HYDROGEN PRODUCTION FROM CARBON-FREE NUCLEAR ENERGY

Overview of Current Policies and Recommendations for Government Actions

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Nuclear Hydrogen Initiative

Contents

This White Paper has been developed by the Nuclear Hydrogen Initiative led by Clean Air Task Force (CATF) with the **collaboration from various partners as follows:**

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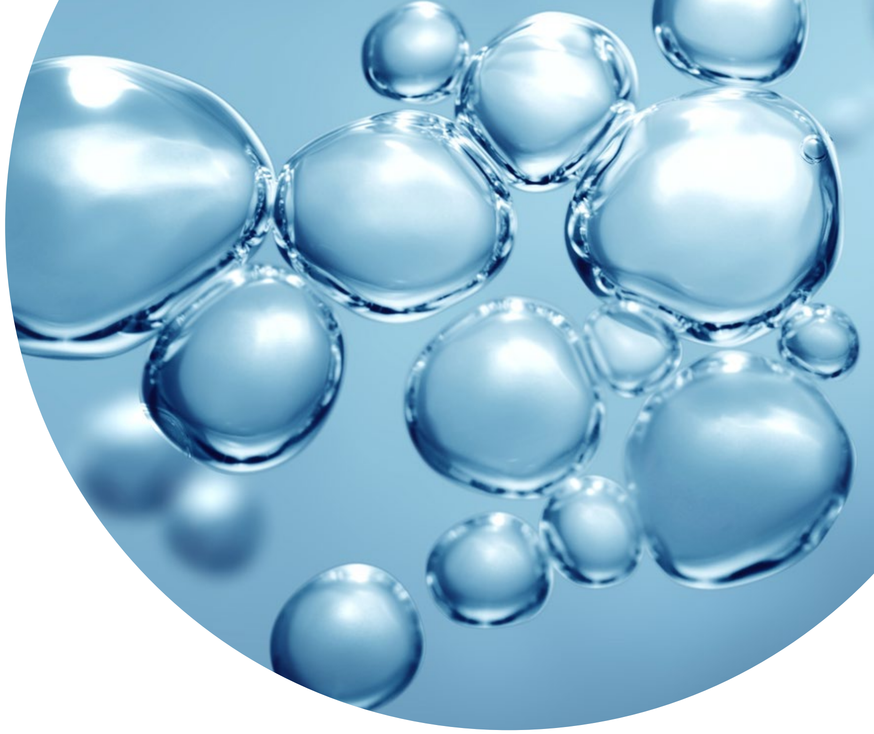
SECTION 01



Introduction

As governments and private sector leaders consider solutions to decarbonize the global energy matrix in order to address climate change, hydrogen has increasingly emerged as one promising pathway to net-zero emissions. The world's most abundant element is an energy carrier that can be used not only to store energy, but also to decarbonize hard-to-abate energy sectors, such as transportation, power, industry, and buildings.

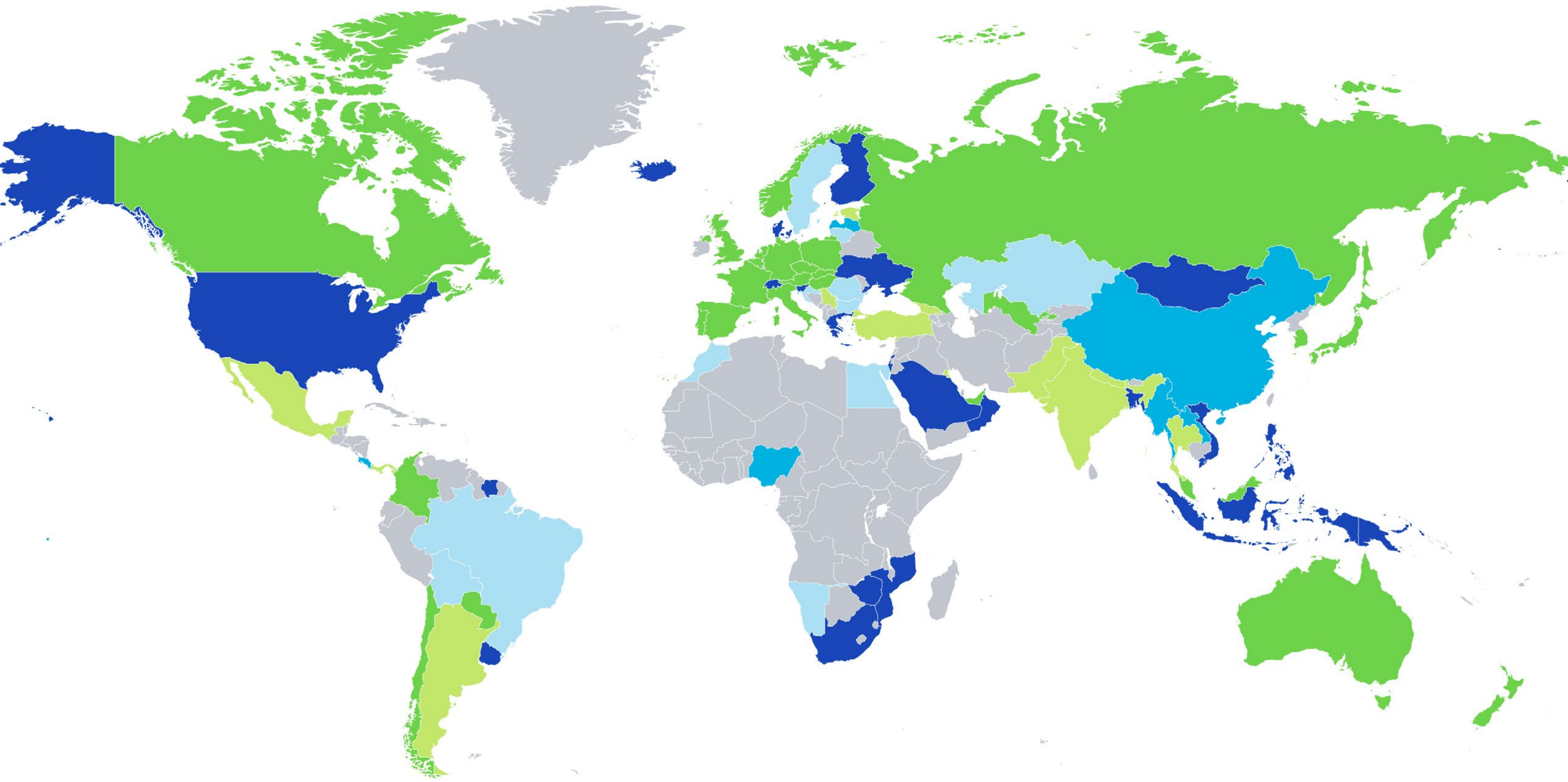
As of the date of the publication of this paper, twenty-six (26) countries and the European Union have issued hydrogen roadmaps and/or strategies. Of these, twenty-one (21) were released in 2020-2021 demonstrating the heightened focus on this lever for decarbonization. Eleven (11) other countries are in the process of preparing hydrogen policies or strategies, seven (7) others have included hydrogen in other clean energy roadmaps or strategies, and twelve (12) are in initial policy discussions with respect to clean hydrogen. Further, twenty-four (24) countries have provided support for hydrogen projects or research and development.

In this transition to a hydrogen economy, there are many forecasts of the expected demand by 2050 which, even in the most conservative estimates, has production levels of clean hydrogen increased by 2.5x-7x compared to today's capacity. Given the exponential nature of the growth of demand, there is a need to explore all paths to produce clean hydrogen. For hydrogen to fulfill its enormous decarbonization potential, its production process must also account for the environmental impact of its energy sources. Today, most hydrogen is produced through steam methane reforming or coal gasification, which result in considerable unfavorable emissions. The carbon impact of hydrogen production from fossil fuels can be mitigated through carbon capture, utilization and storage technologies which are continuing to advance. However, a parallel pathway for hydrogen production from zero-carbon sources is paramount to achieving the element's true decarbonization potential. The production of hydrogen through water electrolysis – where electricity is used to decompose water into oxygen and hydrogen gas – has emerged as one of those pathways. When the required electricity is produced from renewable energy sources, such as wind and solar, the resulting hydrogen is referred to as "green hydrogen". However, nuclear energy is another powerful hydrogen production method, adding benefits not available from any other energy source. Nuclear plants are zero-carbon, operate at capacity factors above 90%, and require minimal land resources compared to renewable energy. Nuclear plants can also produce heat, not just electricity. For that reason, they can be paired with a more efficient high-temperature steam electrolyzer (HTSE), which uses less electricity per kilo of hydrogen produced. Advanced reactors that operate at very high temperatures can produce hydrogen thermochemically, without the use of electrolyzers. The unique characteristics of nuclear energy allow it to pair with these low-cost, high efficiency production processes which facilitates nuclear hydrogen production's economic competitiveness. In this way, nuclear energy can be a catalyst for a clean hydrogen market.

Recognizing the value that nuclear energy can bring to hydrogen production, many endeavors and pilot projects have emerged to pave the way for large scale nuclear hydrogen production. Some of theseinitiatives are included in national hydrogen visions, plans, and strategies, as is the case in the United Kingdom, Canada, and the United States. Countries like France, while not expressly referring to nuclear energy in their hydrogen plans, have defined clean hydrogen production in a technology agnostic way, allowing the inclusion of nuclear energy in clean hydrogen pathway strategies. Table 1 in the Appendix summarizes the status of hydrogen policies in selected jurisdictions that also have existing nuclear energy infrastructure.

The key drivers for these new hydrogen policies and roadmaps include emission reduction, diversification of the energy supply, fostering economic growth, facilitating the integration of clean energy sources, supporting national technology development, and positioning hydrogen for export among other motivations. Furthermore, these initiatives include many support measures, such as research and development support, regulatory reform, financial incentives and support, and governance.

Figure 1: Status of National Support for Clean Hydrogen



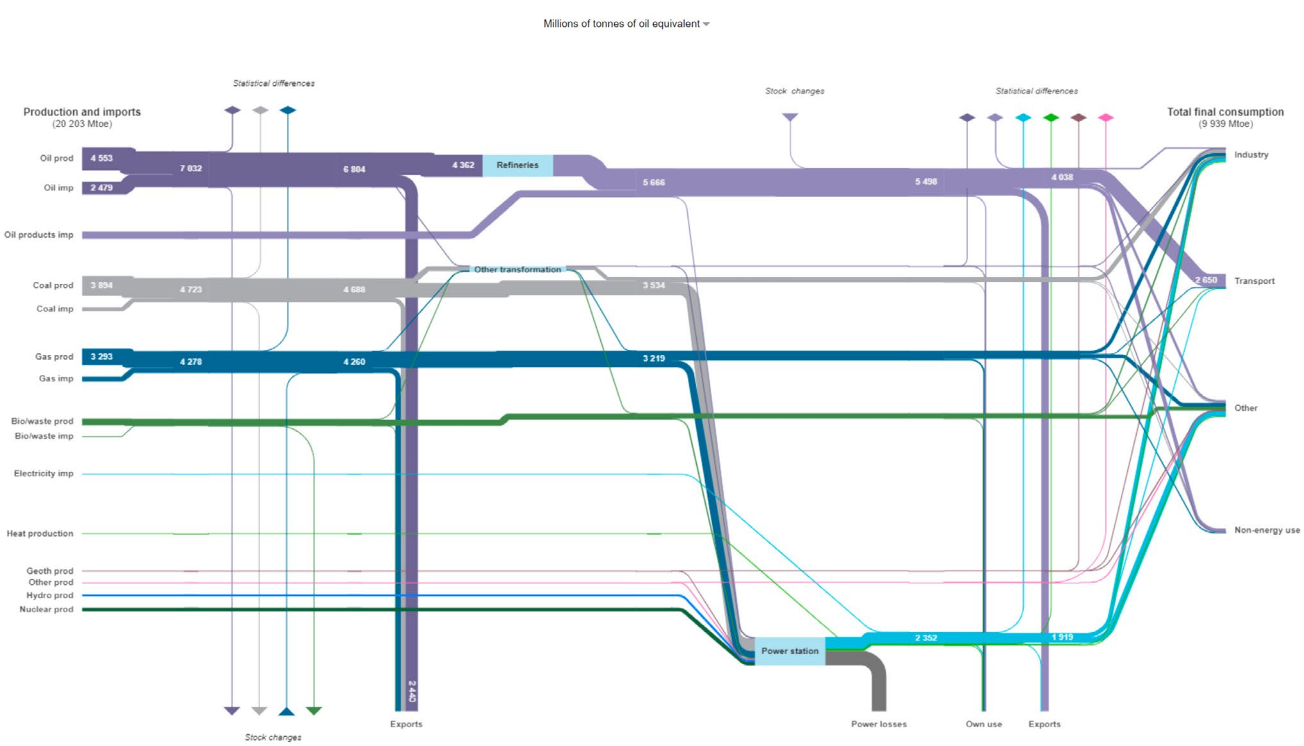
- Initial policy discussions
- Hydrogen strategy or roadmap issued
- Hydrogen strategy or roadmap in preparation
- Hydrogen included in other clean energy roadmaps
- Support for projects and/or R&D

SECTION 02

The Role of Hydrogen in Decarbonizing the Energy Sector

According to data from the International Energy Agency (IEA) (Ref 2), of all the energy consumed today, electricity accounts for approximately 20% of emissions. The remaining 80% is used by hard-to-abate sectors such as shipping, transportation, industrial needs, and building space heating from which almost all of the energy is sourced from fossil fuels. (See Figure 2)

Figure 2: World Energy Balance 2018 (Ref 2)



As the world drives towards decarbonization and many countries have agreed on setting targets of carbon neutrality by 2050, the enormous challenge ahead of us is clear. While much progress has been made, particularly in the electricity sector with natural gas replacing coal and increased renewable generation, much must still be done in the other sectors. Of the many efforts ongoing to mitigate these issues, the increased production, use and leverage of hydrogen as an enabler to transform these sectors has sparked the interest of many key stakeholders in both the public and private sectors. From a policy standpoint, we have seen a dramatic increase in interest, focus and strategy development in the last 24 months, resulting in many jurisdictions preparing and releasing policy and strategy roadmaps to develop and grow hydrogen economies around the world. Although many of these initiatives highlight the importance of sourcing hydrogen production from clean sources, several of them clearly focus on renewable energy to provide the bulk of energy needed for the hydrogen production process. However, several countries already recognize the transformative strategic role that nuclear technology can play.

