ITS AMERICA

Hydrogen in Transportation

ITS America Sustainability Community of Practice

Issue Brief

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Executive Summary

Hydrogen has unique capabilities to power our transportation system toward a greener future, and ITS America members are developing and deploying solutions using hydrogen to power a cleaner transportation system across the country. This paper looks at the potential for hydrogen to be a game-changer for surface transportation, particularly emphasizing its application in commercial and public fleets, from heavy-duty trucks to lighter vehicles, and its potential to support the mission of a smarter, greener future that improves mobility options and environmental outcomes for all.

Hydrogen, the most abundant and energy-rich element in the universe, is being harnessed through a variety of methods, each with distinct carbon footprints – ranging from green-powered electrolysis to natural gas-derived blue hydrogen. As hydrogen technology transitions from theory to real-world applications, the interplay between vehicle connectivity, digital infrastructure, and the entire hydrogen supply chain becomes crucial. This brief aims to highlight hydrogen's role in not only reducing the total carbon footprint of the transportation sector, but also in revolutionizing how we perceive and implement sustainable transportation solutions.

Introduction and Motivation – Why Hydrogen for Transportation?

This section discusses the various production methods of hydrogen, highlighting its lower carbon emissions compared to traditional fuels. It explores hydrogen's critical role in decarbonizing transportation and serving as a foundation for future fuels and energy carriers.

Hydrogen is the most abundant element in the universe, the lightest molecule, and is also non-toxic. It contains more energy per unit mass than any other fuel and drives critical geologic and biologic cycles. Throughout modern history, humans have looked at ways to harness the potential of hydrogen for industrial and transportation uses. Today we are at the point where hydrogen technology is being commercialized, with supply chains forming and government funding available to help progress the development and deployment of its uses. Hydrogen's motive power use in transportation applications is rapidly becoming feasible, and hydrogen appears to be suitable for powering multiple modes, especially medium- and heavy-duty vehicle usage. Hydrogen can also play a role in providing resiliency for charging infrastructure.

Hydrogen is produced in multiple ways, with the specific input of electricity. In essence, these processes involve splitting a feedstock that contains the building blocks of hydrogen, often through electrolysis of water by splitting hydrogen and oxygen. There is terminology used to describe the method of hydrogen production, and its carbon intensity, known as the "colors of hydrogen." These are:

- Blue (natural gas, with carbon storage)
- Pink (nuclear powered electrolysis)

- Green (renewable electricity, directly connected electrolysis)
- Grey (natural gas, split using small modular reactors)
- Brown (coal)
- Turquoise (methane splitting, solid carbon output)
- Yellow (existing grid-supported electrolysis)
- White (byproduct of industrial processes, also in a rare naturally occurring form)

Many of these production methods are significantly lower in carbon than diesel or gasoline equivalents for the energy produced in their utilization. Some, such as those that come from renewable energy or made with carbon capture, have no emitted carbon whatsoever. There is currently a role for many of these production methods in providing fuels to support transportation decarbonization, to enable the scaling of hydrogen usage and the establishment of a hydrogen economy. Hydrogen also plays an important role as the basis for several future fuels and energy carriers, such as ammonia, eMethanol, renewable diesels, and Sustainable Aviation Fuel (SAF).

Vehicle Applications

This section delves into the comparison between battery electric vehicles (BEV) and hydrogen fuel cell electric vehicles (HFCEV), emphasizing their respective energy densities, vehicle efficiencies, and refuel times. It highlights the benefits and trade-offs of each technology for different vehicle applications, suggesting that hydrogen may be more suitable for larger, long-haul vehicles while batteries are likely better for light-duty vehicles.

Battery electric vehicles (BEV) and hydrogen fuel cell electric vehicles (HFCEV) are both zero tail pipe-emission vehicles with the potential to be zero-carbon. There are trade-offs between BEV and HFCEV that may make one or the other more beneficial for different vehicle applications. At the vehicle level, these trade-offs fall into three categories: Energy Density, Refuel Time, and Vehicle Efficiency.

Energy Density: The energy density of BEVs is nearly constant with the amount of energy stored. This means that the weight and volume of battery systems increases linearly with the amount of energy required. The energy density of hydrogen storage systems increases with the amount of energy stored. Because of this, hydrogen storage becomes more weight- and volume-efficient for larger energy storage applications. This tends to translate into cost as well. There is some energy capacity at which hydrogen storage is cheaper, smaller, and lighter than the equivalent battery system. This crossover point changes as battery and hydrogen storage systems evolve. Currently, it seems likely that hydrogen storage could be a better solution for large long-haul (medium- or heavy-duty) vehicles. Battery electric energy storage is almost certainly a better solution for light-duty vehicles.

Refuel Time: For both BEVs and FCHEVs, recharge/refuel time increases with the energy capacity of the storage system. However, the rate of recharge/refuel is vastly different between the vehicle types.

For large BEV vehicles, the recharging will range from about one hour to overnight. Hydrogen vehicles will be able to refuel in 6-10 minutes. Depending upon the vehicle usage patterns, this difference may or may not have an impact on consumers and fleet operators Vehicle usages with long dwell times may be able to accommodate the longer recharge time of BEVs. Vehicle usages that cannot tolerate extended periods of down-time will benefit from hydrogen energy.

