop carbon intensity benchmarks (Figure 1) and over 25 nations have announced hydrogen strategies, clear and consistent regulations for global markets, such as those outlined in this framing paper, have not yet been implemented. This represents an opportunity for countries, such as Saudi Arabia, to be a part of this global decision-making process.

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[7] Boil-off losses occur when gaseous hydrogen has to be released from a cryogenic tank due to liquid hydrogen evaporating.

[8] Hydrogen has a high permeation coefficient that allows hydrogen gas to leak through polyethylene (PE) pipeline walls, which is the most common material in the U.S. natural gas distribution network. Hydrogen's permeation rate is about 4 to 6 times faster than for methane in typical polymer pipes. It can also leak through the threads or mechanical joints in steel and ductile iron and through elastomeric seals at joints, but permeation through sidewalls accounts for most gas losses.

The many challenges and opportunities highlighted in the section above require further exploration. Below are some key questions for discussion:

- **What regulations should a global market be guided by? Are they local/national issues only or are standards across boundaries needed for transportation?**

2. Policy Incentives

There is currently no robust global hydrogen economy because hydrogen is more expensive than other fuels and energy carriers. Robust policies could help reduce the associative costs of producing, transporting, and using hydrogen. The following section explores the advantages and shortfalls of policy frameworks designed to spur global hydrogen market formation.

Policies favoring hydrogen market development are important for building global hydrogen infrastructure and decarbonizing hard-to-abate sectors.[9] Without new policies, there will be limited penetration into new markets that need decarbonization options, as well as insufficient research and development (R&D) into the technologies needed to enhance the value of the hydrogen option. Several policies merit discussion in the context of hydrogen including, but not limited to, those that address investment risks, emissions, emissions trading schemes, carbon taxes, competitive auctions, grants or loans, alternate revenue streams, guaranteed off-takers, and targets or quotas. Policies should also be put in place to address workforce displacement and vulnerable communities in the global energy transition.

Carbon Pricing

Cost is a key obstacle to the uptake of hydrogen within the energy system, particularly in countries only considering hydrogen production from renewable energy sources. Tax policies can provide effective instruments that incentivize switching from unabated fossil fuels. Where emissions trading schemes are in place, a higher price on emitted carbon could be a particularly effective incentive to enable a switch to hydrogen fuel. A carbon tax is another option, for example, Norway’s Climate Action Plan 2021-30 proposes to raise the carbon tax from NOK 590 (USD 69) per ton of carbon-dioxide equivalent in 2021 to NOK 2,000 (about USD 233) by 2030. Norway’s carbon tax rate is among the highest and farthest reaching in Europe as it covers more than 80% of national emissions. The country’s

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[9] The Hard-to-Abate sectors can be divided into heavy industry: cement, steel, and chemicals such as plastic and heavy-duty transport such as road trucking, container shipping, and aviation.

