H2@Scale 2.0: Realizing the Benefits of a Hydrogen-Based Energy System

Throughout the world, hydrogen is increasingly recognized as the critical, central component for a clean, sustainable, efficient, and economic energy system. Hydrogen is remarkable for its ability to carry, store, and interconvert energy—its chemical energy can be used for clean and efficient chemical conversions to products and fuels; electricity generation; and heat generation. Hydrogen can be used as a storage medium, even for seasonal storage, to enable larger-scale deployment and use of renewable electricity. As an energy carrier, hydrogen is central to cross-sector coupling and clean, efficient transportation fuels and industrial processes, enabling decarbonization of products and services while meeting customer expectations.

Widespread deployment of hydrogen will require cost reductions, as current large-scale production costs are typically $5–$6/kg or higher. A 3–5x cost reduction is possible with both research and development (R&D) advances and increased availability of low-cost renewable electricity. This would put the world on a path to reach the gigaton (multi-trillion dollar) level annually. **An order of magnitude increase (10x) in U.S. effort toward green hydrogen is required to realize and allow the U.S. economy to benefit from this change** by significantly lowering the cost and increasing the scalability, sustainability, and efficiency of making, storing, moving, and using hydrogen while ensuring these new technologies are made in America.

The Opportunity

There is an opportunity to achieve dramatic cost reductions in making green hydrogen. Technology such as electrolysis liberates the hydrogen from the oxygen in water, providing a zero-carbon energy carrier. The United States has an opportunity to lead the world in creating and domestically manufacturing technologies that provide market-accessible green hydrogen at the same cost as conventional steam-methane reforming within 10 years.

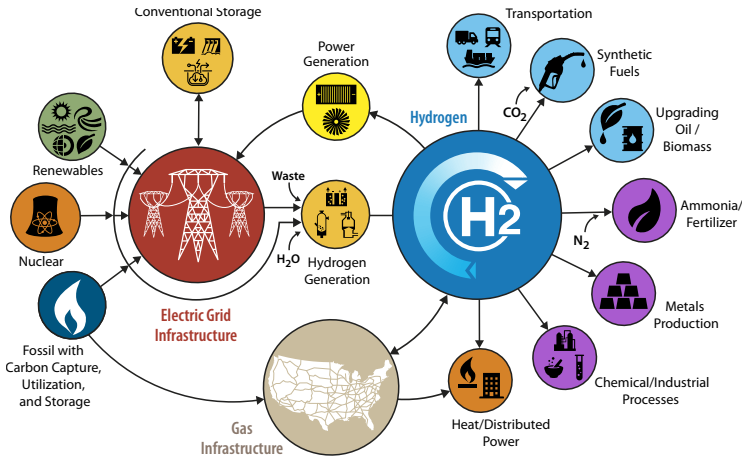
A recent U.S. analysis from NREL states that up to 10x today's U.S. use of hydrogen is technically feasible, but only 2–4x today's use would likely happen based solely on today's market drivers. R&D advances and favorable market and economic policies are expected to drive this opportunity higher.

Decarbonizing All Sectors of the U.S. Energy System

Hydrogen has a unique ability to couple different sectors of our economy in a way that electricity and batteries alone cannot, providing benefits far beyond just a zero-emissions transportation fuel.

Because electrolysis can be a controllable load, hydrogen production can improve the operation of the grid and support increased penetration of wind and solar electricity generation.

Hydrogen can serve as a primary platform for the decarbonization of the transportation sector, connecting the electric grid to transportation through low-greenhouse-gas fuels, either used directly as hydrogen or converted to other synthetic fuels.



Conceptual H2@Scale energy system

Additionally, hydrogen is a way to decarbonize the industrial sector through providing energy, heat, and the basic elemental building block that can be combined with nitrogen and carbon to form compounds such as plastics and other materials required to make today's products.

Improved Economy and Energy Security

Developing the technologies to produce green hydrogen could have a large economic impact on our country. The international Hydrogen Council Roadmap study projects that by 2050, hydrogen will provide $2.5 trillion in global revenues, 30 million jobs, and 18% of the total global energy demand. The rest of the world sees this opportunity, and there is an international competition to become the dominant nation to produce cheap, green hydrogen and export the production equipment to others.

The United States has an opportunity to bring those jobs and revenues here rather than letting other countries take the lead. Additionally, the implementation of H2@Scale in the United States enables increased energy security and valorization of U.S. renewable resources by providing competitive cost advantages in sectors including fuels, products, and manufacturing.

