Hydrogen as a Transportation Fuel in Rural Communities

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Prepared by:

Cory Shumaker

Tom Ebert

Alison Smyth

Center for Transportation and the Environment

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About this Document

This document was prepared for CTAA by the Center for Transportation and the Environment (CTE) in September 2020 as part of the N-CATT cooperative agreement between CTAA and FTA. Primary authors were Cory Shumaker, Tom Ebert, and Alison Smyth of CTE. Opinions expressed or implied in this document are those of the authors. Nothing in this document is to be interpreted as position, policy or guidance from the United States Government. Incidental use of companies' names or the names of their products is made solely to facilitate discussion and should not be regarded as recommendations or endorsements.

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Abstract

Transit agencies are moving toward zero-emission transportation technologies for a variety of reasons, such as improving public health through the elimination of harmful tailpipe emissions and potentially reducing operating costs. However, rural communities have their own specific challenges to implementing zero-emission technologies. Battery electric vehicles do not have the range capabilities of those powered by diesel or other fossil fuel sources, and vehicles operated in rural environments often need to drive significant distances at higher average speeds before refueling.

An alternative option for transit agencies interested in pursuing zero-emission technologies is hydrogen fuel cell electric vehicles. These vehicles have greater range than battery electric vehicles, providing greater flexibility. There could also be opportunities for partnerships with other community agencies, institutions, and businesses to generate the fuel locally and cleanly or to share the fueling station with other fuel cell electric vehicles, thus reducing capital and operating costs paid by the transit agency.

This paper reviews the fuel cell electric vehicle market for transit agencies, hydrogen fueling station configuration options, and considerations for deployment of fuel cell electric vehicles in rural transit.

Introduction

What is Hydrogen?

Hydrogen is an odorless, colorless gas and is the lightest chemical element. Hydrogen has unique properties that require special consideration, but it is important to know that hydrogen is used safely every day across the country as an important industrial chemical and a vehicle fuel. In the United States, ten million metric tons of hydrogen are produced annually[i]. Hydrogen can be used as a fuel for anything that requires electricity, due to a device called a fuel cell that uses hydrogen and oxygen to produce electricity, with the only emission being water vapor (Figure 1).

Hydrogen is the most abundant element in the universe. The challenge is that a hydrogen molecule is so light that in order for it to stay in Earth's atmosphere it either must be bonded to another element (like oxygen or carbon) or stored in a pressurized canister or as a cryogenic liquid. Hydrogen is commonly observed on Earth as bound to oxygen in the form of H_2O, or water, and to carbon in the form of CH_4, or natural gas. It is a carrier of energy, just as batteries store energy and aren't the original source of it.

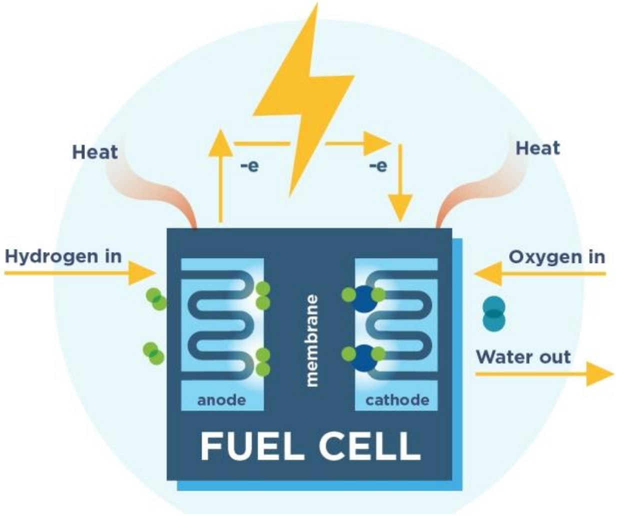

Figure 1: Diagram of basic hydrogen fuel cell operations

Is Hydrogen Safe?