The challenges climate change presents are so significant that we must consider and use every tool at our disposal. Renewable energy such as solar and wind power offer part of the solution, but are unlikely to decarbonize the entire global energy system alone. We must continue developing additional pathways to maximize our likelihood of success – as the consequences of failure are too severe.

For example, we are realistic about the future of fossil fuels, understanding that any transition away from those fuels will take time. Thus, we support technologies that can remove carbon emissions from fossil fueled power plants and directly capture them from the air. Other technologies worth considering include electricity generation from geothermal energy and zero-carbon fuels. In addition, we have concluded that advanced nuclear plant designs and new nuclear technologies are safer, less expensive, more versatile and offer flexibility to allow for alternative applications beyond clean electricity generation.

CATF issued a report in 2018 (Ref 6) that explores how a massive scale-up in the production and use of zero-carbon hydrogen and ammonia might help decarbonize segments of the energy sector, particularly the transportation sector. Figure 3 shows the various potential applications of hydrogen and ammonia in the many energy segments.

Hydrogen and ammonia can be produced and converted into energy through processes that emit zero greenhouse gases. The production of hydrogen and ammonia are massively scalable and highly flexible energy products, given they can be produced and used in a variety of ways.

Hydrogen and ammonia could play important roles in addressing several decarbonization challenges including:

- Storing excess power produced by variable renewable energy sources
- Reducing the carbon intensity of the energy produced by existing power plants
- Reducing the carbon content of natural gas
- Safely and efficiently using ammonia to transport and store hydrogen

Within this context, and recognizing that multiple competing technologies exist or are being developed that have the potential to produce clean hydrogen at scale, it is important to consider using nuclear generation to provide an even faster-to-market and more versatile solution to develop a growing and sustainable clean hydrogen production approach and related economy. Using the many technological innovations that exist or are on the horizon, this can be accomplished using both the existing global nuclear fleet as well as the many advanced reactors which are poised to enter the marketplace during this decade.

Figure 3: Potential Uses and Production of Hydrogen and Ammonia (Ref 6)

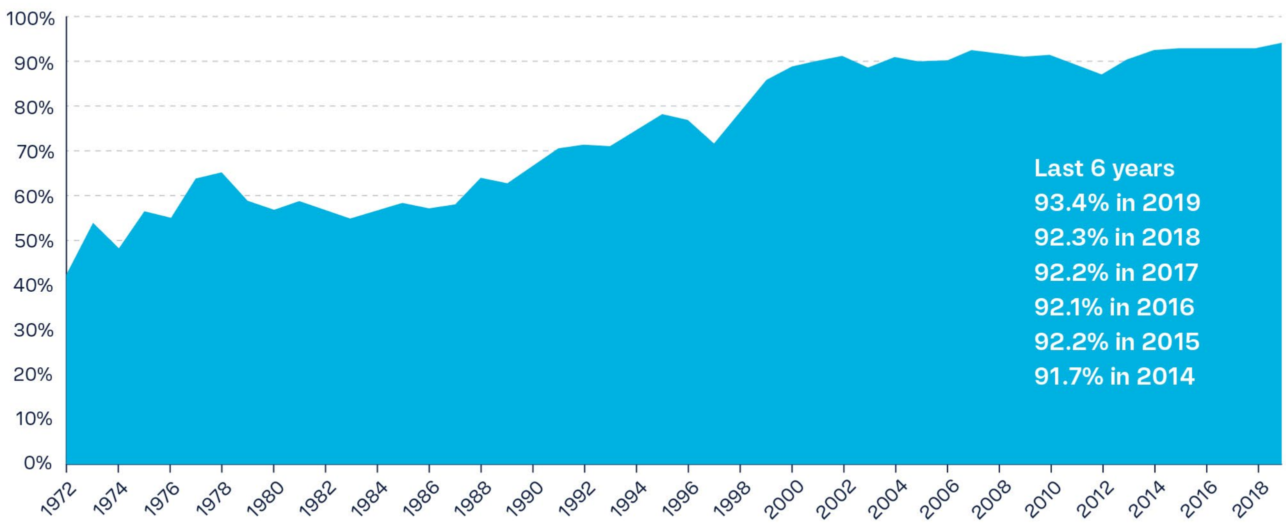
Energy End Use	Hydrogen Conversion Technologies	Ammonia Conversion Technologies
Transportation Heavy Duty		
On/Off Road	Fuel cells (commercially available) *Possibly: Internal combustion engines (ICEs)*	ICEs *Possibly: Direct NH_3 fuel cells*
Rail	Fuel cells – some current light rails in Europe *Possibly: Fuel cells for U.S. light rail*	ICEs *Possibly: Direct NH_3 fuel cells*
Marine	Fuel cells (short distance)	ICEs
Aviation	Unlikely (although there have been studies and designs)	Unlikely
Transportation Light Duty		
Automobiles	Fuel cells – commercial today *Possibly: ICEs (demos exist)*	ICEs *Possibly: Direct NH_3 fuel cells*
Power Generation-Direct		
Grid-connected/central	Combustion turbines	Combustion turnbines, boilers
Remote/distributed	Fuel cells – commercial today	ICEs
Power Generation-Grid Balancing		
Variable renewable energy complement	Combustion turbines *Possibly: Fuel cells*	ICEs
Industrial Process Heat		
Electric/steam/gaseous heat	Boilers – commercial today	Boilers – demonstration in progress in Japan

SECTION 03

Nuclear Technology as an Enabler of a Clean Hydrogen Economy

Today, the existing global nuclear fleet, mostly based on Light Water Reactor (LWR) technologies, operates with great performance, reliability and typically with capacity factors above 90%.
This is an important factor in the consideration of competitive, clean hydrogen production, as shown in Figure 4 (Ref 7). These operating plants are very reliable, and the nuclear industry has established a long history of safe operation which will continue to be key for clean energy generation in the decades ahead.

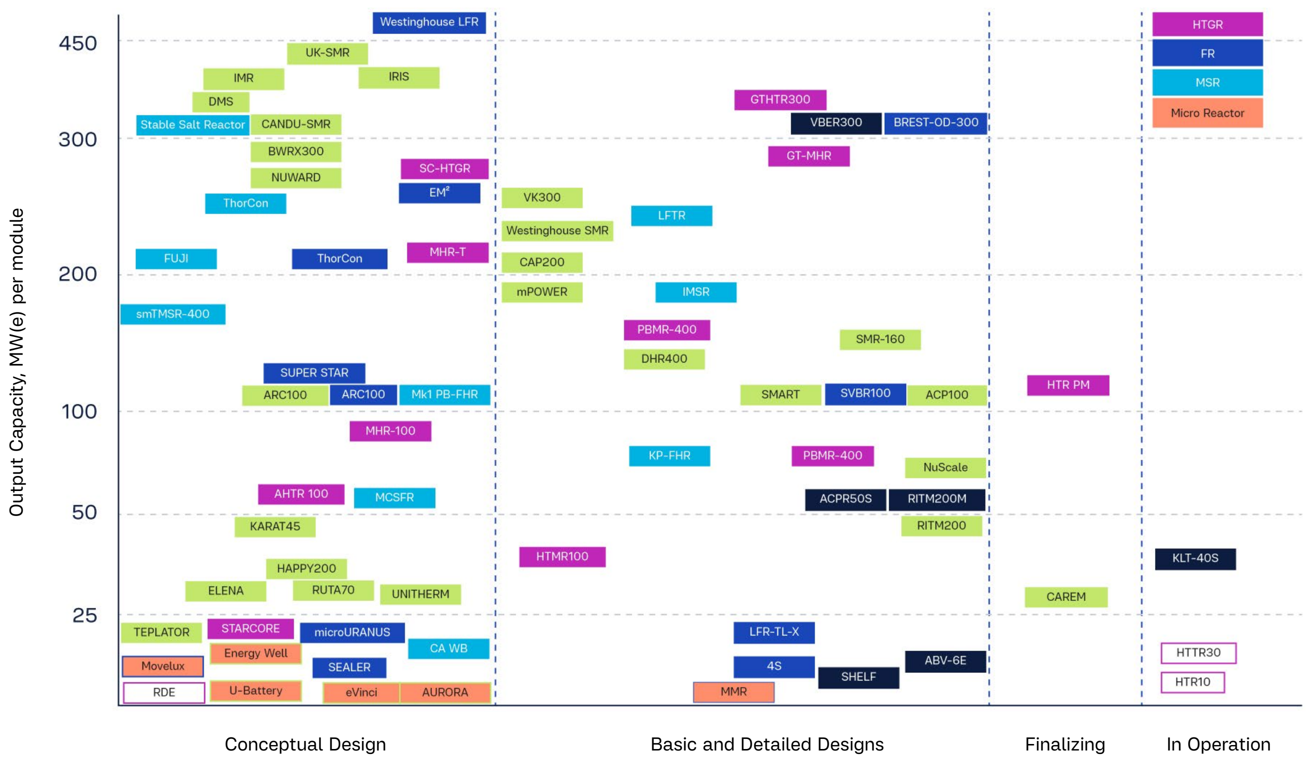
Figure 4: Average U.S. Nuclear Capacity Factor (Ref 7)



Source: NEI

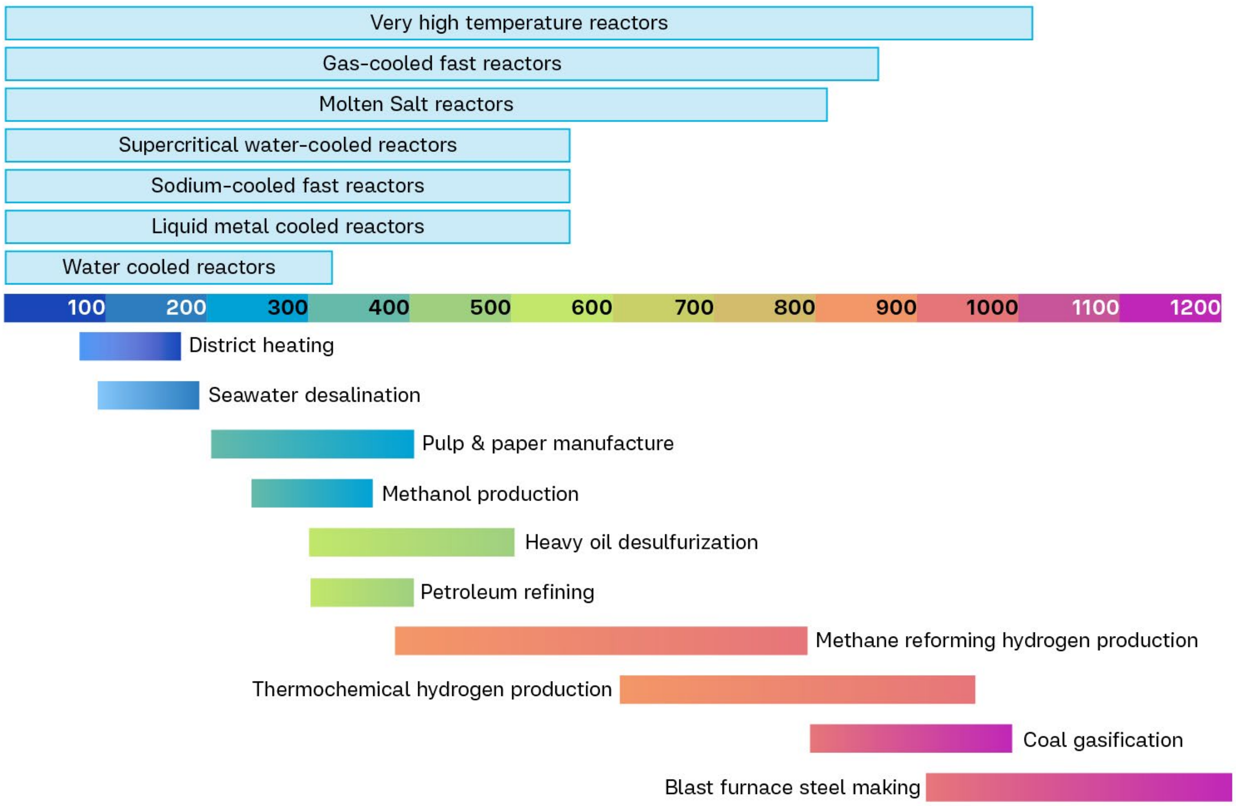
Advanced reactors have the potential for application beyond electricity generation and can be key enablers of the hydrogen economy transformation. Today, there are over 70 advanced reactor designs being developed at various phases of readiness as shown in Figure 5 (Ref 8)

Figure 5: IAEA Summary of Advanced Reactors under development (Ref 8)



These advanced reactors are based on various technologies such as LWRs, High Temperature Gas Reactors (HTGRs), liquid metal coolants (sodium, lead, lead-bismuth) fast reactors (LFRs), Molten Salt Reactors (MSRs), heat pipes, and other advanced and innovative designs. Each brings certain operational characteristics which capitalize on the nuclear power industry's experience to date to offer designs that are even safer than current generation plants, with flexibility and varying degrees of applicability to produce clean hydrogen. Figure 6 depicts some of the various advanced reactor technologies and their potential corresponding uses for different industrial applications based on their operating temperatures, including multiple pathways to produce hydrogen.