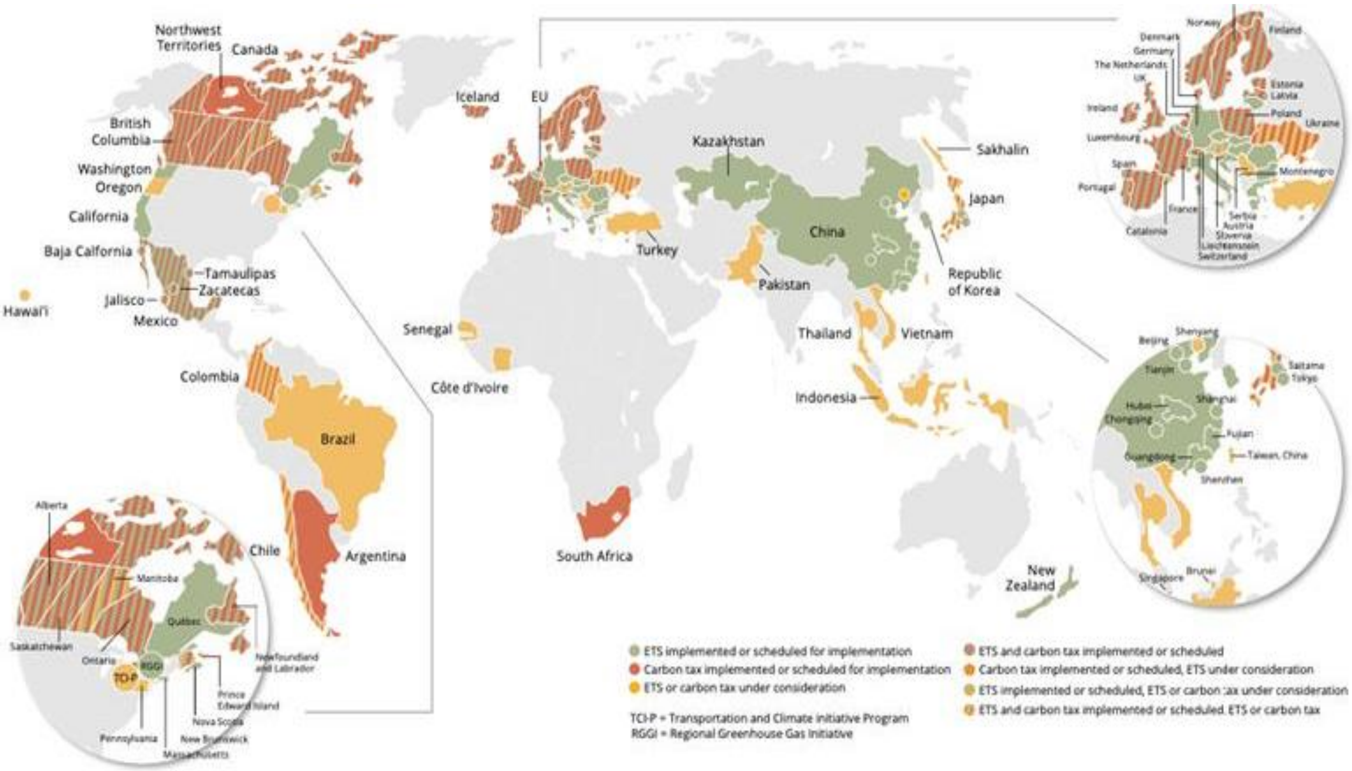
carbon tax provides a strong price signal to encourage increased investments in renewable energy and low-carbon technologies.[xx] Other options look at lowering taxes for hydrogen fuels with reduced transportation-related fees (tolls, parking, etc.) for hydrogen-fueled vehicles and vessels, or by exempting producers from electricity levies to encourage their uptake.[xxi]

Carbon pricing is not politically palatable in some significant hydrogen supply and/or demand potential countries, but it offers one of the most direct ways to reduce emissions rapidly, using a market-based approach. In a cap-and-trade system (an emissions trading program), a hydrogen producer could release emissions up to a certain threshold before needing to buy permits to release additional emissions into the atmosphere. If the abatement costs of retrofitting with capture and storage are less expensive than the total cost of permits needed to cover the facility's emissions, that facility would make the economic decision to deploy capture and storage. On the other hand, if a facility produces very low emissions, it can sell excess permits for revenue.

As of May 2021, there were 64 carbon pricing policies in operation and three scheduled for implementation (see Figure 3). These included both carbon taxes and emissions trading schemes (ETS), covering about 22 percent of global emissions.[xxii] In 2020, carbon pricing instruments generated $53 billion in revenue globally. This is an increase of around $8 billion compared to 2019, largely due to the increase in the EU allowance price[xxiii] More governments are adopting net zero targets and we are beginning to see more ambitious carbon pricing instruments. Thus, is incumbent that producers have mechanisms to accurately account for carbon emissions embedded in their export products.

Carbon pricing policies can help address price barriers that inhibit low-carbon development. However, their effectiveness is limited if not used with other policies that can enhance and complement, by tackling other climate change challenges. For instance, sector-specific regulations and other targeted incentive mechanisms (e.g., research and development funding) may be necessary to enable investments in technologies requiring long lead times to develop and deploy. Other complementary measures are also needed alongside carbon pricing policies to tackle nonprice barriers and to reduce emissions in sectors not covered by carbon pricing.[xxiv]

Figure 3: *Map of Carbon Taxes and Emissions Trading Systems*[xxv]



Countries are color coded based on where they are in terms of implementing an emissions trading system (ETS) or carbon tax. Countries colored green have implemented or are scheduled for implementation of an ETS. Countries in red have implemented or are scheduled for implementation of a carbon tax. Countries in yellow are considering implementation of an ETS or carbon tax.