Hydrogen has been safely used for centuries, dating back to Robert Boyle's experiments with acids and iron in 17th century England.[ii] The English physicist, William Grove, built the first fuel cell in 1842.[iii] In practical terms, hydrogen use dates back to the early 1900s Europe. Today, hydrogen is used in many industries, including the chemical industry, petrochemical refining industry, fertilizer industry, glass industry, steel industry, and electronics manufacturing. Hydrogen is non-toxic and upon release, the lighter-than-air gas escapes extremely quickly (40 miles per hour[iv]) and vertically up into the atmosphere, where it eventually makes its way into outer space.

There are a number of safety codes and standards developed for hydrogen that any installation or use of hydrogen must abide by. The first agency to develop safety protocols for hydrogen was the National Aeronautics and Space Administration (NASA). Since its inception in 1958, NASA has been one of the largest consumers of hydrogen, harnessing its unique properties to conduct space missions.[v] NASA uses hydrogen both as a rocket fuel and as an energy source to provide mission-critical electricity through the use of fuel cells. The topic of hydrogen safety is widely discussed in the industry. In 2019, the Center for Hydrogen Safety was formed to be the premier authority for hydrogen and, along with H2tools.org, to disseminate safety information and materials to users and producers.

Hydrogen infrastructure and hydrogen fuel cell vehicles have gone through rigorous testing and are upheld to extremely stringent safety standards.[vi] The National Fire Protection Association (NFPA) and the Compressed Gas Association (CGA) have published safety standards that address the storage, use, and handling of hydrogen in industrial applications, dating back to the first edition of NFPA 567 (later renumbered as NFPA 50A) circa 1960.[vii] Today, the current version followed by hydrogen infrastructure providers is NFPA 2. According to industry experts, hydrogen fuel cell vehicles are safer than vehicles with internal combustion engines (i.e., gasoline and diesel engines).[viii] With proper safety procedures and components (e.g., leak detectors, flame detectors, ventilation) in place, hydrogen can be safely handled in any environment.

What Are the Benefits to Rural Communities?

Local production—Energy independence

Hydrogen has the highest energy content by weight of all known fuels – three times higher than gasoline – and is a critical feedstock for the entire chemicals and refining industry.[ix] Since hydrogen can be produced locally from a wide variety of resources (including wind, solar, and biogas), it is a great way for communities to increase their energy independence, especially in areas where traditional energy (electricity) production and distribution are difficult or inefficient due to long distances between locations. Hydrogen and fuel cells can enable zero or near zero emissions in transportation, stationary or remote power, and portable power applications. Using local labor and resources, hydrogen can be produced and used as fuel for local fuel cell vehicles and equipment.

Hydrogen can be used to power fuel cell electric cutaway vans and fuel cell electric buses (FCEBs) for transit agencies, as well as fuel cell electric forklifts and privately-owned fuel cell electric vehicles (FCEVs) of the community. Hydrogen can also be used as a source of backup power in emergency situations, a practice already in use at some hospitals, data centers, and other critical infrastructure sites. Using fuel cells as backup power will increase the resilience and energy independence of the community and surrounding area. Some of these production pathways and applications are shown in Figure 2.