Figure 6: Advanced Reactor Types and Potential Industrial Applications (Ref 8)



Advanced reactors should be considered in roadmap development because several are already in advanced stages of development. They have received significant policy and investment support in jurisdictions such as the United States, Canada, China, and Russia. Some of these advanced technologies are expected to complete their design development, pass through the licensing process, and enter the marketplace this decade. This warrants their consideration for potential application in the hydrogen production strategies.

Some of these advanced designs offer favorable operational characteristics which are key for efficient and clean hydrogen production. These reactor types can support both low-temperature and high-temperature electrolysis as well as thermochemical splitting to produce clean hydrogen at large scale. Demonstration projects, initiatives, and feasibility studies are already underway to show the ability of these advanced reactors to produce clean hydrogen via various pathways. In addition, these advanced reactor designs address many of the legacy challenges associated with Generation II and Generation III/III+ large reactor projects, such as issues of construction delays, cost overruns, and affordability of capital and operating expenses (CapEx and OpEx.), as well as backend spent fuel and decommissioning challenges.

Hence, it is important for stakeholders and decision makers to consider the inclusion advanced reactor designs as an active part of the clean energy mix in hydrogen strategies, policies, and roadmaps development.

SECTION 04

Overview of Current National Hydrogen Policies and Strategies

At this time, 80 countries have provided some support for clean hydrogen production - either through the issuance, development or consideration of hydrogen strategies, policies, or roadmaps, or by providing some support for clean hydrogen projects or research and development. A significant number of these countries have an established nuclear infrastructure and operate nuclear reactors, and some of these countries have either expressly included nuclear hydrogen production in their roadmaps and strategies, or have issued policy documents that are technology neutral and would support nuclear hydrogen production due to its zero-carbon attributes. Following are some examples of federal government support for nuclear hydrogen production.

United States

the $1.2 trillion Infrastructure Investment and Jobs Act, signed into law by President Biden on November 15th of 2021, authorizes and appropriates $9.5 billion for clean hydrogen research, development and demonstration programs to be managed by the Secretary of Energy. Importantly, the Act defines "clean hydrogen" by carbon intensity, explicitly including hydrogen produced from nuclear, as well as renewables, fossil fuels and other eligible sources.

The bulk of the Act's funding appropriates $8 billion for fiscal years 2022-2026 to the newly created Office of Clean Energy Demonstrations under the Secretary of Energy to carry out a regional clean hydrogen hub program for four regional clean hydrogen hubs across the U.S. The hubs will have to demonstrate feedstock diversity, as the bill requires at least one hub produce hydrogen from nuclear energy, one from fossil fuels, and one from renewables. Additionally, at least one of each of the hubs will be required to demonstrate hydrogen end-use in either electric power generation, industrial sector, residential heating or transportation. The four hubs are required to be located in different regions of the U.S. and, if feasible, there is preference that at least two hubs be located within natural gas producing regions. The Act requires the Secretary of Energy to solicit proposals for the hubs 180 days after its passage, and select four regional hubs within one year from that date.

The Act also authorizes $1 billion for a clean hydrogen electrolysis program at the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy, with a goal to reduce the cost of producing clean hydrogen to less than $2 per kilogram by 2026. Also through the Office of Energy Efficiency and Renewable Energy, the government will award multiyear grants and contracts for research, development, and demonstration projects to advance new clean hydrogen production, processing, delivery and storage, as well as research for approaches to increase the reuse and recycling of clean hydrogen technologies.

In June 2021 the DOE launched the Energy Earthshots Initiative, to "accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade." The first Energy Earthshot is the Hydrogen Shot, which seeks to reduce the cost of clean hydrogen by 80% to $1 per kilogram in the next decade. The DOE also has a Hydrogen Plan which focuses on conducting coordinated R&D activities across various DOE offices to enable the adoption of hydrogen (H2) technologies across multiple applications and sectors. The DOE H2 Program is led by the H2 and Fuel Cell Technologies Office within the Office of Energy Efficiency and Renewable Energy. The program conducts research and development projects in hydrogen production, delivery, infrastructure, storage, fuel cells, and multiple end uses across transportation, industrial, and stationary power applications. The program also includes activities in technology validation, manufacturing, analysis, systems development and integration, safety, codes and standards, education, and workforce development. The funding authorized in the Infrastructure Investment and Jobs Act will help to achieve these programs.

A key part of the program in the U.S. is the H2@Scale initiative that includes DOE funded projects and national laboratory-industry co-funded activities to accelerate the early-stage research, development, and demonstration of applicable hydrogen technologies. The Idaho National Laboratory is leading several initiatives in this regard. The Energy Act of 2020 included $4B of funding for hydrogen RD&D, including DOE funding of nuclear hydrogen production R&D. Further, numerous bills supporting nuclear energy have recently been passed in Congress on a bipartisan basis.

Finally, further legislation is pending before Congress in the Build Back Better Act, which—if passed—would provide production tax credits for clean hydrogen (< $0.45kgCO_2e/kgH_2$) at a rate of $3/kg, and production tax credits for hydrogen produced by methane reforming of natural gas with carbon capture at rates between $0.6-$1/kg.

Canada

Canada issued its Hydrogen Roadmap in December 2020 and its near-term strategy for the next five years is to lay the foundation for the hydrogen economy in Canada. This includes developing a new hydrogen supply and distribution infrastructure to support early deployment hubs in mature applications while supporting Canadian demonstrations in emerging applications. In the mid-term range, hydrogen use will focus on applications that provide the best value proposition relative to other zero-emission technologies. For example, fuel cell electric vehicles and transit buses are planned to enter the rapid expansion phase as the market for fuel cell and battery technology becomes more defined. Then in its long-term view, it will focus on higher power demand applications, predisposed toward hydrogen energy storage and the lower power demand applications using batteries for energy storage. New transportation applications will move into the commercial and rapid expansion phases during this period.

These recommendations in the Canadian hydrogen roadmap focus on eight pillar areas:

- Forging strategic partnerships
- De-risking of investments
- Innovation and research and development
- Codes and standards
- Regulatory reform
- Awareness of public and private sectors
- Developing regional blueprints
- Working on international hydrogen markets

The inclusion of nuclear produced hydrogen is explicitly included in the Canadian roadmap by planning to leverage existing reactors as well as employ advanced reactors to produce high temperature process heat to enhance the overall efficiency of hydrogen production.

Brazil

Brazil is preparing to issue its hydrogen roadmap as a follow up to its "Pathway for H2 Economy in Brazil", originally issued in 2005. The roadmap is expected to focus on regulations which will address different hydrogen production paths and storage, and the potential for utilizing hydrogen in the energy, transport, fertilizer, chemical, and steel industries. In February 2021, the Brazilian National Council of Energy Policy (CNPE) announced hydrogen to be a publicly funded R&D priority and in August 2021, CNPE issued the Guidelines for its National Hydrogen Plan which focuses on six vectors: strengthening technology foundations; training and professional development; energy

80 countries provided support for clean hydrogen production - either through the issuance, development or consideration of hydrogen strategies, policies, or roadmaps, or by providing some support for clean hydrogen projects or research & development.

planning; regulatory framework; market growth and competitiveness; and international cooperation.

Three preliminary renewables-produced hydrogen projects have surfaced just over the past months, involving state-controlled utility Eletrobras and Germany's Siemens; Australia's Enegix Energy with the Ceara state government; and Australia's Fortescue Future Industries (FFI) and Brazil's port operator Prumo Logistica. The Angra nuclear power station already produces hydrogen from electrolyzers as a byproduct of a local chemical process using sea water and it is considering a feasibility study on the capture of this hydrogen for potential applications in transport, energy storage, and other areas.

European Union

The European Union issued its hydrogen strategy in 2020 with the priority to develop renewable produced hydrogen, using mainly wind and solar energy. In the short and medium term, however, hydrogen produced by other forms of low-carbon technologies will be needed. The hydrogen ecosystem in Europe is likely to develop through a gradual trajectory, at different speeds across sectors and possibly across regions. This will require different policy solutions. The strategy envisions three phases. In the first phase, from 2020 up to 2024, the strategic objective is to install at least 6 GW of renewable based hydrogen electrolyzers in the EU, resulting in up to 1 million tons of renewable produced hydrogen. In a second phase, from 2025 to 2030, hydrogen needs to become an intrinsic part of an integrated energy system. Thus, a strategic objective is to install at least 40 GW of renewable based hydrogen electrolyzers in the EU by 2030, with up to 10 million tons of renewable-produced hydrogen. In a third phase, from 2030 onwards and towards 2050, renewable based hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to-decarbonize sectors where other alternatives might not be feasible.

The role of nuclear energy in the EU Taxonomy is uncertain, although the Joint Research Center (JRC), the EU's scientific arm, determined recently that nuclear energy meets the Do No Significant Harm criterion required for taxonomy inclusion. The EC issued an initial Delegated Act in April 2021 that does not include nuclear energy; there are plans to issue a complementary Delegated Act in the summer of 2021. That Act may include nuclear technologies in the Taxonomy. Inclusion in the Taxonomy would make nuclear based projects more attractive as hydrogen production facilities. The EU position could affect the positions of individual EU member states as well as other jurisdictions looking at hydrogen policies. Nevertheless, other European countries have developed their own hydrogen policies and strategies, with some explicitly including nuclear energy as part of their clean hydrogen production model.

United Kingdom

In the United Kingdom, the government issued on November 2020 its "Ten Point Plan for Green Industrial Revolution", which aims for 5GW of hydrogen production capacity by 2030 (1GW by 2025), followed by a Hydrogen Strategy in August 2021, which lays the framework for implementation of the goals set out in the Plan. The Strategy adopts a twin-track approach to supporting both electrolytic "green" (which includes nuclear and renewables) and carbon capture-enabled "blue" hydrogen production. Nuclear energy is explicitly included in the Plan and the Strategy as a potential source for LTE, THE and Thermo-chemical water splitting processes for clean hydrogen production.

The Hydrogen Business Model under development seeks to overcome the initial cost gap between low-carbon hydrogen and higher-carbon fuels. There are different approaches under consideration including a "Variable Premium" model, which is similar to the Contract-for-Differences structure, and a volume-based model to ensure that adequate capacity exists regardless of whether or not there is demand.

In addition, the Strategy includes a plan launch a Net Zero Hydrogen Fund (NZHF) in early 2022 to support commercial development of new low-carbon hydrogen production projects in the 2020s. It will provide £240 million of government co-investment to support low-carbon hydrogen production by 2025.

In April 2022, the UK issued the "British Energy Security Strategy" which builds on the "Ten Point Plan for Green Industrial Revolution" and calls for a doubling of the previous 5GW target for hydrogen production by 2030. As part of this strategy, the UK plans to set up a hydrogen certification scheme to facilitate the import and export of high-grade hydrogen, as well as create new business models for hydrogen transport and storage infrastructure.

France

France reissued its hydrogen plan in 2020. The plan defines decarbonized hydrogen as hydrogen produced using Renewable Energy Sources (RES) or "carbon-free" electricity. The plan has a target of installed electrolyzer capacity of 6.5GW by 2030 (currently (2021), there is 1MW installed and 900MW planned). "Carbon-free" electricity includes nuclear power, given the country's current power mix includes more than 70% nuclear. France plans investments of $7B euros by 2030 (half by 2023, focusing on Industry (54%), Transport and Trade (27%) and R&D (19%)).