However, carbon taxes are indirectly tied to the social cost of carbon,[10] which includes the negative externalities of releasing carbon into the atmosphere.[xxvi] Like a gas tax, there are equity concerns about consumers disproportionately paying for the rising cost of carbon through the products that they buy. To address these concerns in the U.S., the Climate Leadership Council has developed “The Four Pillars of Our Carbon Dividends Plan,” which includes carbon dividends for American citizens, significant regulatory simplification, a border carbon adjustment, and expansion of the carbon dividend framework to other countries[11]. There are also issues associated with the methodologies used to ascertain Scope 2 and 3 emissions[11] associated with hydrogen and the range of fuel and technology

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[10] The economic costs, or damages, of emitting one additional ton of carbon dioxide into the atmosphere.

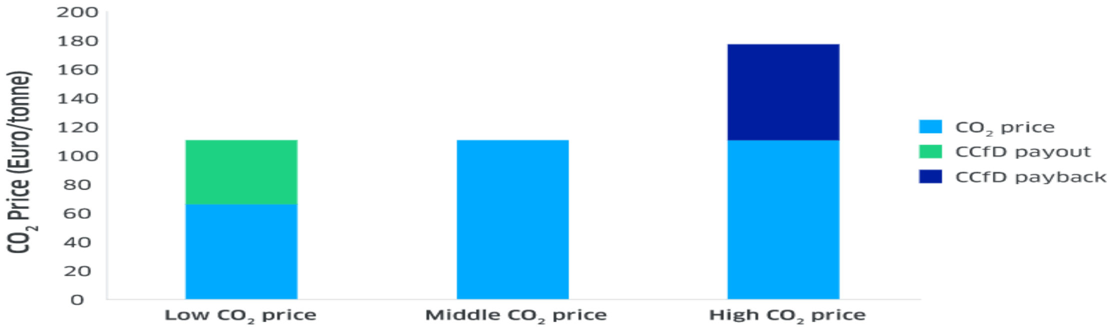
[11] Scope 1 emissions are direct greenhouse (GHG) emissions that occur from sources that are controlled or owned by an organization. Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling. Scope 3 emissions are the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly impacts in its value chain.

options. Thus, establishing consistency between various national carbon pricing regimes will be necessary to avoid unintended consequences and gamesmanship. Another way to minimize adverse effects is to offer dividend payments from the collected tax to communities that may be impacted. At the right price, a carbon tax could raise the cost of producing hydrogen at reformation or gasification plants above clean hydrogen facilities on a per unit basis.

Subsidies

A government can directly fund hydrogen through various programs, as clean hydrogen production cost curves continue to decline. Carbon Contracts for differences (CCfDs), for instance, add nuance to the carbon pricing scheme by setting a fixed cost of carbon over a period of time (i.e., strike price). If the CO_2 price is lower than the strike price, then the government would pay the difference to the investor. However, if the strike price is higher, private companies would need to reimburse the government (see Figure). In some cases, CCfDs do not require a private company to pay back the government.[xxvii] In the case of hydrogen, the price of the contract can work by considering the difference between a conventional SMR and an electrolyzer lifecycle emissions. One way to determine which projects receive a CCfD is through a competitive auction system to determine what that strike price may be.

Figure 3: *An example of how a CCfD could work in the EU for a private entity and a government*



Source: CFM Traction

Governments can also deploy a range of tax credits, research and development grants and loans, prize money, and feed-in tariffs, which all have proven beneficial for other clean energy technologies such as solar and wind. In cases where hydrogen is used as a storage medium to improve grid reliability and flexibility, direct payments could be made to an energy supplier. By bringing down costs of clean hydrogen in the interim, using R&D to further lower costs, and paving the way for new applications of hydrogen entirely, hydrogen as an energy commodity could be accelerated as an accessible resource in regional and international markets.

Government-backed contracting mechanisms

A way for governments to encourage clean hydrogen production is to work with private companies as a guaranteed off-taker. In other words, governments could enter long-term commercial contracts to buy specified amounts of hydrogen or hydrogen-based products (e.g., steel) at an established price. Such a policy solution is not only an option for hydrogen but carbon as well, the latter of which can struggle to find revenue streams in the case of permanent sequestration.[xxviii] Another way for a government to encourage investment is to offer a sovereign guarantee of obligations and assume some of the project risk, such guarantees can ensure payments in the event of default. De-risking the hydrogen business by encouraging long-term contracts that offer guaranteed revenue would further help companies attract investors, new developers, and meet government quotas or targets.