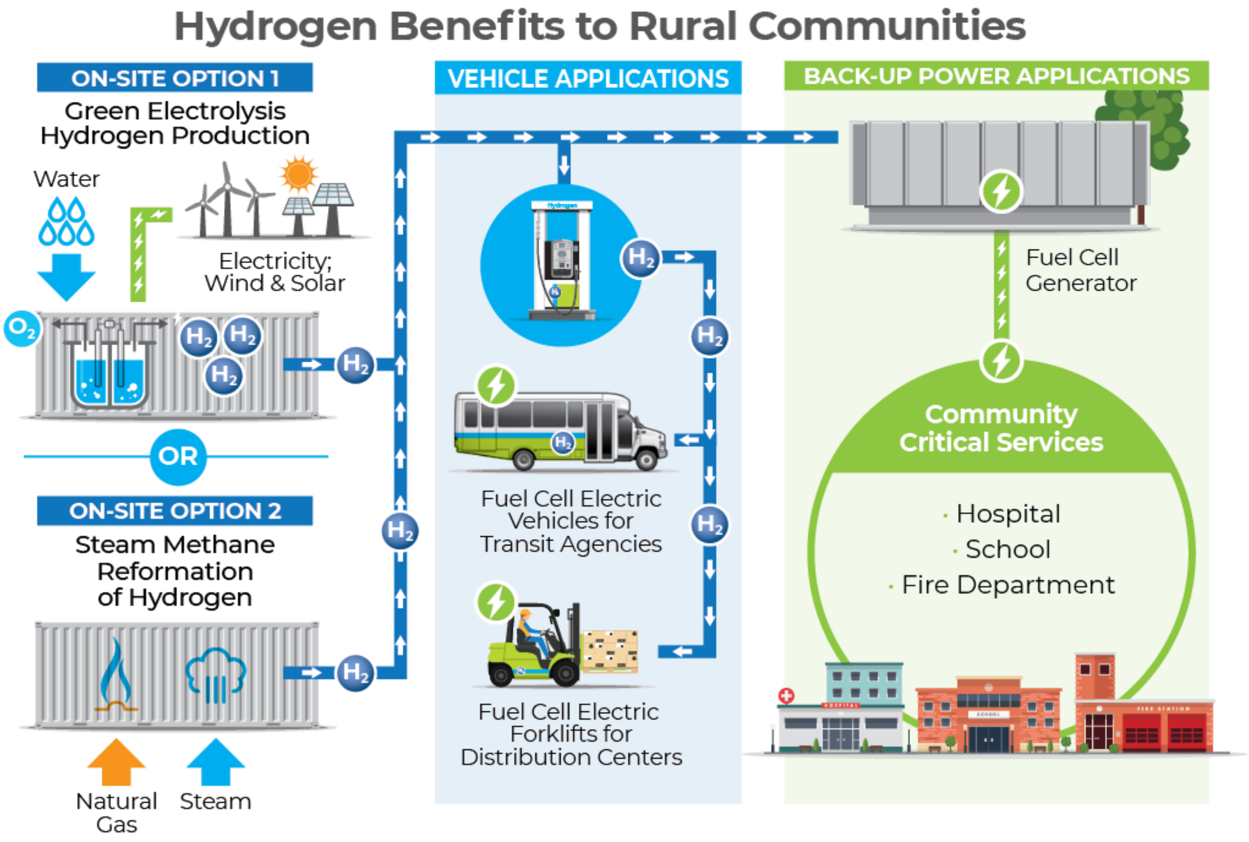

Figure 2: Depiction of some possible production pathways and end uses for hydrogen in a community

Energy Storage Mechanism

Rural communities can have favorable economics for developing a local renewable energy microgrid, and with careful planning, these microgrids can generate more power than the community consumes. This power could be sold to the local utility, but another option presents itself with hydrogen, which can be used as energy storage. When produced with excess renewable power, the green hydrogen produced and stored can later be used to fuel vehicles or serve as clean backup power generation. This approach can be especially useful for power generated when electricity supply exceeds demand, such as when wind power turbines are operating overnight, when that clean power would otherwise be curtailed.

Clean Fuel

Hydrogen, when used in fuel cell vehicles, is a clean and zero-emission fuel. Due to the electrochemical reaction inside the fuel cell, the only byproducts of the reaction are water and heat.[x] Thus, there are no tailpipe emissions like with a conventional internal combustion engine. When hydrogen is produced from renewable energy, there is the possibility of having a fuel source for vehicles that is 100% clean and renewable. If generated on-site, all emissions are removed that would typically occur from transportation of the hydrogen.

Multiple Applications

Hydrogen can be used in multiple applications, from stationary power to a fuel for various types of large and small fuel cell electric vehicles; as well as for clean ammonia production. In Iowa, farmer Jay Schmuecker is producing ammonia from green hydrogen (via solar electrolysis) and nitrogen extracted from the air.[xi] This small ammonia plant is an example of what could be a large scale self-contained, on-site ammonia production for farm use to fertilize crops.