Czech Republic

The Czech Republic issued its Hydrogen Strategy in July 2021. The objective of the Strategy is to reduce greenhouse gas emissions in a way that allows for a smooth transition to low-carbon technologies, with a goal of also stimulating economic growth. Hydrogen production from nuclear power is a key tenet of the strategy. The Strategy defines low-carbon hydrogen as "hydrogen whose production generates a maximum of 36.4 g CO2/MJ1" and specifically includes hydrogen produced by electrolysis using electricity from nuclear sources as an example of low-carbon hydrogen. The Strategy also notes that nuclear hydrogen production is especially promising in the Czech Republic, given the availability of baseload zero-carbon electricity from existing nuclear power plants. However, domestic hydrogen requirements would require three times the electricity currently produced from the Dukovany and Temelin nuclear power plants. The Strategy acknowledges that the construction of new nuclear power plants, including advanced reactors is a possibility, with a large portion of this output dedicated to hydrogen production.

The Strategy presents two options for nuclear hydrogen production: low-temperature electrolysis and thermochemical splitting, with the former having a high technology readiness level and the latter being an option that would require further research and development.

Hungary

Hungary issued its National Hydrogen Strategy in May 2021. The Strategy sets out a vision to develop competencies in key elements of the hydrogen value chain to promote a shift to a zero-carbon society while maintaining economic competitiveness. The priority objectives include production by 2030 of 20 thousand tons per-year low-carbon hydrogen and 16 thousand tons per-year of carbon-free hydrogen (which include nuclear produced hydrogen) and installing 240 MW electrolyzer capacity.

The Strategy focuses on hydrogen produced with renewables (primarily solar) in the long term, but also notes the importance of opportunities for nuclear hydrogen production. In particular, the Strategy notes that the Paks nuclear power plant could be a source of large amounts of carbon-free electricity for the establishment of the hydrogen value chain. Hungary is in the process of constructing two additional reactors 1200 MWe reactors at the Paks site, which already hosts four 500Mwe reactors.

Russia

Russia, as part of its Energy Strategy 2035, has stated a goal to become a world leader in hydrogen production and export, establishing export targets of 0.2 million tons by 2024 and 2 million tons by 2030.

The hydrogen strategy is further detailed in the Roadmap for Hydrogen Development until 2024, released in October 2020, which sets out a multi-year action plan for the development of a hydrogen energy sector in Russia. Finally, Russia released in August 2021 the Concept for the Development of Hydrogen Energy in Russia, which is the first step in the lengthy action plan outlined in the roadmap.

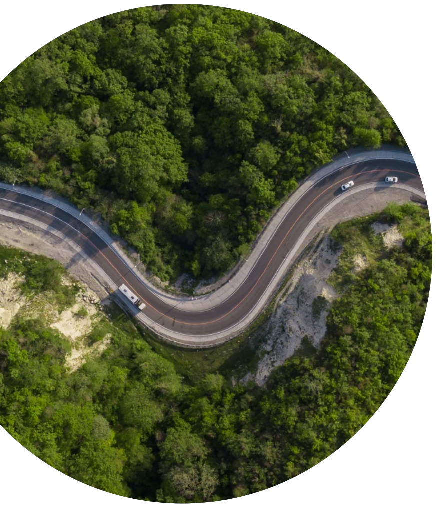
Actions set out in the Roadmap include the increase of hydrogen production based on natural gas, renewables, and nuclear power, and investments in production, transportation and consumption of hydrogen and hydrogen-based energy mixes. In addition, the strategy calls for the development of Russian low-carbon technologies to produce hydrogen by methane pyrolysis, electrolysis and other means, including by way of the localization of foreign technologies. The strategy also focuses on the internal market demand for hydrogen fuel cells in transportation and as energy storage, as well as a conversion tool to increase efficiency of centralized power supply systems. Finally, it centers international partnerships in the hydrogen field and expansion to global markets.

United Arab Emirates

On November 4, 2021, during COP26, the United Arab Emirates (UAE) announced its Hydrogen Leadership Roadmap, which aims to facilitate the decarbonization of the UAE's economy in line with its 2050 net-zero emissions commitments, while positioning the UAE to become a key global hydrogen export hub by targeting a 25% hydrogen market share by 2030. The UAE's Barakah NPP has two reactors in operation, with the third completing construction in November 2021 and a fourth schedule to be completed in 2022. The Emirates Nuclear Energy Corporation (ENEC), the owner of Barakah, has stated that hydrogen production at Barakah NPP is a possibility. ENEC has also signed an MOU with EDF to examine nuclear hydrogen production.

Japan

In March 2019 the government of Japan released its third Strategic Roadmap for H2 and Fuel Cells. Japan considers its domestic uptake of hydrogen as



a viable way to increase its energy self-sufficiency, decarbonize its economy, increase industrial competitiveness, and position Japan as a fuel cell technology exporter. Japan's Roadmap included an ambitious goal of achieving 40,000 fuel cell vehicles by 2020. Beyond 2020, the Roadmap includes goals of 200,000 fuel cell vehicles by 2025 and 800,000 by 2030. In addition, it expects 320 hydrogen refueling stations by 2025, and 900 by 2030. Finally, the Roadmap predicts 1,200 fuel cell buses by 2030.

In October 2020, Japan issued the Green Growth Strategy - a set of industrial policies aiming to support the overarching target set by the Prime Minister in October 2020, namely, make Japan carbon-neutral by 2050. The strategy sets goals in 14 fields, identifies current challenges, and formulates the basis for action plans including budgets, taxes, regulatory reforms, standardization, and international collaboration.

The 14 priority fields include production of hydrogen and ammonia. The Green Growth Strategy specifically includes nuclear energy, such as the demonstration of advanced reactor technology through international collaboration by 2030, the establishment of elemental technology for hydrogen production in a HTGR by 2030, and steady promotion of nuclear fusion research and development through international collaboration such as the ITER project.

South Korea

In January 2019, South Korea announced its H2 Economy Roadmap. The Roadmap outlines a goal of producing 6.2 million fuel cell electric vehicles and rolling out at least 1200 refilling stations by 2040. Additionally, the Roadmap envisioned the roll out on the street of at least 35 hydrogen buses in 2019, ramping this number up to 2000 by 2022 and 41000 by 2040. In terms of the energy sector, the roadmap outlines an objective to supply 15 GW of fuel cells for power generation by 2040. The industry ministry also plans to set up five hydrogen industry clusters in Incheon, Ulsan and the provinces of North Jeolla, North Gyeongang and Gangwon to establish an ecosystem for the energy source nationwide.
In 2022, Elcogen, an Estonia-headquartered company entered into an agreement with Uljin County and Next Energy Corporation to supply solid oxide electrolysis technology for a 200 MW nuclear hydrogen production complex at the Hanul NPP.

Many of these countries have an established nuclear infrastructure and operate nuclear reactors, and some have either expressly included nuclear hydrogen production in their strategies, or have issued policy documents that are technology neutral.

SECTION 05

International Hydrogen Efforts

International cooperation is important to enabling a global clean hydrogen market. While policies and regulations supporting the build-up of hydrogen infrastructure and clean hydrogen production capabilities must be passed at national and local levels, international cooperation can go a long way to support private investment, harmonize regulatory regimes, and create opportunities for cross-border projects. **Several international and regional cooperation initiatives have already been launched, including:**

- **Mission Innovation (MI)** is a global initiative of 22 countries and the European Commission launched alongside the Paris Agreement in 2015 to address clean energy innovation through action-oriented cooperation. In 2018, MI launched the Hydrogen Innovation Challenge, which seeks to reducing end-to-end clean hydrogen costs to $2 per kg (the point at which clean hydrogen becomes competitive) by increasing R&D in hydrogen technologies and industrial processes and delivering at least 100 hydrogen valleys worldwide by 2030.
- **The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)** is an inter-governmental partnership composed of 22 countries whose objective is to facilitate and accelerate the transition to clean and efficient energy and mobility systems using fuel cells and hydrogen technologies. IPHE seeks to "organize and implement effective, efficient, and focused international research, development, demonstration, and commercial utilization activities related to hydrogen and fuel cell technologies. It also provides a forum for sharing information on policies and technology status, as well as on initiatives, codes, and standards to accelerate the cost-effective transition to the use of fuel cells and hydrogen in the economy."
- **The International Energy Agency (IEA)** Technology Collaboration Program on Advanced Fuel Cells (AFC TCP) has the participation of 16 member states. The mission of the AFC TCP is to facilitate opportunities and reduce barriers to fuel cell commercialization by facilitating globally the development of fuel cell technologies and their application, and communicating key messages to industry, governments, and the public. The ACP TCP carries out this mission through coordinated research, technology development and systems analysis projects, as well as knowledge sharing platforms and events.

To support the use of nuclear energy as a key hydrogen production source, projects and programs enabling nuclear hydrogen production should be included in these and other burgeoning international cooperation efforts.

SECTION 06

Recommended Policy Actions for Nuclear Hydrogen Production

It is encouraging to see jurisdictions and government leadership, with the support of the private sector, debate, develop and issue hydrogen strategies, policies and roadmaps while seeking to decarbonize hard-to-abate energy sectors such as transportation, shipping, electricity, heating, and industrial processes. Nuclear energy can have a key role in the clean production of hydrogen and some of the countries with established nuclear energy infrastructure are already including nuclear hydrogen production as part of their overall plans. Some plans include initiatives for feasibility studies, R&D investments, and prototype developments.

However, to promote and enable a more robust approach for including a nuclear hydrogen production option to further accelerate and sustain the transformation of these energy sectors, the following recommendations should be considered when developing the various strategies, policies, and roadmaps.

Make Hydrogen Plans Technology Neutral

Governments preparing hydrogen plans and policies should include all low-carbon hydrogen production technologies in their plans. Preferably, hydrogen plans and policies should avoid the color scheme in favor of inclusion of technologies based on carbon footprint.

Include Nuclear Technology in Hydrogen Policies and Plans

- Nuclear hydrogen production should be expressly included as a key zero-carbon hydrogen pathway in hydrogen plans and roadmaps, as well as in the "guarantee of origin" schemes.
- Explicit goals and metrics for nuclear hydrogen production (e.g., x by year y) should be set and described in the policies and plans.
- Hydrogen hubs should include nuclear hydrogen production facilities.

Targeted Research, Development, and Demonstration (RD&D)

Governments should allocate targeted funding to nuclear energy RD&D with near, medium, and long-term goals. Specifically, **funding should be allocated to:**

1. create a pathway for large-scale commercial hydrogen production from existing reactors within the next three years, starting in 2022;
2. demonstrate hydrogen production using high-temperature steam electrolysis from advanced reactors by 2028;
3. demonstrate pilot thermochemical production of hydrogen within the next five years.

Set Production Incentives

- Provide tax incentives to nuclear based hydrogen producers. Examples include Investment Tax Credits, Production Tax Credits, and exemptions from other applicable taxes (e.g., carbon taxes, electricity production taxes, grid tariffs if applicable).
- Ensure that nuclear based hydrogen producers are eligible for various financial incentives (e.g., loan guarantees, low-interest government loans, etc.).

Establish End-User Incentives

- Subsidize during an initial period (e.g., five years) the purchase of nuclear-produced hydrogen through contract-for-difference schemes (e.g., government pays users the difference between the market price of fossil-fuel produced hydrogen and low-carbon hydrogen).
- Provide tax incentives to hydrogen users for the offtake of nuclear-produced hydrogen.
- Provide loans, grants or dedicated funds to industrial companies to decarbonize through the use of low-carbon hydrogen, and specifically include nuclear produced hydrogen as eligible for the incentives.

Leverage Government Procurement

Governments should, through public procurement, preferentially buy products (e.g., steel) made through the use of low-carbon hydrogen, including nuclear produced hydrogen.

