2023 – IP10

U.S. National Clean Hydrogen Strategy and Roadmap

The Biden-Harris Administration released the first-ever U.S. National Clean Hydrogen Strategy and Roadmap on the 05 June 2023. The strategy represents a comprehensive framework for accelerating the production, processing, delivery, storage, and use of clean hydrogen, and underscores the U.S government's pathways to addressing the climate crisis and achieving a carbon-free grid by 2035 and a net-zero emissions economy by 2050.

The Strategy and Roadmap outlines a vision for the role of clean hydrogen in achieving national decarbonization objectives across various industries in the coming years. It explores potential future demands and identifies strategic opportunities for the domestic production of 10 mega tonnes (Mt) of clean hydrogen per year by 2030, 20 Mt per year by 2040, and 50 Mt per year by 2050. Currently, more than 95% of the approximately 10 Mt of hydrogen produced annually in the US is grey. This represents 1% of the US energy consumption.[1]

The U.S. National Strategy outlines three essential approaches to ensure the effective development and adoption of clean hydrogen as a tool for decarbonization.

Strategy 1:
Concentrating efforts on identifying and implementing high-impact applications for clean hydrogen with strategic significance and substantial impact. This is aimed to maximize the utilization of clean hydrogen in applications with limited decarbonization alternatives (e.g., industrial sector, heavy-duty transportation, and long-duration energy storage to enable a clean grid), thus, ensuring the greatest benefit is derived from its use.

Strategy 2:
Decrease the cost associated with producing clean hydrogen by accelerating innovation and scale, encouraging private sector investments, and establishing a robust clean hydrogen supply chain. In June 2021, the Department of Energy (DOE) initiated the Hydrogen Energy Earthshots[2] to unleash the market potential of clean hydrogen by aiming to achieve an 80% cost reduction, bringing it down to $1 per 1 kilogram within a decade.

Strategy 3:
Prioritizing the development of regional networks that enable substantial clean hydrogen production and its proximity for immediate end-use. Further, driving significant expansion and facilitating the successful initiation of the market while leveraging opportunities specific to promote equity, inclusion, and environmental justice.

For the **first Strategy**, Government agencies **will prioritize the utilization of clean hydrogen in sectors** such as industry and heavy-duty transportation, which present challenges for electrification. They will also target early markets where agencies like the Departments of Defence and entities procuring stationary power or commercial vehicle fleets can create opportunities for early adoption of hydrogen. This strategic approach aims to decarbonize sectors that are hard to electrify and capitalize on initial hydrogen demand in specific markets.

Hydrogen in Chemicals: To illustrate, the manufacturing of ammonia and methanol is responsible for a significant portion of global greenhouse gas (GHG) emissions in the chemical industry.

[1] Shearman & Sterling. Hydrogen's Present and Future in the US Energy Sector. October 2021.
[2] DOE. Office of Energy Efficiency & Renewable Energy. Hydrogen Shot. September 2021.

Currently, both sectors heavily rely on natural gas as fuel and feedstock. However, by transitioning to the utilization of clean hydrogen, these processes have the potential to achieve a decarbonization rate of over 90 percent. **Hydrogen in Steelmaking:** The steelmaking industry is responsible for approximately 7% of global greenhouse gas emissions and currently relies on coke and natural gas for the reduction of iron ore. However, by transitioning to clean hydrogen as a reductant, emissions can be reduced by an estimated 40-70%. **Hydrogen for Industrial Heat:** More than 50 % of emissions from industrial activities currently stem from the direct combustion of fossil fuels, primarily used for generating heat and power. While it is generally feasible to electrify lower-temperature heat generation processes, around 30 percent of industrial heat is generated at temperatures exceeding 300°C, making it necessary to rely on clean fuels for decarbonization. Furnaces that utilize pure hydrogen or hydrogen-natural gas blends are crucial options for achieving decarbonization in these applications. **Hydrogen in Transport:** Hydrogen presents a strong value proposition in the transportation sector, especially in the trucking industry, where it is particularly advantageous for fleets operating heavy-duty vehicles, long-distance routes surpassing 500 miles, or multi-shift operations that demand fast refuelling capabilities. Additionally, hydrogen serves as a crucial feedstock to produce liquid fuels that will play a vital role in meeting the energy needs of large-scale applications such as aviation, rail, and marine transportation. **Hydrogen for power; Back-up and Stationary Power:** Fuel cells used for backup power and stationary applications offer a viable alternative to diesel generators, providing a resilient power source for critical facilities that require continuous 24/7 power, including hospitals and data centres. Moreover, these fuel cell systems present promising opportunities for delivering steady and reliable power in remote locations, such as microgrids and telecom towers. **Hydrogen for Power; Energy Storage and Electricity Generation:** The implementation of large-scale hydrogen energy storage systems could involve the utilization of electrolysers to produce hydrogen using surplus power from the grid. The produced hydrogen can then be stored in bulk, such as underground storage facilities, and later used to generate power during periods of high demand. In the near to mid-term, the co-firing of hydrogen in natural gas turbines for power generation could serve as a transitional approach towards the adoption of 100 percent hydrogen-fired turbines. These hydrogen-fired turbines will be essential for achieving full decarbonization of the electricity system.