Incentivizing Carbon Sequestration

Hydrogen market development could benefit from policies that support the capture and sequestration of carbon from hydrocarbon-related hydrogen production, such as methane reformation or coal gasification plants. Once the carbon is captured, if it is not utilized it must be stored. While there are multiple utilization options to monetize CO^2 - such as enhanced oil recovery (EOR), chemical production, food and beverage, and carbon-cured concrete - permanent storage will require a significant role in reaching net-zero. Participation in a government-supported carbon market may offer a way to keep such businesses profitable. A tax credit for sequestering carbon is desirable to deploy capture at fossil-intensive facilities. In the United States, for example, 45Q offers $85/t for storage, recently codified in the Inflation Reduction Act.[xxix] Another option may be to allow facilities with capture to participate in low carbon fuel standard (LCFS) markets, so they can receive credits for the capital-intensive process of capturing, transporting, and storing carbon.

Assisting Workforce Transition

As oil and gas demand declines in favor of cleaner energy sources, those with experience in those industries will require training to facilitate the energy transition. Both governments and the private sector will need to offer specialized skills training in the new technologies of the hydrogen production value chain. Policies that encourage companies to hire workers from those industries and offer them the support they need to succeed are among the most promising for ensuring skilled laborers are not left behind or choose to exit the workplace.

This could be further supported by complementary policies that encourage domestic manufacturing within the hydrogen supply chain, the creation of jobs through infrastructure development funds, and ensuring competitive wages for the jobs that are created through heavy investment.[xxx]

The many challenges and opportunities highlighted in the section above require further exploration. Below are some key questions for discussion:

- **Is a carbon pricing market needed for hydrogen market facilitation?**
- **Do we know how many or the value of new job creation? What jobs are transferrable?**
- **Are national subsidies commercially viable in a global market?**
- **Can storage become an independent commercial negotiation? Should storage be evaluated independently or as part of a contract?**
- **To minimize risk, what should be the key features of hydrogen purchase contracts?**

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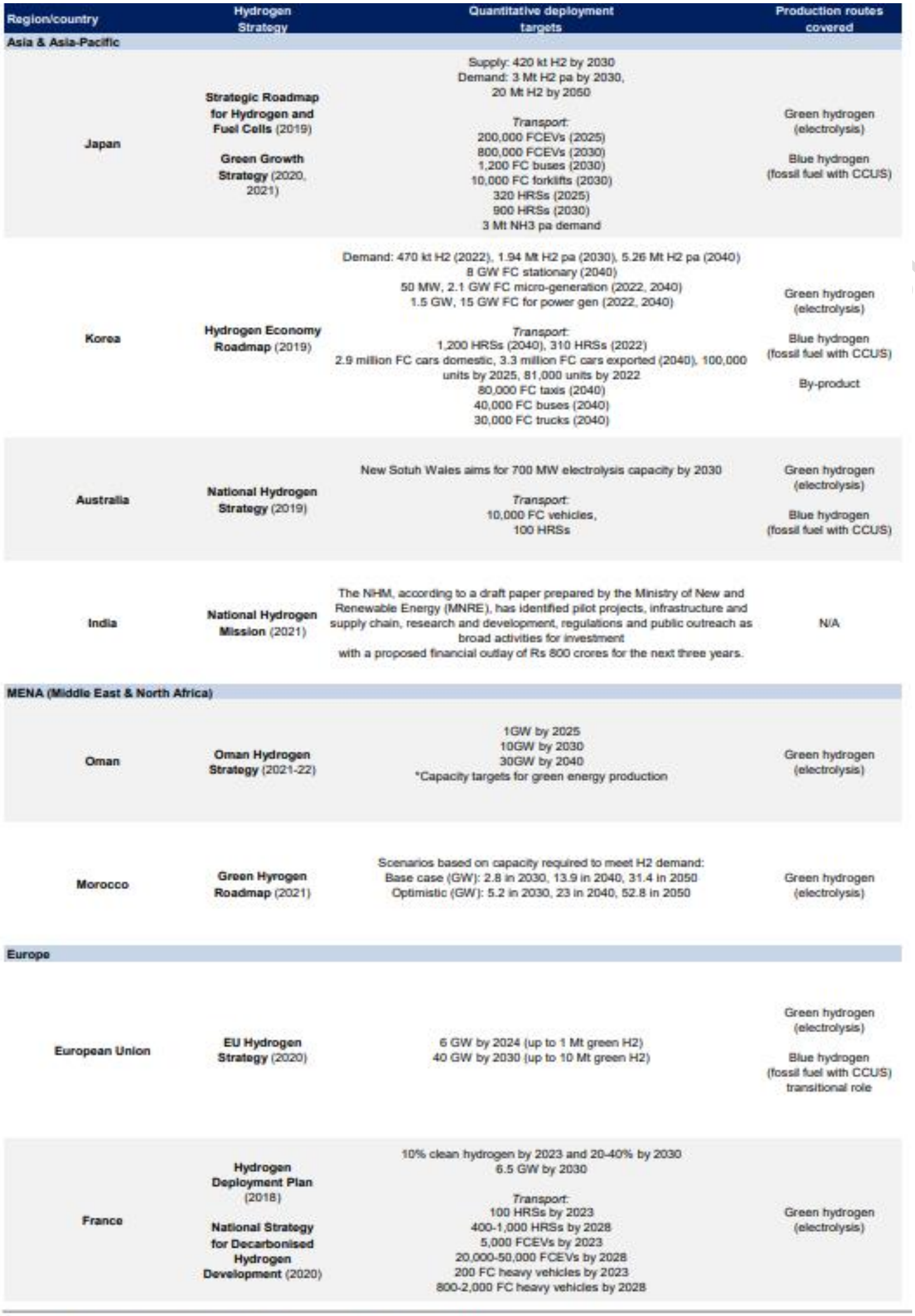
3. Appendix –