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Appendix

Table 1: Status of Hydrogen Support at the Government Level Worldwide

Country	Status
Argentina	Initial policy discussions[1]
Australia	Issued (2018)[2,3]
Austria	Issued (2018)[4]
Bangladesh	Support for projects and/or R&D[5]

[1] https://www.bnamericas.com/en/interviews/argentinas-us84bn-green-hydrogen-project-awaiting-the-fine-print
[2] https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/national-hydrogen-roadmap
[3] https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy
[4] https://www.iphe.net/austria
[5] https://www.h2bulletin.com/bangladesh-first-pilot-hydrogen-production-plant/

Country	Status
Belgium	Issued (2021)[6]
Bolivia	In preparation[7]
Brazil	In preparation[8]
Bulgaria	In preparation[9,10]
Canada	Issued (2020)[11]
China	Hydrogen included in other clean energy roadmaps / strategies[12]
Chile	Issued (2020)[13]
Colombia	Issued (2021)[14]
Costa Rica	In preparation[15]
Croatia	In preparation[16]
Czech Republic	Issued (2021)[17]
Denmark	Support for projects and/or R&D[18]
Egypt	In preparation[19]
Estonia	Initial policy discussions[20]
Finland	Support for projects and/or R&D[21]
France	Issued (2020)[22]
Georgia	Initial policy discussions[23]
Germany	Issued (2020)[24]
Greece	Support for projects and/or R&D[25]
Hungary	Issued (2021)[26]

6 https://news.belgium.be/nl/federale-waterstofvisie-en-strategie
7 https://fuelcellsworks.com/news/bolivia-ministry-of-hydrocarbons-promotes-plan-to-generate-green-hydrogen/
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9 https://www.icis.com/explore/resources/news/2020/12/07/10583498/bulgaria-targets-1-1gw-green-hydrogen-capacity-by-2030
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11 https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf
12 https://www.ispionline.it/en/pubblicazione/chinas-emerging-hydrogen-strategy-30431
13 https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf
14 https://www.minenergia.gov.co/documents/10192/24302627/Hoja+de+Ruta+H2+Colombia_Borrador.pdf
15 https://latam-green.com/costa-rica-presenta-estrategia-nacional-de-hidrogeno-con-apoyo-del-bid/
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26 https://cdn.kormany.hu/uploads/document/a/a2/a2b/a2b2b7ed5179b17694659b8f050ba9648e75a0bf.pdf

Country	Status
Iceland	Support for projects and/or R&D[27]
India	Issued (2022)[28]
Indonesia	Support for projects and/or R&D[29]
Israel	Support for projects and/or R&D[30]
Italy	Issued (2020)[31]
Japan	Issued (2017)[32]
Jordan	Initial policy discussions[33]
Kazakhstan	In preparation[34]
Kuwait	Initial policy discussions[35]
Laos	Hydrogen included in other clean energy roadmaps / strategies[36]
Latvia	Hydrogen included in other clean energy roadmaps / strategies[37]
Lithuania	In preparation[38]
Luxembourg	Issued (2021)[39]
Malaysia	Issued (2021)[40]
Maldives	Support for projects and/or R&D[41]
Malta	Support for projects and/or R&D[42]
Mexico	Initial policy discussions[43]
Mongolia	Support for projects and/or R&D[44]
Morocco	Issued (2021)[45,46]
Mozambique	Support for projects and/or R&D[47]

27 https://fuelcellsworks.com/news/icelandic-new-energy-has-launched-2030-vision-for-hydrogen-in-iceland/
28 https://pib.gov.in/PressReleasePage.aspx?PRID=1799067
29 https://www.argusmedia.com/en/news/2231095-indonesias-pertamina-eyes-hydrogen-to-meet-2026-goal
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46 https://www.mem.gov.ma/Pages/actualite.aspx?act=278
47 https://www.energyvoice.com/oilandgas/africa/petrochemicals-africa/302854/tcrk-bruton-mozambique-hydrogen/

Country	Status
Myanmar	Hydrogen included in other clean energy roadmaps / strategies[48]
Namibia	In preparation[49]
Netherlands	Issued (2020)[50]
Nepal	Initial policy discussions[51]
New Zealand	Issued (2019)[52]
Nigeria	Hydrogen included in other clean energy roadmaps / strategies[53]
Norway	Issued (2020)[54,55]
Oman	Initial policy discussions[56]
Pakistan	Initial policy discussions[57]
Panama	Issued[58]
Papua New Guinea	Support for projects and/or R&D[59]
Paraguay	Issued (2021)[60]
Poland	Issued (2021)[61]
Portugal	Issued (2020)[62]
Philippines	Support for projects and/or R&D[63]
Romania	In preparation[64]
Russia	Issued (2020)[65,66]
Saudi Arabia	Support for projects and/or R&D[67]
Serbia	In preparation[68]
Singapore	Hydrogen included in other clean energy roadmaps / strategies[69]

[48] http://d2ouvy59p0dg6k.cloudfront.net/downloads/myanmar_s_electricity_vision_final_web.pdf
[49] https://www.energyvoice.com/renewables-energy-transition/hydrogen/africa-hydrogen/390807/namibia-ol-hydrogen-2023/
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[69] https://www.ema.gov.sg/energy-2050-committee-report.aspx

Country	Status
Slovakia	Issued (2021)[70]
Slovenia	Support for projects and/or R&D[71]
South Africa	Issued (2021)[72]
South Korea	Issued (2019)[73]
Spain	Issued (2020)[74]
Suriname	Support for projects and/or R&D[75]
Sweden	In preparation[76]
Switzerland	Support for projects and/or R&D[77]
Thailand	Initial policy discussions[78]
Turkey	Initial policy discussions[79]
United Arab Emirates	Issued (2021)[80]
United Kingdom	Issued (2021)[81]
United States	Support for projects and/or R&D[82]
Ukraine	Support for projects and/or R&D[83]
Uruguay	Support for projects and/or R&D[84]
Uzbekistan	Issued (2021)[85]
Vietname	Support for projects and/or R&D[86]
Zimbabwe	Support for projects and/or R&D[87]

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Table 2: Summary of Current National Hydrogen Roadmaps and Strategies from Selected Countries/Regions with Nuclear Infrastructure

	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
Argentina	Argentina already has legislation to promote the research, development, production, and use of hydrogen as fuel (Law 26.123, passed in 2006). During the 2021 forum "Towards a National Hydrogen 2030 Strategy", the current president Alberto Fernández announced the elaboration of a national hydrogen strategy by the end of 2021.	Argentina aims to limit its greenhouse gas emissions to 313 $MtCO_2e$ by 2030	No direct reference to date. Currently, Argentina operates 3 nuclear plants, has an Advanced Reactor under construction (CAREM project), with plans for new build with the Hualong PWR design.	TBD	None to date
Belgium	Belgium presented its federal hydrogen vision and strategy, approved by the Council of Ministers, on 29 October 2021. The strategy sets out four pillars as follows: • Belgium will position itself as the hub for Western Europe's import of renewable-produced hydrogen. The government has calculated that importing hydrogen is more efficient than producing it in country. The strategy envisions a limited local capacity of 150 MW for electrolysis production by 2026. On November 4, 2021, during COP26 in Glasgow, the Belgian ports of Antwerp and Zeebrugge signed an agreement with the Chilean Ministry of Energy to develop green hydrogen trade between Chile and Western Europe. • Strengthen the role of local companies and research institution in the hydrogen economy by federal support for innovation (including through tax incentives). • Establishing a robust hydrogen market, with optimal and safe transport of hydrogen. • Cooperation with neighboring countries and Belgian regions. The Flemish and Walloon regions have already issued hydrogen strategies and calls for hydrogen projects.	None to date	The strategy relies on solar and wind energy to produce hydrogen.[88] Belgium has two operating nuclear power plants, but the current plan is to phase out nuclear power generation completely by 2025. Unless that policy changes, hydrogen production from nuclear in the country is unlikely.	The federal government intends draw on funds set aside for Belgium's green energy transition and the national plan to finance the strategy.[89] The Walloon Government is providing $25M for financing of hydrogen projects that will promote the energy transition in the region.[90]	None to date

[88] https://www.h2-view.com/story/belgium-federal-hydrogen-vision-and-strategy-approved-by-ministers/
[89] https://www.brusselstimes.com/belgium/191240/belgium-wants-to-become-a-hub-for-renewable-hydrogen/
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	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
Brazil	Issued in 2005, "Pathway for H2 Economy in Brazil", Ministry of Mines and Energy preparing H2 Roadmap to be delivered in 2021H2. Focus to be on regulations to address different hydrogen production paths, storage and its potential in the energy, transport, fertilizer, chemical, and steel industries. In Feb 2021, the Brazilian National Council of Energy Policy (CNPE) announced hydrogen to be an R&D priority to be funded publicly (no details provided as of yet). Three preliminary renewables-produced hydrogen projects have surfaced over the past month, involving state-controlled utility Eletrobras and Germany's Siemens; Australia's Enegix Energy with the Ceara state government; and Australia's Fortescue Future Industries (FFI) and Brazil's port operator Prumo Logistica.	The National Energy Policy Council (CNPE) issued in August 2021 the Guidelines for its National Hydrogen Plan which focuses on six vectors: strengthening technology foundations; training and professional development; energy planning; regulatory framework, market growth and competitiveness; and international cooperation.	A project exploring nuclear hydrogen production has commenced at Angra NPP. Nuclear currently enjoys strong support in Brazil, with funding allocated to finish the construction of Angra 3 and additional 6GW of units to be sited in the Northeast of Brazil. The Advanced Reactor option is being closely studied in Brazil.	No funding details yet	Project at Eletronuclear's Angra NPP to capture and use the hydrogen being generated as a by-product of a chemical process and currently being released into the atmosphere.
Bulgaria	None	Bulgaria is planning to develop a hydrogen roadmap targeting 1.1GW of hydrogen production capacity by 2030, in line with the European Commission hydrogen strategy.	The announcements to date have focused on hydrogen production using renewable sources with a goal of installing additional 800MW wind and 280MW solar capacity by 2030. Bulgaria has two nuclear reactors generating about one-third of its electricity and has proposed two additional reactors. Therefore, hydrogen production from nuclear power is possible.[91]	TBD	None to date

[91] https://www.icis.com/explore/resources/news/2020/12/07/10583498/bulgaria-targets-1-1gw-green-hydrogen-capacity-by-2030

Canada

Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
H2 Strategy for Canada (issued Dec 2020) **Near-term strategy:** In the next five years, Canada plans to lay the foundation for the hydrogen economy in Canada. This includes developing new hydrogen supply and distribution infrastructure to support early deployment hubs in mature applications while supporting Canadian demonstrations in emerging applications. Target 3MT/yr. **Mid-term:** To reach the opportunities outlined in the 2050 Transformative scenario, Canada should aim to be 10-20% of the way there by 2030 in terms of deployment volumes and GHG abatement. Hydrogen use in the mid-term will focus on applications that provide the best value proposition relative to other zero-emission technologies. For example, fuel cell electric vehicles and transit buses will enter the rapid expansion phase as the market for fuel cell and battery technology becomes more defined. Target 4MT/yr **Long-term:** higher power demand applications (utility biased) predisposed toward hydrogen energy storage and the lower power demand applications (efficiency biased) using batteries for energy storage. New transportation applications will move into the commercial and rapid expansion phases during this period. Target 20 MT/yr	Recommendations have been proposed in eight pillar areas: 1. Strategic Partnerships - Strategically use existing and new partnerships to collaborate and map out the future of hydrogen in Canada. 2. De-Risking of Investments - Establish funding programs, long-term policies, and business models to encourage industry and governments to invest in growing the hydrogen economy. 3. Innovation – Take action to support further R&D, develop research priorities, and foster collaboration between stakeholders to ensure Canada maintains its competitive edge and global 4. leadership in hydrogen and fuel cell technologies. 5. Codes and Standards - Modernize existing and develop new codes and standards to keep pace with this rapidly changing industry and remove barriers to deployment, domestically and internationally. 6. Enabling Policies and Regulation - Ensure hydrogen is integrated into clean energy roadmaps and strategies at all levels of government and incentivize its application. 7. Awareness - Lead at the national level to ensure individuals, communities, and the private sector are aware of hydrogen's safety, uses, and benefits during a time of rapidly developing technologies. 8. Regional Blueprints - Implement a collaborative, multi-level government effort to facilitate the development of regional hydrogen blueprints to identify specific opportunities and plans for hydrogen production and end use. 9. International Markets - Work with international partners to ensure the global push for clean fuels includes hydrogen.	H2 Strategy specifically includes nuclear: • Hydrogen production at existing reactors: "Opportunity for nuclear hydrogen production today is in Ontario, where three of the four nuclear generation stations are located, and in New Brunswick." • Advanced reactors can produce high temperature process heat, which enhances the overall efficiency of hydrogen production … "Commercial deployment of advanced reactors and small modular reactors is not expected to be a near-term opportunity but offers a longer-term opportunity for production of hydrogen." • "Using the steam produced by nuclear reactors as the reactant in the steam methane reformation process … would eliminate the need to use natural gas to create steam and would simplify and lower the cost of carbon capture." • Use of SOEC electrolyzers to improve the efficiency of hydrogen production. • Thermochemical water splitting explored. Nuclear enjoys strong support in Canada. Billions of dollars allocated to refurbishment of existing reactors in Ontario. Canada launched in 2020 the Small Modular Reactor Action Plan for the development, demonstration and deployment of Advanced Reactor for multiple applications at home and abroad.	Limited R&D funding; additional funding streams to be established.	• Efforts underway to study the economics of nuclear hydrogen production at the Bruce Nuclear Generating Station. • Ontario Tech advancing thermochemical production of H2 Studies at CNL