Many large corporations throughout the country utilize hydrogen inside warehouses and distribution centers to fuel zero-emission forklifts powered by hydrogen fuel cells (Figure 3). In the United States today, there are over 32,000 hydrogen fuel cell electric forklifts in operation, the majority built by Plug Power.[xii] In fact, across the US there are 80 hydrogen stations for fuel cell electric forklifts, including many in rural parts of the country.[xiii]

Figure 3: Picture of hydrogen fueling station for fuel cell forklifts[xiv]

By combining multiple uses of hydrogen fuel cells into one site, the cost per kilogram of the hydrogen used can go down due to economies of scale. Hydrogen infrastructure has the ability to support goods movement, people movement, and power generation.

Hydrogen Fuel Cell Vehicles

What Are They?

A hydrogen FCEV is a zero-emission electric vehicle with the drive axle powered (either directly or through a transmission) by an electric motor. Electricity is provided to the electric motor from a hydrogen fuel cell that converts compressed gaseous hydrogen from onboard storage tanks into electricity through an electrochemical reaction with oxygen from outside air. The result of the reaction is electricity and an emission of pure water vapor at the tailpipe. The size of the fuel cell can be scaled up to handle any class of vehicle from passenger cars to heavy-duty trucks and buses (Figure 4). Most FCEVs also have a small high-voltage battery to efficiently buffer energy and provide electricity to the electric motor during instances of high power requirement (e.g., acceleration, going up an incline). The images in Figure 4 show some of the fuel cell vehicles available today.

Figure 4: Examples of FCEVs. Top left: Hyundai Nexo[xv]; Top Right: Toyota Mirai[xvi]; Middle: Kenworth T680 fuel cell truck[xvii]; Bottom Left: New Flyer Xcelsior Charge H2[xviii]; Bottom Right: Class 6 UPS Fuel Cell Delivery Van[xix]

How Do FCEVs Compare to Battery Electric Vehicles?

Fuel cell electric vehicles have longer range than pure battery electric vehicles due to the way FCEVs carry their energy onboard. This is especially important in rural areas where greater distances are covered at higher speeds (requiring more energy) than in urban areas. While battery electric vehicles solely rely on energy stored in a battery (which is directly proportional to, and therefore limited by, weight and volume), FCEVs use energy from hydrogen, which is extremely lightweight itself, that is stored as compressed gas in cylinders. Even with the additional weight of hydrogen cylinders and a fuel cell, FCEVs are able to achieve a longer range due to the amount of energy-dense hydrogen they can carry onboard while meeting the vehicle gross weight rating and volume constraints.

In comparing a New Flyer Xcelsior Charge 40’ electric bus and a New Flyer Xcelsior Charge H2 40’ fuel cell bus, the fuel cell bus has 46% more range and 6% less weight than the battery electric bus of the same overall length.[xx] While both zero-emission vehicles experience range variability due to temperature change and other factors, FCEVs are proven to have better range in cold climates compared to battery electric vehicles (BEV). The results of an analysis performed by CTE, Cleveland State University, and the Stark Area Regional Transit Authority (SARTA) show that the loss in range during a temperature change from 50-60° F to 22-32° F was greater for battery electric buses (37.8% decrease) than for fuel cell electric buses (23.1% decrease).[xxi]

Fueling FCEVs is a completely different experience than “fueling” battery electric vehicles, which often require long recharge times. FCEVs are fueled similarly to the way compressed natural gas (CNG) vehicles are fast-fueled: via a dispenser that passes a compressed gas (hydrogen in this case) through a nozzle into the vehicle. This process is broken down into more detail in the next section of this white paper. The time to refuel an FCEV is just minutes; passenger cars can fully refuel a 300–400 mile range hydrogen tank in 3–5 minutes.[xxii] Like CNG vehicles, FCEVs can be refueled quickly at a central location, requiring less space than parking and charging a battery electric fleet.

What FCEVs Are Available Today for Rural Transit?