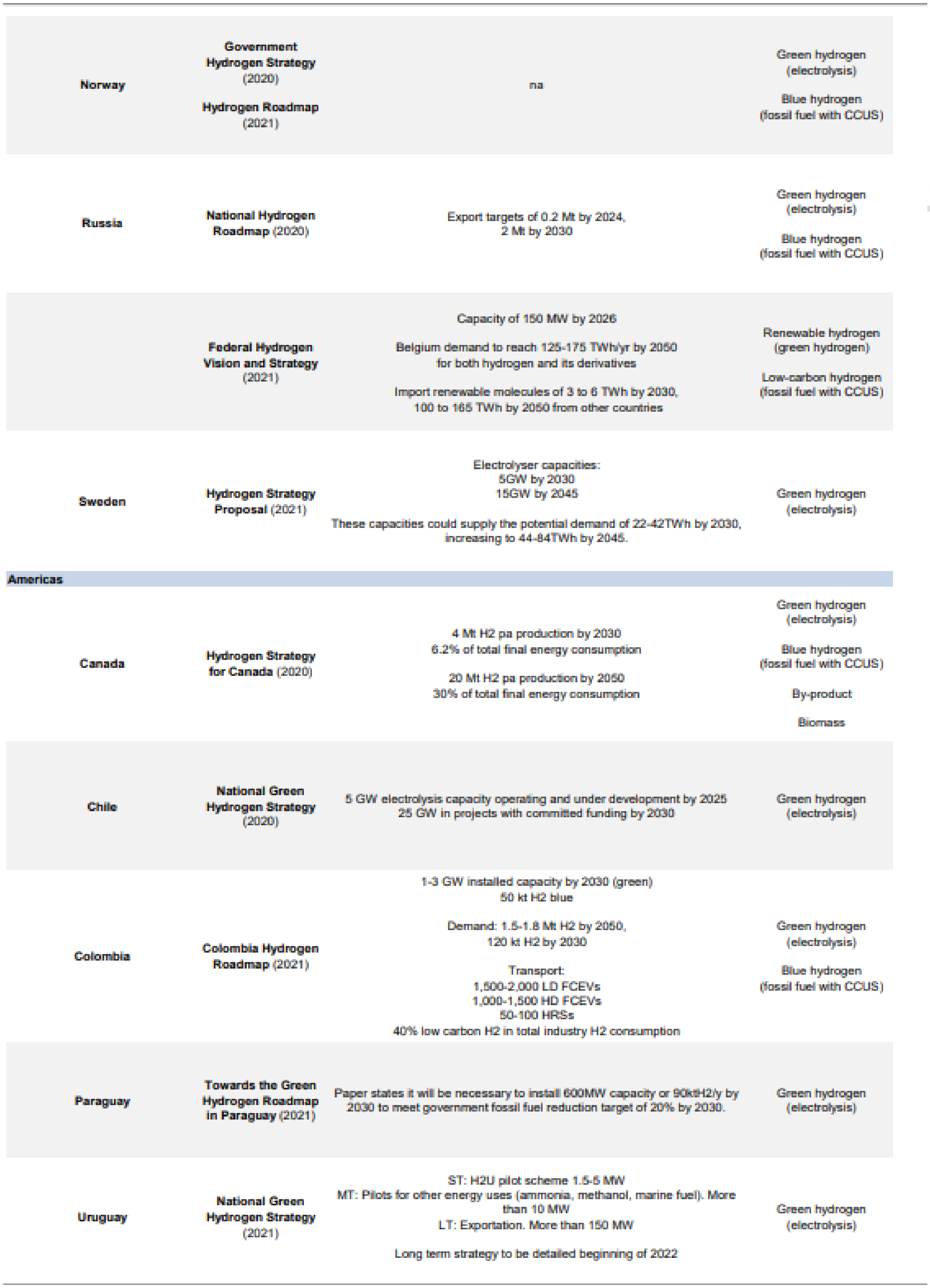
Summary of Key Hydrogen Targets Across Hydrogen Strategies