	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
China	China today is the world's largest producer of gray hydrogen. Hydrogen is listed in the country's latest five-year plan (14th Five Year Plan, FYP, 2021-2025), but the country currently lacks a comprehensive clean hydrogen plan. China did release in 2016 its first Hydrogen Fuel Cell Vehicle (FCV) Technology Roadmap, which aims for mass application of hydrogen in the transport sector by 2030 -- interim targets for 5,000 FCVs in demonstration alongside 100 hydrogen refueling stations (HRS) by 2020. The Roadmap also envisions over 1 million FCVs by 2030 and over 1,000 stations by 2030, by which time 50 per cent of hydrogen production is expected to come from renewable sources. Beijing forecasts its hydrogen use for road transport and power generation to reach 50 tons a day by 2023, and 135 tons by 2025 and between 2021 and 2025, some 4,400 trucks are expected to shift to fuel cells.	The National Development and Reform Commission (top economic planning agency) is drafting a plan to develop its hydrogen industry as it seeks to cut emissions. The plan may be released 2021/2022.[92]	Given the important role of nuclear in China's energy mix and China's rapid expansion of nuclear power as well as RD&D in non-electric uses of nuclear, it is expected that nuclear hydrogen production will be part of China's hydrogen strategy.	TBD	China's Institute of Nuclear and New Energy Technology is piloting several lab-scale projects, including hydrogen production via high temperature electrolysis and thermochemical splitting.
Czech Republic	The Czech Republic issued its Hydrogen Strategy on July 26, 2021 in the context of the European Green Deal objective of climate neutrality by 2050. The objective of the Strategy is to "reduce greenhouse gas emissions in such a way that the economy shifts smoothly to low-carbon technologies" with the goals of (1) reducing greenhouse gas emissions and (2) stimulating economic growth. To achieve these objectives, the Strategy sets four specific goals: • Volume of low-carbon hydrogen production • Volume of low-carbon hydrogen consumption	None to date	The Strategy defines low-carbon hydrogen as "hydrogen whose production generates a maximum of 36.4 g CO2/MJ1" and specifically includes hydrogen produced by electrolysis using electricity from renewable or nuclear sources as examples of low-carbon hydrogen. The Strategy further notes that "[p]roduction using nuclear energy appears to be promising, especially under the conditions existing in the Czech Republic, but even the future available capacity of nuclear facilities may not be sufficient for hydrogen production." The Strategy also states that nuclear power plants are "[p]otential technologies	The Strategy relies on the use of existing schemes to support hydrogen production and infrastructure, noting that there are more advantages for applicants and support organizations be using programs for which financial resources are allocated or planned. There are no plans to create special programs to support the Hydrogen Strategy.	None to date

[92] China is Formulating a Hydrogen Plan But Its Timing is Uncertain - Bloomberg

	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
	• Infrastructure readiness for hydrogen transport and storage • Progress in R&D and production of hydrogen technologies The Hydrogen Strategy is based on four pillars: • Low-carbon hydrogen production • Low-carbon hydrogen use • Hydrogen transport and storage • Hydrogen technologies		that could produce sufficient quantities of low-carbon hydrogen directly in the Czech Republic" and that "it will also be possible to continue discussions on the construction of new nuclear sources, potentially including small modular reactors that would use a larger portion of their output to produce low-carbon hydrogen." The Strategy discusses both LTE from nuclear and thermochemical hydrogen production.		
European Union	**H2 Strategy July 2020** The priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy. In the short and medium term, however, other forms of low-carbon hydrogen are needed. The hydrogen ecosystem in Europe is likely to develop through a gradual trajectory, at different speeds across sectors and possibly across regions and requiring different policy solutions In the first phase, from 2020 up to 2024, the strategic objective is to install at least 6 GW of renewable hydrogen electrolyzers in the EU and the production of up to 1 million tons of renewable hydrogen. In a second phase, from 2025 to 2030, hydrogen needs to become an intrinsic part of an integrated energy system with a strategic objective to install at least 40 GW of renewable hydrogen electrolyzers by 2030 and the production of up to 10 million tons of renewable hydrogen in the EU In a third phase, from 2030 onwards and towards 2050, renewable hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to-decarbonize sectors where other alternatives might not be feasible.	The policy focus will be on laying down the regulatory framework for a liquid and well-functioning hydrogen market and on incentivizing both supply and demand in lead markets, including through bridging the cost gap between conventional solutions and renewable and low-carbon hydrogen and through appropriate State aid rules.	Nuclear not included in hydrogen plans. At the level of the European Parliament, discussion is solely focused on renewable produced hydrogen at the moment. The role of nuclear in the EU Taxonomy still uncertain, although the JRC, the EU's scientific arm, determined last month that nuclear meets the Do No Significant Harm criteria required for taxonomy inclusion. EC issued initial Delegated Act in April 2021 that does not include nuclear; plans to issue a complementary Delegated Act in summer 2021 potentially including nuclear in the Taxonomy. Inclusion in the Taxonomy could make nuclear projects more attractive as hydrogen production facilities. EU position could affect the positions of EU member states as well as other jurisdictions looking at hydrogen policies. Note: CEE countries, such as Poland, the Czech Republic, Slovakia, Hungary, Romania and Bulgaria have all included nuclear as key to their energy mix. These countries have not yet announced hydrogen plans.	From now to 2030, investments in electrolyzers could range between €24 and €42 billion In addition, over the same period, €220-340 billion would be required to scale up and directly connect 80-120 GW of solar and wind energy production capacity to the electrolyzers to provide the necessary electricity. In addition, investments of €65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refueling stations. From now to 2050, investments in production capacities would amount to €180-470 billion in the EU.	*See specific countries*

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Finland	The Finnish government has set targets for the country to become carbon-neutral by 2035 and carbon-negative by 2050. Although Finland does not have a stand-alone hydrogen strategy or roadmap, hydrogen is considered an integral part of the national energy and climate strategy of Finland. Further, several industrial sectors in Finland have prepared their own hydrogen roadmaps with specific actions. One example is the Hydrogen Roadmap created by a team of experts from VTT Technical Research Centre.[93] It is estimated that the total potential for green hydrogen production in Finland is between 100 kt and 150 kt in 2030 There is convergence in recommending the following: • Creating a national vision/strategy of Hydrogen for Finland • Creating the regulation governing the hydrogen economy • Creating appropriate incentives for the Hydrogen marketplace	No official plan proposed to date	Some of the industry-developed hydrogen strategies are explicit in including nuclear as a clean source of low-carbon hydrogen production. Currently, Finland operates four nuclear reactors with a fifth under construction.	As part of Finland's Sustainable Growth Programme, the Finnish Government allocated EUR 150 million in public funding to projects to hydrogen and carbon capture and utilization projects. Part of the funding will be directed to projects linked to the European-wide hydrogen Important Project of Common European Interest (IPCEI), while some funding will be reserved for national projects.[94]	No projects as of the publication of this report
France	France reaffirmed its hydrogen plan in 2020. It defines decarbonized hydrogen which uses Renewable Energy Systems or "carbon-free" electricity. Target of installed electrolyzer capacity of 6.5GW by 2030 (current 1MW installed and 900MW planned)	N/A	"Carbon-free" electricity intended to include nuclear. The country's current power mix includes more than 70% nuclear.	$7B Euros to 2030 (half to 2023 focusing on Industry (54%), Transport and Trade (27% and R&D (19%)) Funds include an initial €2bn as part of a €100bn stimulus package through 2022 against the Covid-19 related economic slump.	EDF is planning hydrogen production at its existing fleet, but no specific plans announced. On April 27, 2021, EDF Group and Rosatom signed an agreement to jointly promote clean hydrogen projects in Europe and Russia.

[93] https://www.businessfinland.fi/4abb35/globalassets/finnish-customers/02-build-your-network/bioeconomy--cleantech/alykas-energia/bf_national_hydrogen_roadmap_2020.pdf
[94] https://www.electrive.com/2021/06/03/ipcei-to-fund-12-european-hydrogen-mobility-projects/

	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
Germany	**Core Objectives:** (1) Green hydrogen will play a central role in the promotion and completion of Germany's energy transition policy • For decarbonization • As a means of storing renewable energy • As an energy source • As raw material (2) Fulfilling the global responsibility to meet the challenge of reducing CO2 emissions (3) Building a hydrogen society is a collective task for the EU	**Hydrogen use in Germany** • 2030: 90-110 TWh • 2050: ~380 TWh **Major Policies:** Support for conversion to fuel cells for automobiles, trains, and coastal and inland water transportation vessels (~2023) Support for development of hydrogen refueling and recharging infrastructure (~2023) Support for hydrogen technology research (e.g., NIP II, a program for innovation in hydrogen and fuel cell technology) (~2026) Support for PtL facilities that convert electricity to liquid fuel (~2023) Investment in new technologies and large-scale facilities (~2023) Support for the introduction of fuel cell heaters (~2024) Support for hydrogen research and industrialization through the Real-World Laboratories program (~2023) Support for research on the practical application of fuel cell powered airplanes and ships (~2024)	Germany's current policy is to shut down of nuclear plants by 2022; hence, nuclear is not included in national hydrogen plans.	$12.36B Euros allocated to investments	N/A
Hungary	Hungary issued its National Hydrogen Strategy in May 2021, with a vision to develop competencies in key elements of the hydrogen value chain, which, "supplemented through targeted RDI and economic development activities, will serve to promote the shift towards a carbon-free society and to maintain the competitiveness of the Hungarian economy." **The Strategy sets out four priority objectives to be achieved by 2030:** (1) Production of large volumes of low-carbon and decentralized carbon-free hydrogen:	None to date	The Strategy focuses on the renewables (primarily solar) produced hydrogen in the long term, but also notes the importance of opportunities for nuclear hydrogen production. In particular, the Strategy notes that the Paks nuclear power plant "may supply a significant amount of carbon-free	The Strategy does not discuss how the priority objectives will be funded.	None to date

	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
	• 20 thousand tons / year low-carbon hydrogen • 16 thousand tons / year of carbon-free hydrogen • 240 MW electrolyzer capacity (2) Decarbonization of industrial consumption, partly with hydrogen: • 20 thousand tons / year low-carbon hydrogen • 4 thousand tons / year of carbon-free hydrogen • avoiding the emission of 95 thousand tons of CO2 (3) Accelerating the transition to clean modes of transportation. (4) Building sector integration ability				
India	India issued the first phase of its hydrogen roadmap in February 2022, offering incentives to aid the government in meeting its climate targets and turn India into a green hydrogen hub. The Green Hydrogen/Green Ammonia Policy offers a waiver of inter-state transmission charges for 25 years for projects set up before July 2025 and will also give manufacturers of Green Hydrogen and Ammonia priority connectivity to the grid. Manufacturers of green hydrogen and green ammonia will also be allowed to set up bunkers near ports for storage for export. The Policy will also facilitate the banking of unconsumed renewable power with distributors for 30 days, so that clean power producers can store surplus output with another utility to be used later.	India is proposing to launch a comprehensive National Hydrogen Energy Mission in 2021-22 "for generating hydrogen from green power sources."[95] It published the first step towards its National Hydrogen Mission in February 2022.[96]	Unclear to date. Statements from government officials are focused on renewables produced hydrogen, however given India's substantial and quickly growing nuclear fleet, nuclear hydrogen production is a logical option for the country. India has installed capacity of 6.78 GW of nuclear, more than 4 GWe of nuclear under construction and ambitious plans to grow nuclear capacity to 22.48 GW by 2031.	None to date	None to date

[95] https://www.cnbc.com/2021/03/10/india-turns-to-green-hydrogen-in-a-bid-to-decarbonize-its-economy.html
[96] https://pib.gov.in/PressReleasePage.aspx?PRID=1799067

	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
Japan	In March 2019 the Government of Japan released its third Strategic Roadmap for H2 and Fuel Cells. Japan considers its domestic uptake of hydrogen as a viable way to increase its energy self-sufficiency; decarbonize its economy; increase industrial competitiveness; and position Japan as a fuel cell technology exporter. **Japan's H2 Roadmap has an ambitious goal of:** • 40,000 fuel cell vehicles by 2020; 200,000 fuel cell vehicles by 2025; and 800,000 by 2030; • 320 Hydrogen refueling stations by 2025; and 900 by 2030; and • 1,200 fuel cell buses by 2030. In October 2020, Japan issued the Green Growth Strategy - a set of industrial policies aiming to support the overarching target set by the Prime Minister in October 2020: make Japan carbon neutral by 2050. The strategy sets goals in 14 fields, identifies current challenges and formulates the basis for action plans including budgets, taxes, regulatory reforms, standardization and international collaboration. The 14 priority fields include hydrogen and ammonia.	The hydrogen portion of the green growth strategy aims to: • Achieve a supply cost of 30 yen/Nm3 (less than 1/3 of the current sales price) by 2030 and make a hydrogen power generation cost lower than gas-fired power generation cost (less than about 20 yen/Nm3 hydrogen) by 2050, which will be competitive enough with fossil fuels. • Introduce a maximum of 3 million tons of hydrogen in 2030. Aim to supply around 20 million tons of hydrogen in 2050.	The Green Growth Strategy specifically includes nuclear, which includes: • demonstration of small modular reactor technology through international collaboration by 2030 • **establishment of elemental technology for hydrogen production in HTGR by 2030**, and • steady promotion of nuclear fusion R&D through international collaboration such as the ITER project.	The total government budgetary support for hydrogen for this financial year (ending March 2021) is 70 billion yen and includes: • subsidies for fuel cell vehicles; • subsidies for hydrogen refueling stations; • research and development on fuel cell technologies, hydrogen supply infrastructure, international research collaboration projects for innovative technologies in clean energy (for example carbon capture); • pilot projects to develop the hydrogen supply chain; and • technology development to produce, store and utilize hydrogen. In January 2020 the Japan Bank for International Cooperation (JBIC) designated hydrogen as an "essential resource", unlocking more government funding for hydrogen projects (covering the entire supply chain including production, transportation, supply and utilization) to be undertaken in developed countries.	Japan Atomic Energy Agency (JAEA) is pursuing the demonstration of nuclear hydrogen production through thermochemical splitting at an HTGR.
Mexico	Hydrogen was singled out for the first time in SENER (Energy Ministry) Proseden national development plan earlier this year as a potential future replacement for fossil fuels in power plants operated by Comisión Federal de Electricidad (CFE). Mexico launched earlier in 2021 the Asociación Mexicana de Hidrógeno (AMH), which includes more than 30 energy companies, energy trade groups and agencies from the states of Coahuila, Sonora, Tamaulipas, Hidalgo, Campeche, Puebla and Nuevo León.	N/A	Mexico operates two BWR reactors at Laguna Verde and has been exploring the construction of additional reactors at the site. CFE, which operates Laguna Verde, has also expressed interest in Advanced Reactors.	None to date	None to date