In the past few years, production of hydrogen fuel cell buses in the 40’ and 60’ categories has been increasing. Transit agencies in different parts of the country (e.g., California, Massachusetts, South Carolina, Ohio) now have experience with fuel cell buses from a variety of manufacturers as part of various state and federal funding programs. Today, the most prominent North American manufacturers for large format public transit fuel cell buses are New Flyer and ENC. The average price for a 40’ fuel cell bus is $1,015,000.[xxiii] While this is significantly higher than the price of a diesel bus equivalent (approximately $550,000), there are federal programs (e.g., Low or No Emissions Program) in place, as well as some state programs, to offset the increase in price to achieve zero emissions.

For smaller vehicles more suited to rural transit (e.g., vans and cutaways), fuel cell models are not as readily available, but they are in development. For large format passenger vans, such as the 15-passenger Ford Transit, there are available fuel cell versions. Lighting Systems offers a fuel cell Ford Transit passenger van with up to a 300-mile range for around $200,000. As for a fuel cell cutaway, Lighting Systems also offers this vehicle model for around $270,000.

OEMs that have certified that their FCEBs are Buy-America compliant include Lightning Systems, New Flyer, and ENC. While it is not guaranteed they will meet or certify Buy America compliance in the future, it is a fair assumption that they are more likely to do so having certified in the past.

Hydrogen Fueling Stations

One of the many perks of using hydrogen as a fuel source for transit vehicles is the fact that the process of fueling is nearly identical to what one would expect from fueling up on diesel or other conventional fuels. Operators pull up to the fuel dispenser, which looks and functions similarly to conventional fueling stations, and simply fills up the FCEV with hydrogen in a matter of minutes.

Configurations

There is no one-size-fits-all solution for hydrogen fueling stations. Several factors, such as size of fleet, fleet utilization, available funding for capital equipment and operations, location, and possible community partners will all influence what will be the best option for a transit agency. Other variables that will impact the design of a hydrogen fueling station include access to gaseous and liquid hydrogen supplies in the region; availability of power, gas, and water utilities; availability of renewable energy; local permitting and environmental compliance requirements; and the environmental conditions or need to remediate existing contamination at a particular site.[xxiv]

The configuration of vehicles in the fleet, whether 40’ FCEBs or other vehicles such as cutaway vans and sedans, will impact the requirements for the fueling station. Currently in the United States, FCEBs all require hydrogen to be dispensed at 350 bar (“H35”). Light-duty vehicles will have a higher-pressure requirement at 700 bar (“H70”), which should be taken into consideration when designing a hydrogen fueling station. Most hydrogen fueling stations will include:

1. Liquid or gaseous hydrogen delivery system, including parking pads, stanchions for connections, and bulk storage tanks (as primary supply or as backup to hydrogen production system). Liquid would be transferred from a delivery truck to a storage tank. Gaseous hydrogen can either be a trailer swap or a transfer of gas from trailer to storage tanks.
2. On-site hydrogen production system (as an alternative to hydrogen delivery for primary supply);
3. Liquid pump or gas compressor;
4. High-pressure ground storage tank(s);
5. Vaporizer (in case of liquid storage);

6. Chiller;
7. Hydrogen dispenser.

There are several options for how to bring hydrogen fuel to a site, whether it is delivered (either in liquid or gaseous form) or produced locally on-site (either by electrolysis of water or steam-methane reformation of natural gas). The type of hydrogen supplier a facility might use depends on the local availability of hydrogen and on-site capabilities (available utilities and space) of the transit agency. These variables impact the economics of building and operating a station. **Figure 5** below gives examples of these options.