Region/country	Hydrogen Strategy	Quantitative deployment targets	Production routes covered
Asia & Asia-Pacific			
Japan	**Strategic Roadmap for Hydrogen and Fuel Cells** (2019) **Green Growth Strategy** (2020, 2021)	Supply: 420 kt H2 by 2030 Demand: 3 Mt H2 pa by 2030, 20 Mt H2 by 2050 *Transport:* 200,000 FCEVs (2025) 800,000 FCEVs (2030) 1,200 FC buses (2030) 10,000 FC forklifts (2030) 320 HRSs (2025) 900 HRSs (2030) 3 Mt NH3 pa demand	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
Korea	**Hydrogen Economy Roadmap** (2019)	Demand: 470 kt H2 (2022), 1.94 Mt H2 pa (2030), 5.26 Mt H2 pa (2040) 8 GW FC stationary (2040) 50 MW, 2.1 GW FC micro-generation (2022, 2040) 1.5 GW, 15 GW FC for power gen (2022, 2040) *Transport:* 1,200 HRSs (2040), 310 HRSs (2022) 2.9 million FC cars domestic, 3.3 million FC cars exported (2040), 100,000 units by 2025, 81,000 units by 2022 80,000 FC taxis (2040) 40,000 FC buses (2040) 30,000 FC trucks (2040)	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS) By-product
Australia	**National Hydrogen Strategy** (2019)	New Sotuh Wales aims for 700 MW electrolysis capacity by 2030 *Transport:* 10,000 FC vehicles, 100 HRSs	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
India	**National Hydrogen Mission** (2021)	The NHM, according to a draft paper prepared by the Ministry of New and Renewable Energy (MNRE), has identified pilot projects, infrastructure and supply chain, research and development, regulations and public outreach as broad activities for investment with a proposed financial outlay of Rs 800 crores for the next three years.	N/A
MENA (Middle East & North Africa)			
Oman	**Oman Hydrogen Strategy** (2021-22)	1GW by 2025 10GW by 2030 30GW by 2040 *Capacity targets for green energy production	Green hydrogen (electrolysis)
Morocco	**Green Hyrogen Roadmap** (2021)	Scenarios based on capacity required to meet H2 demand: Base case (GW): 2.8 in 2030, 13.9 in 2040, 31.4 in 2050 Optimistic (GW): 5.2 in 2030, 23 in 2040, 52.8 in 2050	Green hydrogen (electrolysis)
Europe			
European Union	**EU Hydrogen Strategy** (2020)	6 GW by 2024 (up to 1 Mt green H2) 40 GW by 2030 (up to 10 Mt green H2)	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS) transitional role
France	**Hydrogen Deployment Plan** (2018) **National Strategy for Decarbonised Hydrogen Development** (2020)	10% clean hydrogen by 2023 and 20-40% by 2030 6.5 GW by 2030 *Transport:* 100 HRSs by 2023 400-1,000 HRSs by 2028 5,000 FCEVs by 2023 20,000-50,000 FCEVs by 2028 200 FC heavy vehicles by 2023 800-2,000 FC heavy vehicles by 2028	Green hydrogen (electrolysis)