Vehicle Efficiency: There are significant differences in the energy efficiency of the different power trains. Internal combustion vehicles, running on gasoline, diesel, or hydrogen have efficiencies roughly in the range of 30% to 40%. HFCEVs are about 60% efficient and BEVs have 90% or better efficiencies.

Potential Challenges for Hydrogen in Transportation

Hydrogen technology for transportation is progressing, but there are several challenges to consider. These include technical challenges related to infrastructure, such as compressor reliability and the construction of hydrogen fueling stations. The cost of resources and materials is another significant challenge along with the total carbon footprint of producing hydrogen components compared to batteries. Additionally, there are concerns about the ethics of the supply chain and sourcing of materials.

Other challenges include the need for standardization and market readiness of materials, connectors, and compressors. Safety considerations, such as fire risk, pressurized vessel safety, and workforce training are also important. Finally, transportation and distribution issues, such as pipeline leaks and cracking, need to be addressed before hydrogen can scale in the transportation industry

Fueling Stations and Storage: Hydrogen fueling stations are essential for the deployment of HFCEVs. These stations are not as readily available as traditional fueling stations, and fleet owners typically need to construct their own facilities. The infrastructure for hydrogen fueling requires significant space, especially if hydrogen production is done onsite. This involves using an electrolyzer to split water into hydrogen and oxygen, which requires a large area and a substantial power supply. Electrolysis is often supported by renewable energy sources like solar or wind power.

Hydrogen fuel comes in two forms: gaseous and liquid. Gaseous hydrogen is stored in pressurized tanks, while liquid hydrogen requires cryogenic temperatures for storage. Although liquid hydrogen has a higher energy density, it comes with additional cold-chain infrastructure costs and slower fueling times compared to high-pressure gas systems.

Materials and Resources: The technology for hydrogen fueling is still new so replacement parts and maintenance can be more challenging compared to more common equipment for gasoline fueling or even electric battery charging stations today. Additionally, the cost of resources and materials for hydrogen fueling stations is a significant challenge. The total cost of ownership for hydrogen fueling infrastructure is higher than for electric vehicle charging, and operational interruptions may be longer due to the limited supply chain for hydrogen fuel and associated equipment. Regardless of the type of hydrogen selected for a user's application, the technology will be new and novel. This means that replacement parts – from fueling nozzles to storage tanks – will be more difficult to maintain and replace when compared with mass-market equipment.

Additionally, a grid connection of multiple megawatts may also be needed to support the power needs associated with hydrogen production. Upgrades of this scale will require coordination with local utility companies to determine feasibility, timeline, and cost. Electrolysis also requires an on-site water source, and some municipalities and water reclamation districts have begun to evaluate the feasibility of wastewater as a source of water for hydrogen electrolysis.

The cost of building a hydrogen station depends on several factors, including its size and complexity. A single station can cost anywhere from $1 million to $5 million, or even more. This cost includes labor, materials, equipment, and site preparation costs. According to the U.S. Department of Energy Hydrogen Program Record, for 111 new fueling stations in California, the average hydrogen station has median capacity of 1500 kg/day with median capital costs close to $1.9 million.[1] Stations that use hydrogen delivered as a gas have an average storage of 770 kg/day and an estimated total cost of $2 million, which includes equipment, design, construction, and commissioning.

Safety: Although hydrogen is being used safely in many industrial contexts, it does have unique safety considerations that must be considered and managed in the transportation context. Hydrogen is highly flammable and, as it is colorless and odorless, it requires special sensors to detect dangerous levels of hydrogen. Another unique safety aspect of hydrogen in vehicles is the fact that it is often stored on vehicles at extremely high pressure. While the pressure vessels used for this purpose have an incredibly good safety record, it is critical that mechanics, operators, and first responders be trained in the special considerations needed when working with a high-pressure gas system. Additionally, hydrogen fuel production can cause greenhouse gas emission byproducts and potentially impact public health if not carefully managed. This may lead to greater scrutiny of hydrogen fuel from environmentalists and those who may say it is not worth the risk.

Hydrogen Investments: Given the high cost of hydrogen fueling infrastructure, there is a need for significant private and public sector investment to spur hydrogen fuel at scale in our transportation system. The Biden-Harris Administration has announced $7 billion for America's first clean hydrogen hubs, which will drive clean manufacturing and deliver new economic opportunities nationwide. These hubs are expected to collectively produce three million metric tons of hydrogen annually, reaching nearly a third of the 2030 U.S. production target and lowering emissions from hard-to-decarbonize industrial sectors.

The Regional Clean Hydrogen Hubs Program (H2Hubs) includes up to $7 billion to establish regional clean hydrogen hubs across America. This program is part of a larger $8 billion hydrogen hub program funded through the Bipartisan Infrastructure Law. The H2Hubs will form the foundation of a national clean hydrogen network that aims to decarbonize multiple sectors of the economy, such as heavy industries and heavy-duty transportation. The hubs will create networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the use of hydrogen as a clean energy carrier.