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Netherlands	**Strategy announced on March 30, 2020:** **2019-2021:** preparatory program for the roll-out of hydrogen, using ongoing initiatives and projects as a point of departure, to be concluded with an evaluation to inform the further specifications and objectives of the next phases. Decision on actions beyond 2030 to be made by end of 2021. **2022-2025:** based on the results of the first phase, particularly if the cost reduction of electrolysis and the commitment of the relevant parties provide a sufficient basis, scaling up to 500 MW of established electrolysis capacity by 2025, in conjunction with the development of the demand for hydrogen and regional infrastructure and the connection of various clusters. 2025: decision on the final structure of the next phase. **2026-2030:** scaling up to 3-4 GW of established electrolysis capacity, connection to storage sites and expansion of infrastructure, on the condition of additional growth of renewable electricity.	N/A	Nuclear is not specifically included or excluded. The objective is to support sustainable hydrogen, primarily based on electrolysis using sustainable electricity, but also based on sustainable biogenic feedstocks. "Sustainable" hydrogen (or "clean" hydrogen), is within the meaning of Do No Significant Harm (DNSH) and includes "blue hydrogen." The result on the inclusion of nuclear in EU taxonomy may have an impact. The Netherlands is considering additional nuclear power, including Advanced Reactors. There's currently one operating reactor in the country.	EUR 10 million in 2021, EUR 35 million per year thereafter. Primary aim: accelerate cost reduction.	The Netherlands has one nuclear reactor generating a small amount of its electricity.
Pakistan	None	UK-based Oracle Power and PowerChina International Group signed an agreement to jointly set up a 400-MW solar PV-powered hydrogen production plant in Pakistan. The partnership is seeking secure governmental support in Pakistan to establish a green hydrogen economy and seek to develop industrial collaboration with the government's assistance, while also working to set up a valuable export avenue.[97]	TBD. Pakistan has five operating reactors, with a further unit under construction.	TBD	None to date

[97] https://renewablesnow.com/news/oracle-powerchina-to-explore-400-mw-green-h2-project-in-pakistan-756957/

Russia

Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
Energy Strategy 2035: goal for Russia to become a world leader in hydrogen production and export, established export targets of 0.2 million tons by 2024 and 2 million tons by 2030. Actions include: • increase of hydrogen production based on natural gas, including using renewable and **nuclear power**; investments in production, transportation and consumption of hydrogen and hydrogen-based energy mixes • development of Russian low-carbon technologies to produce hydrogen by methane pyrolysis, electrolysis and other means, including by way of foreign technologies localization • internal market demand for hydrogen fuel cells in transportation and as energy storage and a conversion tool to increase efficiency of centralized power supply systems • international partnerships in the hydrogen field and expansion to global markets. **H2 Roadmap 2024:** high-priority pilot hydrogen projects: • **nuclear-based hydrogen production** • development, production and use of pilot equipment for carbon-free hydrogen production • development, manufacturing and testing of gas turbines for methane-hydrogen fuel • development of a hydrogen-run railway transport prototype • development of pilot sites for low-carbon hydrogen production at hydrocarbon processing facilities or natural gas production facilities	N/A	Nuclear hydrogen production is a key component of Russia's hydrogen strategy.	TBD	Rosatom selected adiabatic steam methane reforming to study nuclear hydrogen production concept from the MHR-100 (Modular Helium Reactor with prismatic fuel assemblies ~200 MWt(t) designed by OKBM Afrikantov) for the near-term deployment in Russia. CO2 by-product to be used for various industrial end-uses. Rosatom signed in 2020 an agreement with the Government of Japan to export hydrogen to Japan. In April 2021, Russia's Ministry for the Development of the Far East and the Arctic, the Government of the Sakhalin Region and Rosatom signed an MOU for the "Creation and Development of a Hydrogen Cluster" project, which provides for cooperation in the construction of a hydrogen production complex; organization of the hydrogen supply chain to foreign markets and local consumers; and creation of a hydrogen park with enterprises implementing projects in this area. In September 2021, the Government of the Sakhalin Region, Rosatom, Russian Railways and Transmashholding (TMH) signed a protocol concerning a project for organizing a railway service using hydrogen fuel cell trains on Sakhalin island. Rosatom is responsible for the production and supply of hydrogen, as well as the organization and operation of the refueling infrastructure.[98]

[98] https://www.neimagazine.com/news/newsrussia-plans-to-build-experimental-hydrogen-trains-on-sakhalin-island-9060984

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Slovakia	The Government approved the National Hydrogen Strategy on June 23, 2021. The Strategy states that Slovakia should use hydrogen as an energy source in all industries and economic activities where electrification is not possible or economic. The Strategy envisions that hydrogen will be used mainly in the chemicals, petrochemicals, steel and heating industries as well as in transport.	None to date	TBD. Slovakia has five nuclear reactors generating half of its electricity and two more under construction.	TBD	None to date
Slovenia	None to date	Four Slovenian companies (Plinovodi, ELES, Holding Slovenske elektrarne (HSE) (a state-owned generation company) and Hidroelektrarne na spodnji Savi (HESS)) have submitted an application to the European Innovation Fund for Slovenia's first hydrogen project -- SLOP2G Project - which links two energy locations where renewable electricity and the surplus of electricity in the system will be converted to green hydrogen which, through methanation, will be further converted into synthetic methane. On both locations, the hydrogen and synthetic methane will be available for injection into the gas transmission network and for use by industrial and commercial users.	TBD. Slovenia has one nuclear reactor at the Krško Nuclear Power Plant, the ownership of which it shares with Croatia. The country is currently considering adding a second unit at Krško. HSE is the operator of Krško. It's unclear whether the SLOP2G Project would partially rely on electricity produced at Krško.	TBD	TBD. It's unclear whether the SLOP²G Project would involve electricity produced at Krško.
South Africa	Following its Special Cabinet Meeting in mid-September 2021, the South Africa's Cabinet approved the extension of the Hydrogen Society Roadmap (HSRM) for the next 10 years. The HSRM gives effect to the Hydrogen South Africa Strategy that was approved by Cabinet in 2007 to prepare the country for a hydrogen economy.	The Hydrogen Society Roadmap seeks the effective integration of hydrogen-related technologies in various sectors of the economy to foster inclusive growth and help reduce poverty and inequality. The strategy includes information on the creation of an export market for South Africa, decarbonization of intensive industries, decarbonization of transport sectors, hydrogen generation, storage and distribution, financial frameworks and skills development. Subcomponents of the roadmap included, for example, a research and development program around	No direct mention of the role of nuclear in the hydrogen plans. Currently South Africa operates two nuclear power plants at the Koeberg site and the government has demonstrated interest in new nuclear. Note that South Africa has a historic interest in the development of PBMR reactor technology.	TBD	None to date

	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
		using green hydrogen to make value-added products such as fertilizer and sulphuric acid, as well as diesel and methanol.			
South Korea	In January 2019, South Korea announced its H2 Economy Roadmap. The Roadmap outlines goal of producing 6.2 million fuel cell electric vehicles and rolling out at least 1200 refilling stations by 2040. Additionally, the plan aims to roll out on the street at least 35 hydrogen buses in 2019 ramping this number up to 2000 by 2022 and 41000 by 2040. In terms of the energy sector, the roadmap outlines an objective to supply 15 GW of fuel cell for power generation by 2040. The industry ministry also plans to set up five hydrogen industry clusters in Incheon, Ulsan and the provinces of North Jeolla, North Gyeongang and Gangwon to establish an ecosystem for the energy source nationwide.	N/A	The Korean government does not currently support the expansion of nuclear domestically, although it provides support for Korean nuclear exports. A new agreement signed in 2022 between Elcogen, Uljin County, and Next Energy will allow nuclear hydrogen production to be introduced into South Korea.[99]	The government will spend 824.4 billion won on the hydrogen economy this year, up 40% from a year earlier. The funds will be used for hydrogen mobility, hydrogen production and retail infrastructure, as well as core technology development.	Starting in 2005, KAERI worked on evaluating nuclear hydrogen production through three different cycles: • Sulfur Iodine; • High Temperature Electrolysis and • Methane-Methanol-Iodomethane. The status of these projects is unclear.
Spain	In October 2020, the Spanish government approved the "Hydrogen Roadmap: A Commitment to Renewable Hydrogen". The Roadmap seeks to contribute to achieving climate neutrality and a 100% renewable electricity system with objectives for 2030 and a vision for 2050, to be executed in three phases. • 1st Phase (2020-2024): Installation of 300-600 MW of electrolyzer plants • 2nd Phase (2025-2030): Installation of at least 4 GW of electrolyzer plants; renewable hydrogen contributing at least 25% of production in all industries; commercial hydrogen projects operational by 2030 for storage • 3rd Phase (2030-2050): economy based on the production and application of renewable hydrogen	There are other strategic and policy documents issued in support of clean hydrogen including the National Integrated Energy and Climate Plan ("PNIEC") 2021-2030; the Draft Law on Climate Change and Energy Transition; the Long Term Decarbornization Strategy 2050; the Fair Transition Strategy; and the Energy Storage Strategy.	The Roadmap focuses on hydrogen produced from renewables only. Spain currently has seven operating nuclear reactors.	In November 2020, the Spanish Government announced that it would allocate €1.5bn to boost the use and production of renewable hydrogen by 2023 through the European Recovery Instrument. The Government estimates that investment of over $10 billion will be required during the period 2020-2030 to meet the goals in the Roadmap, although much of this will come from the private sector.	TBD

[99] https://www.neimagazine.com/news/newsrussia-plans-to-build-experimental-hydrogen-trains-on-sakhalin-island-9060984

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Sweden	None to date	The Government of Sweden ordered the Swedish Energy Agency to produce a national hydrogen strategy, which was planned to be finalized in July 2021 but has not been issued at the date of publication of this paper. Swedish Energy Agency is to analyze and quantify the potential for increased production, storage, transport and use of hydrogen, electric fuels and ammonia in various sectors in Sweden and an overview of the opportunities for cooperation with other countries and actors in Europe.	TBD. Sweden hosts three nuclear power plants in the country, with a total of six reactors in operation. Nuclear power currently represents approximately 35% of Sweden's national power supply.	TBD	None to date
United Arab Emirates	The UAE's Ministry of Energy and Infrastructure (MOEI) announced on November 4, 2021 at COP26 the Hydrogen Leadership Roadmap, a key component of the UAE's "Net Zero by 2050 Strategic Initiative." The objectives of the Hydrogen Leadership Roadmap include exports of low-carbon hydrogen, derivatives and products to key importing regions and fostering new hydrogen derivative opportunities through products like low-carbon steel and sustainable kerosene. The UAE is seeking to be a global leader in low-carbon hydrogen with seven projects already underway targeting 25% market share in the key export markets, including Japan, South Korea, Germany, India, Europe and East Asia.	TBD	TBD. The UAE's Barakah NPP has two reactors in operation, one that has completed construction, and one under construction. ENEC has made statements about the possibility of green hydrogen production at Barakah.[100]	TBD	ENEC has made statements about hydrogen production at Barakah NPP. ENEC and EDF have announced plans to cooperate on nuclear energy R&D under an MOU which includes exploring nuclear hydrogen production.[101]

[100] https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/012021-uaes-enec-expects-all-four-nuclear-reactors-to-be-operational-in-4-years-ceo
[101] https://world-nuclear-news.org/Articles/ENEC-EDF-announce-nuclear-R-D-cooperation-plans