Source: Various sources; data compiled by Goldman Sachs Global Investment Research

Netherlands	**National Climate Agreement** (2019) **Government Strategy on Hydrogen** (2020)	500 MW by 2025, 3-4 GW by 2030 *Transport:* 50 HRSs by 2025 15,000 FCEVs by 2025 3,000 heavy duty trucks by 2025 300,000 FCEVs by 2030	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
Spain	**National Hydrogen Roadmap** (2020)	4 GW by 2030 (25% consumption of industrial hydrogen to be green by 2030), 300-600 MW by 2024 *Transport:* 5,000-7,500 FC vehicles by 2030 150-200 FC buses by 2030 100-150 HRSs by 2030	Green hydrogen (electrolysis)
Portugal	**National Hydrogen Strategy** (2020)	1.5-2.5 GW by 2030 5 GW by 2050 50-100 HRSs 10-15% injection in gas networks 1-5% consumption of road transport 3-5% consumption of shipping 2-5% consumption in industry 1.5%-2% consumption in final energy	Green hydrogen (electrolysis)
Germany	**National Hydrogen Strategy** (2020)	5 GW by 2030 (14 TWh) Another 5 GW to be added by 2035-40 *Transport:* 400 HRSs by 2025	Green hydrogen (electrolysis)
Czech Republic	**Hydrogen Strategy** (2021)	97 kt H2 pa by 2030 consumption of low carbon hydrogen 2035 - 273 kt H2/yr, 2040- 857 kt H2/yr, 2045 - 1241 kt H2/yr, 2050 - 1728 kt H2/yr *Transport:* 900 FC buses by 2030 45,000 FC cars by 2030 4,000 FC trucks by 2030	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
Hungary	**National Hydrogen Strategy** (2021)	36 kt H2 pa (low carbon) by 2030 of which 16 kt H2 pa green 240 MW electrolysis *Transport:* 4,800 FCEVs by 2030 20 HRSs by 2030 10 kt H2 pa carbon free Min 2% pa blending in gas system 60 MW cut-off capacity	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
Italy	**National Hydrogen Strategy Preliminary Guidelines** (2021)	5 GW by 2030 2% hydrogen penetration in final energy demand by 2030 and 20% by 2050	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
United Kingdom	**UK Hydrogen Strategy** (2021)	5 GW low carbon production by 2030, 1GW by 2025	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
Poland	**Polish Hydrogen Strategy** (2021)	2 GW by 2030 Transport: 100-250 FC buses by 2025 2,000 FC buses by 2030 32 HRSs	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)



Norway	**Government Hydrogen Strategy** (2020) **Hydrogen Roadmap** (2021)	na	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
Russia	**National Hydrogen Roadmap** (2020)	Export targets of 0.2 Mt by 2024, 2 Mt by 2030	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
	Federal Hydrogen Vision and Strategy (2021)	Capacity of 150 MW by 2026 Belgium demand to reach 125-175 TWh/yr by 2050 for both hydrogen and its derivatives Import renewable molecules of 3 to 6 TWh by 2030, 100 to 165 TWh by 2050 from other countries	Renewable hydrogen (green hydrogen) Low-carbon hydrogen (fossil fuel with CCUS)
Sweden	**Hydrogen Strategy Proposal** (2021)	Electrolyser capacities: 5GW by 2030 15GW by 2045 These capacities could supply the potential demand of 22-42TWh by 2030, increasing to 44-84TWh by 2045.	Green hydrogen (electrolysis)
Americas			
Canada	**Hydrogen Strategy for Canada** (2020)	4 Mt H2 pa production by 2030 6.2% of total final energy consumption 20 Mt H2 pa production by 2050 30% of total final energy consumption	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS) By-product Biomass
Chile	**National Green Hydrogen Strategy** (2020)	5 GW electrolysis capacity operating and under development by 2025 25 GW in projects with committed funding by 2030	Green hydrogen (electrolysis)
Colombia	**Colombia Hydrogen Roadmap** (2021)	1-3 GW installed capacity by 2030 (green) 50 kt H2 blue Demand: 1.5-1.8 Mt H2 by 2050, 120 kt H2 by 2030 Transport: 1,500-2,000 LD FCEVs 1,000-1,500 HD FCEVs 50-100 HRSs 40% low carbon H2 in total industry H2 consumption	Green hydrogen (electrolysis) Blue hydrogen (fossil fuel with CCUS)
Paraguay	**Towards the Green Hydrogen Roadmap in Paraguay** (2021)	Paper states it will be necessary to install 600MW capacity or 90ktH2/y by 2030 to meet government fossil fuel reduction target of 20% by 2030.	Green hydrogen (electrolysis)
Uruguay	**National Green Hydrogen Strategy** (2021)	ST: H2U pilot scheme 1.5-5 MW MT: Pilots for other energy uses (ammonia, methanol, marine fuel). More than 10 MW LT: Exportation. More than 150 MW Long term strategy to be detailed beginning of 2022	Green hydrogen (electrolysis)