[1] U.S. Department of Energy Hydrogen Program Record, 2020.

The U.S. Department of Energy has also announced funding for projects to advance hydrogen fueling infrastructure. These projects aim to develop and demonstrate hydrogen-powered equipment and improve processes essential for the deployment of hydrogen technologies. This includes the construction of hydrogen fueling stations for both light- and heavy-duty vehicles.

Hydrogen Fuel versus Lithium Batteries – What is necessary for broader deployment?

To create a hydrogen world versus a lithium battery-filled world, several key elements need to be put in place for each ecosystem. Recently, the private and public sector have invested funding into lithium battery production and sourcing at an unprecedented level.

For a hydrogen world, the ecosystem would need to include:

- **Hydrogen Production**: This involves various methods such as electrolysis of water using renewable energy sources like solar or wind power, as well as other methods like natural gas reforming with carbon capture and storage.
- **Hydrogen Storage and Distribution**: Hydrogen can be stored as a gas in pressurized tanks or as a liquid at cryogenic temperatures. The infrastructure for transporting hydrogen, including pipelines and tanker trucks, needs to be developed.
- **Hydrogen Fueling Stations**: These stations are essential for refueling hydrogen fuel cell vehicles (HFCEVs). They require significant space and infrastructure, including electrolyzers for on-site hydrogen production.
- **Standardization and Market Readiness**: This includes the development of standards for materials, connectors, compressors, and other components. Ensuring market readiness and reliability of these components is crucial.
- **Safety Considerations**: Addressing safety concerns such as fire risk, pressurized vessel safety, and training for handling hydrogen is important.
- **Integration with Other Sectors**: Hydrogen can be used as an input for other processes, making it valuable for various sectors of the economy.

For a lithium battery world, the ecosystem would need to include:

- **Battery Production:** This involves the extraction and processing of raw materials like lithium, cobalt, and nickel, as well as the manufacturing of battery cells and packs.
- **Battery Storage and Distribution:** Efficient storage and distribution systems for batteries, including warehouses and transportation logistics, need to be established.

- **Electric Vehicle (EV) Charging Infrastructure:** A widespread network of EV charging stations is essential to support the growing number of electric vehicles. This includes fast-charging stations and home charging solutions.
- **Recycling and Disposal:** Developing efficient recycling processes for used batteries to recover valuable materials and minimize environmental impact is crucial.
- **Standardization and Market Readiness:** Similar to hydrogen, the development of standards for battery components and ensuring market readiness is important.
- **Safety Considerations:** Addressing safety concerns related to battery storage, handling, and disposal is necessary.

Both ecosystems require significant investment in infrastructure, research and development, and regulatory support to ensure their successful implementation and sustainability. Each has its own set of challenges and opportunities, and the choice between them may depend on specific use cases, regional resources, and policy priorities.

Key Considerations Going Forward

Hydrogen fuel cell vehicles and the hydrogen supply chain are both relatively immature markets in 2024, and there are several resources, costs, and infrastructure barriers to more widespread adoption. Given the complexities and costs associated with hydrogen fueling, there are many considerations for consumers and public agencies before moving forward with hydrogen transportation options.

Hydrogen sourcing and production is the first consideration when addressing the viability of hydrogen as an alternative fuel in vehicles. While hydrogen is the most abundant element in the universe, isolated hydrogen molecules for industrial and transportation uses need to be produced through energy-intensive processes. Hydrogen availability will be a primary driver of feasibility. The U.S. government's H2Hubs program will help jumpstart green hydrogen production and consumption in seven regions across the US, but supply chains in these areas will take years to develop fully.

Along with the fueling infrastructure costs, vehicle costs are higher than standard internal combustion vehicles and similar to the prices of battery electric vehicles on the market today. Given the limited supply chain for hydrogen fuel and associated equipment, maintenance costs will likely be higher than for more common equipment. Similarly, operational interruptions will likely be longer than those experienced for easier to maintain equipment and/or for fuel sources available from multiple suppliers.

While hydrogen is still a new technology and implementation comes with risks and high costs, users are increasingly deploying hydrogen for transportation applications where zero emissions are necessary and where battery electric vehicle technology is not suitable. These applications include medium- and heavy-duty vehicles, bus routes that are too long for a single charge, and freight.

There are many opportunities to take advantage of government programs and funding availability associated with hydrogen energy. Opportunities such as IRS Section 45V tax credits for hydrogen production, Infrastructure Investment and Jobs Act and Inflation Reduction Act funding programs, and initiatives that explore ways to reduce the cost associated with hydrogen fuel production and broaden its use cases are key areas where the U.S. government can support hydrogen in transportation.

Hydrogen energy can be a contributor to achieving sustainability goals and reducing carbon emissions from the transportation sector, but only if it is sourced or generated in a way that minimizes or eliminates carbon emissions. ITS America continues to support innovation that improves transportation sustainability, including technologies developed for climate-friendly hydrogen fueling of light-, medium-, and heavy-duty vehicles. ITS America members look forward to greater collaboration among the public and private sectors on the deployment of hydrogen power for transportation as an opportunity to make our transportation system greener for all.

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