The primary focus of the **second strategy** is to **prioritize the reduction of costs associated with clean hydrogen.** Hydrogen Shot represents a flagship initiative by the Department of Energy (DOE) aimed at driving down the cost of clean hydrogen. This effort is closely aligned with the acceleration of deployment and scaling through various means, including Regional Clean Hydrogen Hubs, loan guarantees, and other mechanisms. In the United States, a combination of hydrogen production methods is expected to be employed at least until 2050. This includes hydrogen production through water electrolysis, hydrogen production from fossil fuels with carbon capture and storage, as well as hydrogen production from biomass and waste feedstocks.

Electrolytic hydrogen: More than 50 percent of the cost of hydrogen production through electrolysis is attributed to the cost of clean electricity. RDD&D (Research, Development, Demonstration, and Deployment) efforts can contribute to achieving the Hydrogen Shot target by reducing the cost of clean electricity through advancements in renewable energy and nuclear power. Additionally, enhancing the efficiency of electrolysis, decreasing capital costs of electrolysers, and enabling dynamic integration of electrolysers with the grid and renewable/nuclear generators can provide access to low-cost variable power, further driving down hydrogen production costs. **Hydrogen Production from Fossil Fuels with Carbon Capture**

and Storage: Research, Development, Demonstration, and Deployment (RDD&D) efforts are underway to reduce costs and enhance the performance of steam methane reforming (SMR) and autothermal reforming (ATR) systems with carbon capture and storage (CCS). Future cost reductions can be achieved through improved process integration of CO_2/H_2 separation, utilization of high-pressure or high-temperature separations utilizing membranes, solid CO_2 sorbents, advanced catalysts, and innovative methods of oxygen separation. However, it is important to note that utilizing low-cost natural gas remains the most crucial approach for obtaining a more affordable hydrogen production cost through reforming with CCS pathways. **Hydrogen Production from Biomass and Waste Feedstocks:** Additional pathways to hydrogen production involve biomass gasification coupled with CCS, as well as SMR or ATR utilizing feedstocks such as biogas derived from organic landfill material, sewage, or agricultural wastes instead of natural gas. These pathways offer low-carbon or carbon-negative hydrogen depending on the feedstock. Lifecycle emissions across the entire biomass supply chain, including direct and indirect land-use changes, and agricultural inputs such as fertilizer should be considered when evaluating this pathway. **Other system costs:** The goal of cost reduction extends beyond hydrogen production alone. It is crucial to address the costs associated with all essential technologies throughout the entire value chain, which includes mitigating vulnerabilities in the supply chain and enhancing domestic manufacturing capabilities. To achieve this, the Department of Energy (DOE) has published a series of assessments focused on clean energy supply chains, including those related to fuel cells and electrolysers. These assessments aim to identify areas for improvement and guide efforts to enhance the efficiency and competitiveness of the clean energy supply chain. The costs for various technologies and components across the hydrogen value chain are shown in Figure 1.[3] With increasing real-world operational data, both government agencies and the private sector can focus on key priorities that enable cost reduction and enhance commercial viability.