World-Class National Capabilities

The United States has unique national capabilities, largely developed for the application of hydrogen in light-duty transportation, that can be leveraged to institutionalize a strategic advantage in the further development of hydrogen technologies. The nation's crown jewels of research staff and experimental capabilities reside in its national laboratory system. The nation's universities drive the innovation and create the future technical scientists and engineers to support this growth. And, finally, industry provides not only the technical targets and market drivers, but also the means to scale up laboratory innovations into manufacturable solutions and domestic jobs.

The Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy has already been seeding collaboration among this set of organizations through consortia such as H2NEW, MMFCT, HydroGEN, HyMARC, and HyBlend.

Virtual and physical connections among these organizations can be made through recent initiatives such as the research platform called Advanced Research on Integrated Energy Systems (ARIES). This platform matches the complexity of the modern energy system to conduct integrated research to support the development of groundbreaking new energy technologies, including hydrogen systems.

Investments Needed for Research and Development

Significant additional national investments are needed to accelerate development of hydrogen technologies and provide the opportunity for U.S. market leadership internationally. The highest return on investments can be informed by integrated energy-systems-wide modeling and analysis, amplified by high-performance computing. This will guide a combination of longer-term and higher-risk research with big payoffs, balanced with near-term demonstrations of existing technologies to accelerate the market and awareness of hydrogen as a zero-emission solution. Additional research, development, demonstration, and deployment are all essential ingredients to keep the innovation pipeline flowing toward market success.

Advanced Production Technologies

Research opportunities exist in advanced water-splitting technologies such as water electrolysis, photoelectrochemical water splitting, and solar thermochemical hydrogen production. These hydrogen production technologies can take advantage of today's renewable and nuclear power or use solar energy directly.

Large-Scale Demonstrations

Large-scale demonstrations need to be performed that show how hydrogen can stabilize the future electricity grid, both with high-renewable penetration and variability, as well as using baseline nuclear power.

Hydrogen infrastructure needs additional investment in the form of pipelines (dedicated hydrogen as well as blended with natural gas) and hydrogen storage (high-pressure and liquid hydrogen, advanced materials, and bulk/geologic storage).

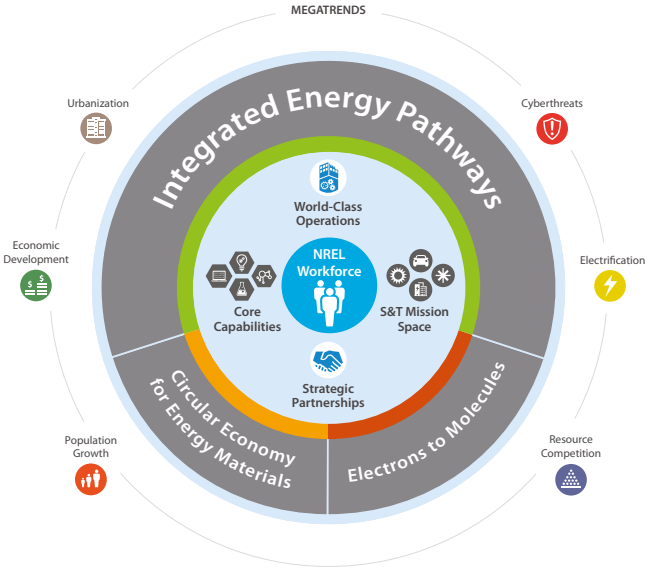
Expanded Hydrogen End Uses

Light-duty fuel cell vehicles have been the primary focus for the past few decades and have resulted in significant technology advancement. Heavy-duty applications including long-haul trucking, marine, rail, and stationary applications are emerging areas of focus and are connected to HFTO's new Million-Mile Fuel Cell Truck Consortia. Other end uses such as HySteel, HyBlend, and hydrogen as a feedstock in chemical processes need further development.

National Benefit

Increasing our investment in developing hydrogen technologies will provide significant national security, economic, and environmental benefits to our country. National security will be improved by increasing U.S. energy competitiveness, increasing energy security, and decreasing the cost of manufacturing products domestically. The economy will be strengthened through new jobs and increasing gross domestic product (GDP). Finally, there will be societal environmental benefits in the form of clean air, water, and reduced climate impact through CO_2 reductions.

Contact NREL Associate Laboratory Director Bill Tumas at bill.tumas@nrel.gov to learn more.



NREL's 10-Year Plan: A Vision for the Future

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