Source: Various sources; data compiled by Goldman Sachs Global Investment Research

4. Endnotes

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[i] https://www.sciencedirect.com/science/article/abs/pii/S1364032122006487

[ii] https://www.opec.org/opec_web/en/2211.htm

[iii] https://www.energypartnership.cl/newsroom/hydrogen/#:~:text=In%20order%20to%20promote%20the,offshore%20and%20onshore%20infrastructure%20needed.

[iv] Hydrogen cooperation potential between Saudi Arabia and Germany, A joint study by the Saudi-German Dialogue, pub. 7 June 2022.

[v] https://www.kapsarc.org/research/publications/saudi-arabias-clean-hydrogen-ambitions-opportunities-and-challenges/

[vi] https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.103

[vii] https://h2tools.org/bestpractices/best-practices-overview

[viii] https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-production-standard.pdf

[ix] https://www.vsl.nl/en/about-vsl/news/hydrogen-purity-analysis-fuel-cell-vehicles

[x] https://h2tools.org/bestpractices/incident-reporting-procedures

[xi] https://genh2hydrogen.com/hydrogen-a-to-z-series-p-for-purity/

[xii] https://www.e3s-conferences.org/articles/e3sconf/pdf/2019/44/e3sconf_icaeer18_03042.pdf

[xiii] https://static1.squarespace.com/static/5b8eae345cfd799896a803f4/t/5e58ebfc9df53f4eb31f7cf8/1582885917781/WP2+Report+final.pdf

[xiv] https://www.nationalgrid.com/gas-transmission/document/138181/download pg. 6

[xv] https://www.energy.gov/eere/fuelcells/hydrogen-storage

[xvi] https://www.iea.org/articles/proving-the-viability-of-underground-hydrogen-storage

[xvii] https://acp.copernicus.org/preprints/acp-2022-91/acp-2022-91.pdf

[xviii] https://energyinnovation.org/wp-content/uploads/2022/03/Assessing-the-Viability-of-Hydrogen-Proposals.pdf

[xix] https://www.energypolicy.columbia.edu/research/commentary/hydrogen-leakage-potential-risk-hydrogen-economy

[xx] https://www.oecd-ilibrary.org/sites/59e71c13-en/index.html?itemId=/content/publication/59e71c13-en

[xxi] https://www.worldenergy.org/assets/downloads/Working_Paper_-_National_Hydrogen_Strategies_-_September_2021.pdf pg. 10

[xxii] https://openknowledge.worldbank.org/handle/10986/35620

[xxiii] https://openknowledge.worldbank.org/handle/10986/35620 pg. 31

[xxiv] https://openknowledge.worldbank.org/handle/10986/35620 pg. 16

[xxv] https://openknowledge.worldbank.org/handle/10986/35620 pg. 22

[xxvi] https://www.epa.gov/sites/default/files/2016-12/documents/social_cost_of_carbon_fact_sheet.pdf

[xxvii] Carbon-Contracts_CFMP-Policy-Brief-2020.pdf (climatestrategies.org)

[xxviii] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf

[xxix] https://energyfuturesinitiative.org/wp-content/uploads/sites/2/2021/09/BuildingToNetZero_Report.pdf

[xxx] Harnessing the Infrastructure Investment and Jobs Act to train the next generation of workers (brookings.edu)