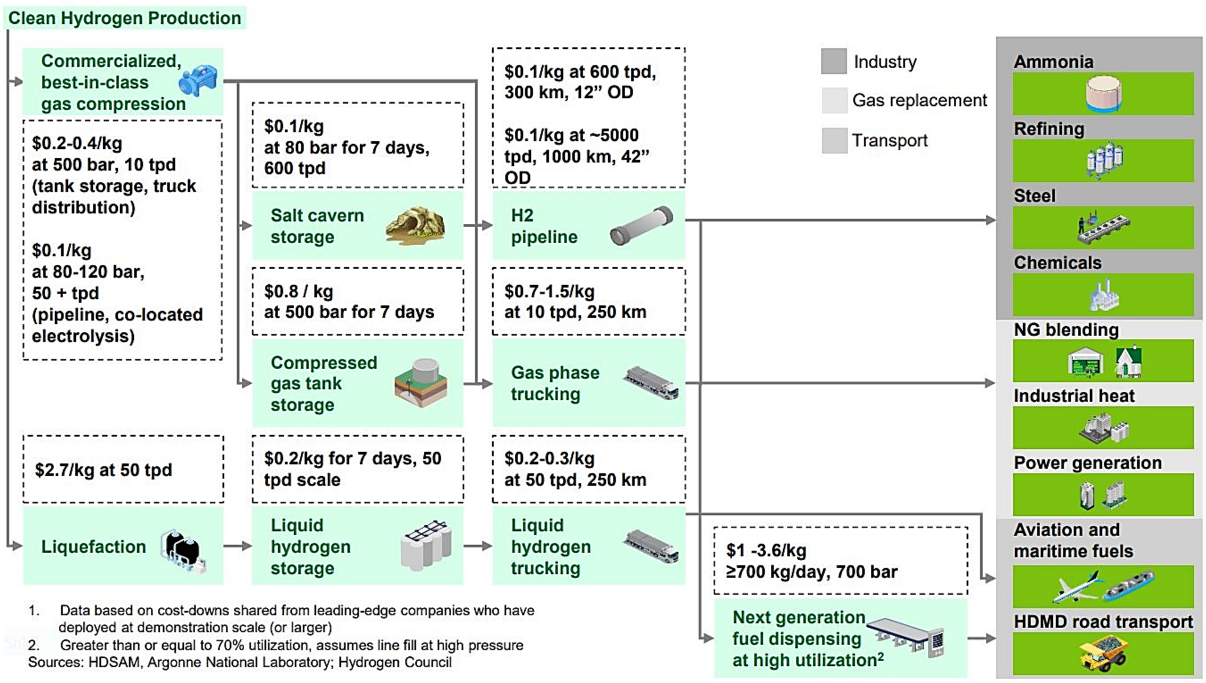

Figure 1. Industry-informed estimates of midstream costs by 2030 and potential end uses

[3] DOE. U.S. Clean Hydrogen Strategy and Roadmap. June 2023.

The **third strategy aims to achieve commercially viable adoption of clean hydrogen** by ensuring that the scale-up of clean hydrogen supplies aligns with the growing regional demand for it. By strategically co-locating large-scale clean hydrogen production facilities alongside multiple end-use applications, it enables the development of cost-effective hydrogen and the essential supporting infrastructure. This approach serves as a catalyst for jumpstarting the hydrogen economy, particularly within significant market segments. Furthermore, adopting a regional approach to hydrogen development enables companies throughout the supply chain to leverage the advantages that arise when related businesses co-locate in industrial clusters. Industrial clusters benefit from the proximity of innovation to manufacturing, leading to knowledge sharing across firms and can also help to create stronger social and civic engagement, as workers have multiple job opportunities in the region so are more likely to form lasting ties with the community. Ultimately, developing hydrogen through a hub approach will create stronger and more competitive regional economies, much as the creation of auto industry (e.g., Detroit) has done in the past.

To effectively support the three primary strategies, federal agencies will leverage the entire continuum of activities across basic science through applied research, development, demonstration, and large-scale deployments. The continuum of activities will be supported by foundational and crosscutting efforts to promote diversity, equity, inclusion, and accessibility; engage communities, ranging from environmental justice groups to Tribes, tribal organizations, and labour unions; develop the workforce; advance policy; support the technology and energy transition; and enable market adoption at scale.