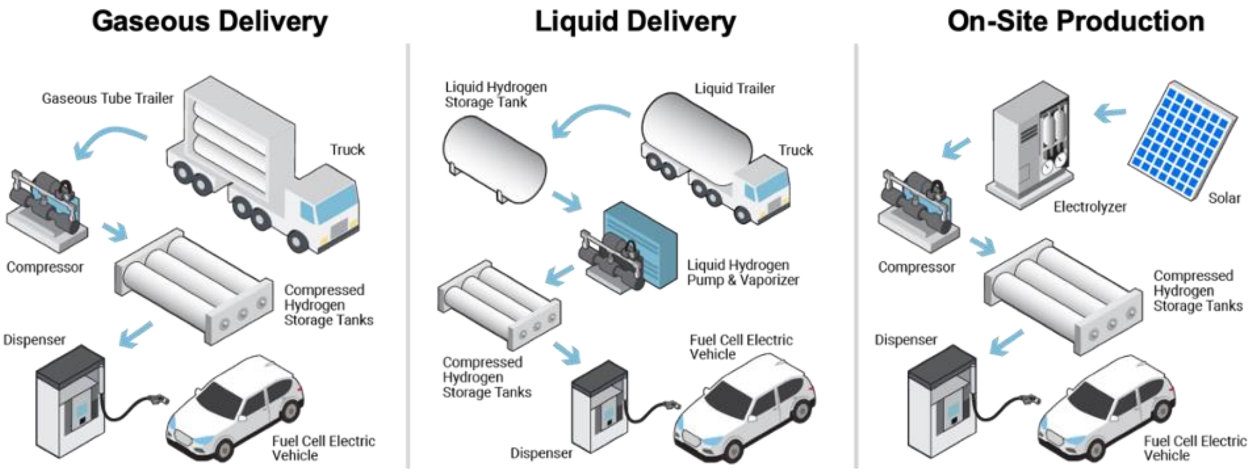

Figure 5: Options for hydrogen delivery[xxv]

Having hydrogen delivered can be a way to drive down the capital costs needed for on-site hydrogen production infrastructure, but may result in higher dispensed fuel costs. While hydrogen delivery does lower local energy costs, the cost per unit of hydrogen may be higher, especially if hydrogen producers and distributors are far away from the fueling site. There are two forms of hydrogen available for delivery: gaseous and liquid. Liquid hydrogen can be more attractive to some transit users as its delivered price is cheaper on a per kilogram basis than gaseous hydrogen and it has a higher storage capacity within a set footprint to handle fueling a larger fleet. Gaseous hydrogen requires both high- and low-pressure systems for storage and can be delivered by truck. In some cases, a hydrogen pipeline may be possible, but this is not typical in locations away from coastal industrial centers.

Instead of hydrogen being delivered to the fueling site, on-site production can be an attractive option for some organizations. With on-site generation the organization has control of the entire supply chain of hydrogen, as well as the opportunity to bring down the cost per unit of hydrogen. However, there are additional regulatory and safety requirements, as well as an increase in upfront capital costs and maintenance costs.

There are two main ways of producing hydrogen, described below; both are relatively energy intensive but require different feedstocks. One may be more feasible than the other for a transit agency.

- **Electrolysis -** Electricity is used to split water into hydrogen and oxygen gas. The hydrogen is stored and oxygen can be captured and sold off as a byproduct or simply released into the atmosphere. A great way to meet greenhouse gas (GHG) reduction goals, if renewable energy is available to the organization, is to combine the renewable energy with electrolysis. Even with the use of power from the grid, this method produces hydrogen that is cleaner than conventional fuels. High electricity rates will increase the cost per unit of hydrogen.

- **Natural Gas Steam-Reformation (SMR)** - This production method uses natural gas and steam at high temperatures to create carbon dioxide and hydrogen. If the proposed fueling site is near a natural gas pipeline, this might be a smart choice. There is also the possibility of supplementing the needed natural gas feedstock with the output from anaerobic digesters—which take in biomatter sources such as manure—that can be found on farms or waste water treatment facilities in the area. One downside of steam-methane reformation is the release of carbon dioxide into the atmosphere, which is a greenhouse gas. However, even with the upstream process of producing hydrogen from natural gas as well as delivering and storing it for use in FCEVs, the total greenhouse gas emissions are cut in half and petroleum is reduced over 90% compared to today's gasoline vehicles.[xxvi] If biogas is used as the source of natural gas, the carbon intensity of the hydrogen produced can even be negative.