Country	Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
Ukraine	None to date	In June 2021, Ukrainian Foreign Minister Dmytro Kuleba noted that, per encouragement from the EU for Ukraine to become a priority supplier of green hydrogen, "Ukraine is now actively working on ways to develop its [hydrogen] exports."[102]	TBD. Ukraine has 15 nuclear reactors generating about half of its electricity. Ukraine has signed agreements with Westinghouse to finish building a new reactor at Khmelnitsky using AP1000 components from an aborted US project and additionally build four AP1000 reactors at established sites. Ukraine has also signed agreements with Holtec to deploy its Advanced Reactortechnology in the country. A "draft Roadmap for production and use of hydrogen in Ukraine" developed by UNECE suggests as a pilot project "[a]nalysis of the potential for hydrogen production from nuclear power in Ukraine."[103]	TBD	None to date
United Kingdom	The Prime Minister's Ten Point Plan for a Green Industrial Revolution issued in December 2020 set out a goal of 5GW of low-carbon hydrogen production capacity by 2030 and announced new funds and policies that aim to set the UK on the pathway to meet this ambition, including £240 million for government co-investment in production capacity through the Net Zero Hydrogen Fund (NZHF), a hydrogen business model to bring through private sector investment, and plans for a revenue mechanism to provide funding for the business model. The UK issued its Hydrogen Strategy in August 2021, which lays the framework for how the UK shall scale up hydrogen production to accomplish the goals set out in the Ten Point Plan. It takes a "whole system" approach, including an infrastructure plan to support the scale up of the UK's hydrogen network and storage infrastructure required for a UK hydrogen economy. Some key commitments include:	Consultations seek comments on a proposed Hydrogen Business Model, a UK Low-Carbon Hydrogen Standard, and the NZHF.	Point 3 of the Ten Point Plan is the government's commitment to develop new nuclear power, from large-scale to small and advanced modular reactors. This includes investment of GBP525 million (USD696 million) for "the next generation of small and advanced reactors". The Strategy adopts a twin-track approach to supporting both electrolytic "green" (which includes nuclear and renewables) and carbon capture-enabled "blue" hydrogen production. Nuclear energy is also explicitly included in the Hydrogen Strategy as potential source for LTE, THE and Thermo-chemical water splitting processes for clean hydrogen production. The Nuclear Industry Council (NIC) - a joint forum between the nuclear industry and government - produced the H2 Roadmap which stated that nuclear power could produce one-third of the UK's clean hydrogen needs by 2050.	The NZHF will support commercial deployment of new low-carbon hydrogen production projects during the 2020s and will provide up to £240 million of government co-investment to support new low carbon hydrogen production out to 2025. The Hydrogen Business Model plans for a revenue mechanism to provide directed funding. The objective of the business model is to kick-start the industry by attracting private sector investment. The Model, which is still under development, will provide revenue support to hydrogen producers to overcome the initial cost gap between low carbon hydrogen and higher carbon fuels, with the aim of enabling producers to price hydrogen competitively and encourage private sector investment in hydrogen projects. The Strategy also has provisions for volume support to ensure that adequate capacity exists regardless of whether there is demand.	The EDF-led H2 to Heysham (H2H) consortium recently wrapped up a study that concluded the nuclear-powered hydrogen was feasible on technical and safety grounds, with the potential to be scaled-up from a planned demonstrator project at its Heysham 2 nuclear power station in northwest England. EDF UK is also exploring the production and use of hydrogen at Sizewell C in two ways: • (a) Lowing emissions during construction. This would include a <10 MW project to produce hydrogen potentially powered by electricity from neighboring Sizewell B and / or renewables in the area, which can be further scaled up to meet demand. The production facility could also meet other requirements in the region such as transportation use, maritime decarbonization and requirements of local authorities

[102] https://jamestown.org/program/hydrogen-production-in-ukraine-escape-from-energy-dependency-and-a-new-source-of-revenue-after-nord-stream-two/
[103] https://unece.org/sites/default/files/2021-03/Draft%20Roadmap%20for%20production%20and%20use%20of%20hydrogen%20in%20Ukraine_Final%20.pdf

Hydrogen Plan / Policy (existing)	Hydrogen Plan / Policy / Legislation (proposed)	Support for Nuclear / Inclusion of Nuclear in Hydrogen Plans	Government Funding to Hydrogen Projects	Nuclear Hydrogen Projects
Production: • Deliver 5GW of low carbon hydrogen production capacity by 2030, with 1GW of production capacity by 2025. • Launch the Net Zero Hydrogen Fund in early 2022 (£240 million). • Provide up to £60 million under the Low Carbon Hydrogen Supply competition, which will develop novel hydrogen supply solutions. • Finalize the design elements of a UK standard for low carbon hydrogen by early 2022. • Finalize the Hydrogen Business Model business model in 2022, enabling the first contracts to be allocated from Q1 2023. **Networks & Storage:** Support R&D and testing to explore development of hydrogen network infrastructure; reviews of systemic hydrogen network requirements; up to £68 million for the Longer Duration Energy Storage Demonstration competition. **End uses - industry, power, heat and transport:** various R&D initiatives, grant funding to support fuel switching and other technologies, various competitions to demonstrate innovative solutions for various applications. **Market framework:** consideration of regulatory changes, establishment of a Hydrogen Regulators Forum. In 2022 the UK issued the British Energy Security Strategy which builds on the Prime Minister's Ten Point Plan and calls for a 10GW target for hydrogen production by 2030. Additionally, the UK plans to set up a hydrogen certification scheme to facilitate the import and export of high-grade hydrogen, as well as create new business models for hydrogen transport and storage infrastructure.[104]				• (b) Once Sizewell C is operational, using some of the heat it generates (alongside electricity) to make hydrogen more efficiently.[105]

[104] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1069969/british-energy-security-strategy-web-accessible.pdf
[105] https://www.edfenergy.com/energy/nuclear-new-build-projects/sizewell-c/news-views/sizewell-c-and-hydrogen

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United States	In November 2021, Congress passed the Infrastructure Investment and Jobs Act which defines "clean hydrogen" as hydrogen "produced with a carbon intensity equal to or less than 2 kilograms of carbon-dioxide equivalent produced at the site of production per kilogram of hydrogen." The Act also authorizes and appropriates $9.5 billion to the DOE for clean hydrogen research, development, and demonstration programs. This includes: • $8 billion for four regional clean hydrogen hubs. Project selection will be managed by the DOE's newly created Office of Clean Energy Demonstrations. The Act requires the Secretary of Energy to solicit proposals for the hubs 180 days after its passage, and select four regional hubs within one year from that date. • $1 billion for a clean hydrogen electrolysis program at DOE EERE, with a goal to reduce the cost of producing clean hydrogen to less than $2 per kilogram by 2026. • $500 million to EERE for multiyear grants and contracts for research, development, and demonstration projects to advance new clean hydrogen production, processing, delivery and storage, as well as research for approaches to increase the reuse and recycling of clean hydrogen technologies. The DOE in June 2021 announced the Hydrogen Shot, the first project under the DOE's Energy Earthshots Initiative, which seeks to reduce the cost of clean hydrogen by 80% to $1 per kilogram in the next decade. Until the announcement of the Hydrogen Shot, the U.S. Government's hydrogen strategy was limited to the annual DOE H2 Plan, which focuses on conducting coordinated RD&D activities across various DOE offices to enable the adoption of hydrogen technologies across multiple applications and sectors.	**Build Back Better Act:** Sec. 45X, Clean Hydrogen Production Tax Credit – provides production tax credits for clean hydrogen (< 0.45kgCO_2e/kgH_2) at a rate of $3/kg, and production tax credits for hydrogen produced by methane reforming of natural gas with carbon capture at rates between $0.6-$1/kg for facilities placed into service before 2027. Inclusive of nuclear-produced hydrogen. **Clean Energy Hydrogen Innovation Act** (H.R. 1788) (Reps. Carson (IN-07) and Pence (IN-06)) – seeks to amend the Energy Policy Act of 2005 to make hydrogen production (including nuclear hydrogen), delivery, infrastructure, storage, fuel cells and other projects eligible for loan guarantees. **Clean Hydrogen Production and Investment Tax Credit Act of 2021** - (H.R. 5192) (Rep. Larson D-CT) – Tax credit for investment or production of qualified clean hydrogen, defined as compared to hydrogen produced by steam-methane reforming, achieves a percentage reduction in lifecycle greenhouse gas emissions that is not less than 40%. **Energy Sector Innovation Credit (ESIC)** *(under development)*, Sec. 45V CLEAN H2 PRODUCTION. Flexible ITC or PTC designed to promote innovation in clean hydrogen production, including from LWR and non-LWR nuclear. **H.R.1512** (Pallone Jr. – D-NJ-06) - Establishes H2 as "clean" fuel for a 21st century energy grid. **Clean Energy for America Act** (Sen. Wyden (D-OR) – tax incentives for domestic production of clean fuel, including H2. **S.1034** (Sen. Coons, D-DE) – Seeks to amend the Internal Revenue Code (IRC) to extend the publicly trade partnership ownership structure	Yes. Several DOE offices (EERE, NE) provide support to Nuclear H2 projects. The Energy Act of 2020 included $4B of funding for hydrogen RD&D, including DOE funding of nuclear hydrogen production R&D. Further, numerous bills supporting nuclear energy have been passed in Congress on a bi-partisan basis. *For example:* The Energy Act of 2020, among other actions: • Authorized the Advanced Reactor Demonstration Program (awards made in 2020) • Established an advanced fuels (HALEU) RD&D Program. • Provided other R&D funding important to advanced reactor demonstration. Other legislation: • Nuclear Energy Innovation and Modernization Act (NEIMA) – seeks to NRC's fee collection more transparent and predictable, caps NRC fees for existing reactors and directs NRC to establish advanced reactor licensing framework by 2027 (NRC will establish by 2024) • Nuclear Energy Innovation and Capabilities Act (NEICA) - established the National Reactor Innovation Center and furthered DOE and NRC ability to support advanced reactor development. • Infrastructure Investment & Jobs Act (IIJA): Requires at least one of four regional hydrogen hubs to produce hydrogen from nuclear energy.	Various funding opportunities provided by the DOE (relatively small scale). Oct 2020, The U.S. Department of Energy has provided funding worth tens of millions of dollars seeking to advance hydrogen generation by nuclear reactors. A new solicitation for an additional $20M was issued in Feb. 2021.	1. Energy Harbor, Xcel Energy, and APS are spearheading a multi-pronged project to develop and demonstrate nuclear-hydrogen hybrids and their commercial applications. Consortium obtained funding and technical support from DOE's Light Water Reactor Sustainability (LWRS) Program, as well as from its Integrated Energy Systems program. 2. Exelon obtained funding from the DOE's H2@Scale program under the Office of Energy Efficiency and Renewable Energy (EERE), and technical expertise from INL, Argonne National Laboratory, and the National Renewable Energy Laboratory, for a three-year demonstration involving the installation of a Nel Hydrogen 1-MW PEM electrolyzer at one of Exelon Nuclear's 14 boiling water reactors (BWRs). 3. Support to work by FuelCell Energy in conjunction with the Idaho National Laboratory, on a solid oxide electrolysis cell to be used at nuclear stations.

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The DOE H2 Program is led by the H2 and Fuel Cell Technologies Office within the Office of Energy Efficiency and Renewable Energy, conducts research and development in hydrogen production, delivery, infrastructure, storage, fuel cells, and multiple end uses across transportation, industrial, and stationary power applications. The program also includes activities in technology validation, manufacturing, analysis, systems development and integration, safety, codes and standards, education, and workforce development. A key part of the program is the H2@Scale initiative that includes DOE funded projects and national laboratory-industry cofounded activities to accelerate the early-stage research, development, and demonstration of applicable hydrogen technologies. Funding for hydrogen projects is also provided by DOE Nuclear Energy and DOE Fossil Energy. Tri-lab consortium—Idaho National Laboratory (INL), the National Renewable Energy Laboratory (NREL), and the National Energy Technology Laboratory (NETL) are working on coordinated R&D to simultaneously leverage diverse energy generators—including renewable, nuclear, and fossil with carbon capture—to provide power, heat, mobility, and other energy services. Hydrogen production is a key focus area for the consortium.	to energy generation projects and transportation fuels, and for other purposes, including hydrogen storage and fuel cells. **S.1017** (Sen. Heinrich, D-NM) Amends the IRC to establish a tax credit for the production of hydrogen using electricity produced from clean energy resources, including nuclear hydrogen. **S. 3118** (Sen. Cornyn, R-TX) Hydrogen Infrastructure Finance and Innovation Act – Establishes programs for hydrogen pipeline infrastructure and coordination with regional hydrogen hubs. **S. 3112** (Sen. Coons, D-DE) Hydrogen for Industry Act of 2021 – establishes a Hydrogen Technologies for Heavy Industry Grant Program. **S. 3111** (Sen. Cornyn, R-TX) Hydrogen for Ports Act of 2021 – establishes a grant program to support hydrogen-fueled equipment at ports and to conduct a study on using hydrogen and ammonia as marine fuels. **S. 2200** (Sen. Heinrich, D-NM) Advancing the Clean Hydrogen Future Act of 2021 - $200 million per year to research reducing cost of producing hydrogen through electrolyzers. **H.R. 848 Growing Renewable Energy and Efficiency Now (GREEN) Act of 2021** (Thompson D-CA on behalf of all House Ways and Means Democrats) – Amends IRC §48(c) to authorize 30% investment tax credit for energy storage technology, to include hydrogen storage (hydrolysis and electrolysis) and IRC §30C(g) to authorize alternative fuel refueling tax credit for fuel at least 85% of the volume of which consists of hydrogen. **S. 3806** (Sen. Coons, D-DE) Hydrogen for Trucks Act of 2022 - establishes a grant program to			

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	demonstrate the performance and reliability of heavy-duty fuel cell vehicles that use hydrogen as a fuel source, and for other purposes. **H.R. 7065** (Rep. Porter, D-CA-45) - establishes a grant program to support hydrogen-fueled equipment at ports and to conduct a study with the Secretary of Transportation and the Secretary of Homeland Security on the feasibility and safety of using hydrogen-derived fuels, including ammonia, as a shipping fuel.			