An evaluation was conducted on the supply chain vulnerabilities for the production (upstream), transmission & distribution (midstream), and select end uses (downstream) of hydrogen. The findings of this study underscore the important key factors to address that will underpin commercial deployment of clean hydrogen. Potential value chain vulnerabilities are presented in Figure 2. The assessment reinforces the value that CCUS has in scaling up clean hydrogen production, **without CCUS, meeting the clean hydrogen target is not realistic.**

To summarise, the implementation of the U.S. National Clean Hydrogen Strategy and Roadmap will contribute to realizing the envisioned future of hydrogen in the United States: an affordable, clean hydrogen supply for achieving a net-zero carbon future and fostering a sustainable, resilient, and equitable economy. This achievement will be made possible through the collaborative and coordinated efforts of the Federal Government, States, Industry, National Laboratories, Academia, and extensive stakeholder engagement.

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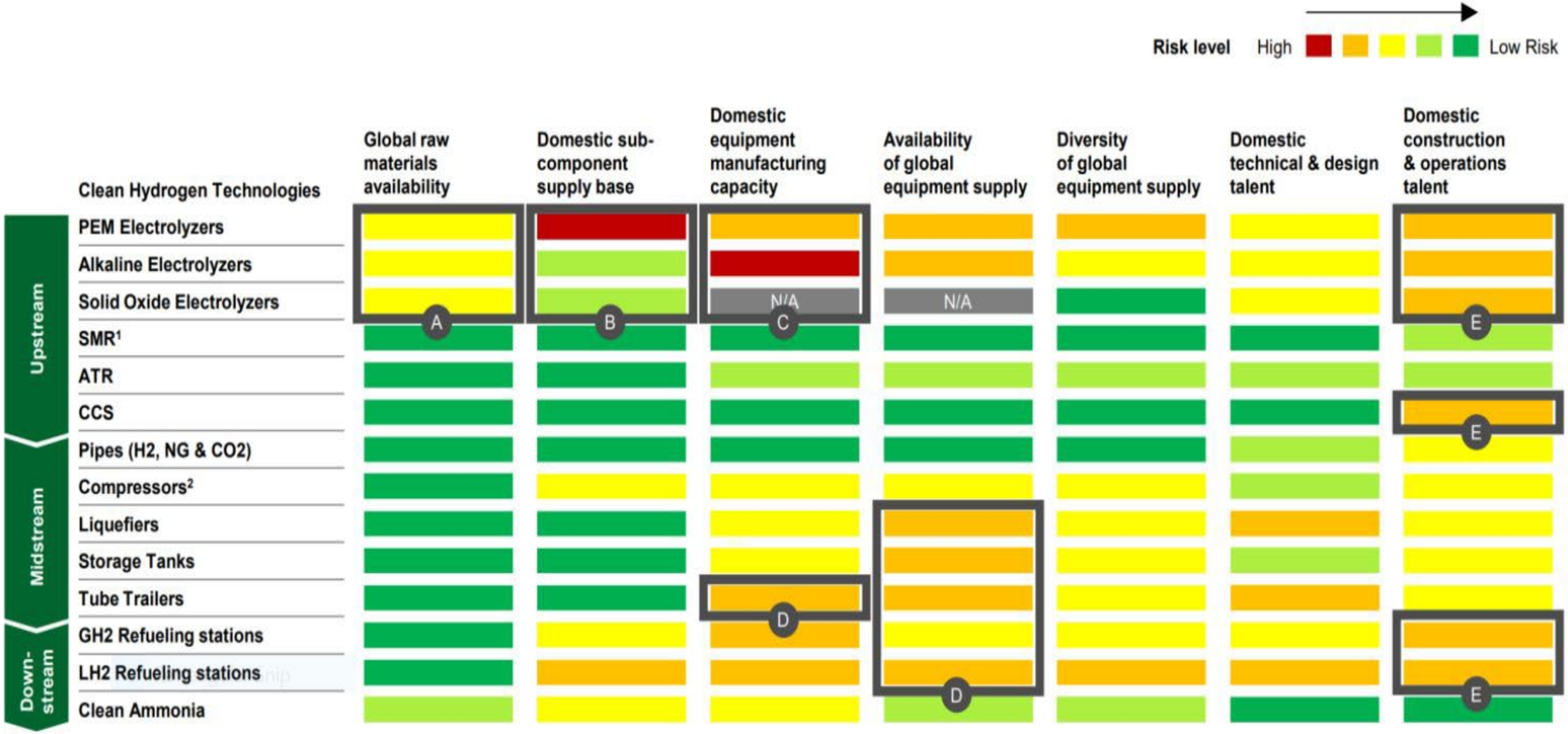

Figure 2. Potential value chain vulnerabilities, 2025.[2]