Pricing for hydrogen infrastructure comes down to the type of station (liquid vs. gaseous), whether the hydrogen is delivered or produced on-site (either by electrolysis or SMR), and the total storage/fueling capacity. It should be noted that it is expected that the costs of renewable or low carbon hydrogen will fall by up to 60% over the next decade.[xxvii]

Training Considerations and Costs

The final step in proper implementation of hydrogen infrastructure is training of the transit agency’s maintenance and service staff who will be responsible for safely fueling and maintaining the fuel cell vehicles; this ensures proper safety precautions are learned and followed. Operators will also go through a training session to familiarize themselves with the alternative fueled vehicles. Trainings performed may incur a cost depending on the vendor.

Opportunities to Reduce Cost and Increase Benefits to Community

While the upfront capital costs for vehicles, fueling, and ongoing operating costs of FCEVs may seem like a high barrier to utilizing the technology, there are several options available to rural communities for funding to bring down costs for implementation.

Section 5339(c) funding in the FAST Act is what is known as the Low or No Emission Vehicle Program (Low-No). In Fiscal Year 2019, the program had $84 million dollars appropriated.[xxviii] This is the main program that the federal government uses to fund zero emission transit projects. Both vehicles and infrastructure costs are eligible under this program. CTE has significant experience in both applying for the Low-No program and the reporting/protocols required for the subsequent deployment of the alternative fueled vehicles.

Rural Transit Assistance Program (RTAP)—RTAP had $13.5 million appropriated in fiscal year 2020. [xxix] RTAP provides technical assistance to rural transit authorities to help develop and promote the needed skills to provide effective transit service. Their resources and database can help overcome information shortcomings during projects and to help educate agencies on best practices.

State funding—Depending on which state the rural agency operates in, there may be other funding resources available, such as voucher programs, that can help provide funds or other forms of assistance to projects. One example is the Volkswagen mitigation settlement funds that states are using to help reduce GHG emissions.[xxx]

Partnerships Within the Community

Community partners can help provide financial, technical, or management help with projects, including cost share for capital or operating costs.

Local Utilities - Working closely with utilities is critical to the success of implementing a hydrogen fuel cell electric fleet. Rural transit agencies can work with their local utilities to provide either the needed power for electrolysis or the natural gas needed for SMR production of hydrogen; both are avenues worth exploring.

Other partners - Other partners worth engaging would be nearby manufacturing or shipping businesses that already need hydrogen for fuel cell forklifts. As fuel cells continue to penetrate the long-haul shipping market, partnerships with truck fueling stations that provide hydrogen fuel and other services for fuel cell trucks is another avenue to explore. For long-haul trucks an extensive hydrogen fueling network will be necessary across the country and in many rural communities located along interstate corridors. Fuel cells are also expected to be used to power excavation, agricultural, and construction equipment in the coming years.[xxxi] Finding additional partners who can share mutual interest in using the fueling equipment presents an opportunity to spread the costs of maintenance and training across multiple organizations.

Action Plan

To introduce hydrogen fuel cell electric vehicles into an agency's fleet, CTE recommends conducting thorough background research and planning studies prior to procuring a vehicle. Proper planning is critical to ensuring a successful deployment.

1. Reach out to peer agencies to learn from their experiences with zero-emission technology.
2. Develop support within the agency for pursuing hydrogen fuel cell technology.
3. Contact local partners and speak to local and state officials about your project proposal. Identify opportunities for collaboration and funding support.
4. Perform a planning study to evaluate feasibility of deploying hydrogen fuel cell vehicles at the agency. A study will likely require the expertise of an outside organization familiar with hydrogen fuel cell electric vehicle technology and hydrogen fueling station, such as CTE. This study should explore the wide variety of options for hydrogen fueling stations and their associated costs given the anticipate fuel cell electric fleet demand.
5. Pursue and secure funding for the fuel cell electric vehicle deployment and associated infrastructure detailed in the planning study.
6. Execute the hydrogen fuel cell electric vehicle deployment project.

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