MIDWEST STATES HYDROGEN FUEL CELL DEMAND STUDY

Prepared for: Stark Area Regional Transit Authority

In Support of the Renewable Hydrogen Fuel Cell Collaborative

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RENEWABLE HYDROGEN FUEL CELL COLLABORATIVE

Midwest States Hydrogen Fuel Cell Demand Study

Now is when we need to move the necessary levers to boost the United States hydrogen economy. Fuel cell electric vehicle (FCEV) technologies, which depend on hydrogen for fuel, are being commercialized across the globe. Governments in Asia and the European Union, in coordination with industry, are now investing billions of dollars each year, and countries like China have communicated that hydrogen is a fuel of choice. This signals that hydrogen is an investment worth making. More importantly, the infrastructure required to support hydrogen requires planning and takes several years to implement. It is imperative that action be taken ahead of the demand curve; a curve that will grow significantly in the next five to ten years. For the U.S. to have a successful hydrogen economy, it is crucial that action is taken beyond the requirements of Zero Emission Vehicle (ZEV) states.

Planning must begin now to prepare for tomorrow's hydrogen demand across Michigan and Ohio. In a recent survey of 22 trucking fleets operating in the Midwest (conducted by the Ohio Fuel Cell Coalition and the North American Council for Freight Efficiency – OFCC/NACFE), 26% of the respondents indicated they planned to introduce hydrogen fuel cell trucks into their fleets in the next 1-3 years, and over 50% indicated they would in the next 4-7 years.[1] Further, they expect to convert about 25% of their fleet to hydrogen fuel cell electric drive. Yet, this introduction will be impossible without first planning a refueling infrastructure responsive to this demand.

This data is important because regional and long-haul freight carrying applications are particularly well suited for fuel cell electric drivetrains, and as a result, are likely to create the first high demand for hydrogen refueling in the Midwest. Today, in states like California, the hydrogen market continues to accelerate, but until the infrastructure expands beyond the state of California it will be difficult to drive vehicles and move goods and products.[2] Fleets are signaling that their fleet fuel type choices are limited based on access to advanced fuels. This was demonstrated in the results from the OFCC/NACFE poll where trucking companies communicated that if hydrogen refueling is available, their interest in deploying fuel cell vehicles will rise from 26 to 37% within the next three years. Even more striking is that 40% of respondents indicated that if infrastructure were available immediately, their consideration of switching to FCEVs would be pulled ahead from 4-7 years to 1-3 years. Likewise, respondents identified range anxiety as one of their most critical impediments to adoption.[3] We need to take steps now to ensure that access to hydrogen and the infrastructure required is available in all regions across the U.S., including the Midwest, within the next five years. Without taking the first steps to bring the infrastructure to meet the growing demand, the potential for the Midwest hydrogen economy will stagnate. The decisions made today will have a lasting, long-term impact on the future of a successful hydrogen economy.

The global competition the U.S. needs to win. Driven by the fight to combat climate change, transportation continues to move toward clean fuels and away from the use of fossil fuels. The replacement of internal combustion with fuel cell electric drive engines is a crucial part in the advancement of vehicles toward zero emissions. The global hydrogen storage market is projected to grow

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[1] P. Valente, and L. Buckhosh, "Measuring Interest in Hydrogen Refueling Infrastructure in the Midwest: A Survey of Delivery Fleets, Heavy-Duty Trucking, and Fuel Distributors," April 30, 2020, http://www.midwesthydrogen.org/site/assets/files/1413/measuring_interest_in_hydrogen_initiative_-_fleet_and_infrastructure_outreach_final_002.pdf

[2] https://www.trucks.com/2020/04/21/daimler-volvo-hydrogen-fuel-cell-truck/

[3] OFCC, et al, footnote 1.

from $467 million in 2016 to $1 billion in 2026. The global hydrogen storage market is being driven by the combination of an increasing demand for industrial and transportation use. Transportation use of hydrogen will accelerate as society finds the environmental and national security risks of oil increasingly unacceptable, leading to government regulations and standards for production of cleaner fuels and development of new applications of hydrogen powered fuel cells for transportation applications.[4] Even though the limited availability of hydrogen refueling infrastructure in developed economies is an extreme obstacle, the market still indicates that there continues to be growth in the demand of transportation fuels. The hydrogen FCEV market size was valued at $652 million in 2018 and is projected to reach $42 billion by 2026.[5] It is of the ultimate importance for the U.S. to be competitive on a global scale and remain a leader in the transportation industry. Other countries continue to move forward in accepting hydrogen and have proactively embraced actions to ensure access to the fuel. As an example, Japan had already sold or leased and has on the road 3,521 fuel cell cars as of November 1, 2019.[6] As the world moves into a post-pandemic era, it is the opportune time to use public money to move a hydrogen economy forward. Australia has already set aside $191M for hydrogen projects and Portugal has plans to build a solar-powered hydrogen plant to produce hydrogen via electrolysis by 2023. The Netherlands are planning for 500 MW of green electrolyzer capacity by 2025.[7] If the U.S. does not move to capture and complete the projects to bring hydrogen infrastructure up to meet future demand, the nation will be left behind other countries.

Hydrogen at the pump today remains more costly than gasoline or diesel fuel. However, this is primarily an artifact of a nascent hydrogen delivery infrastructure system. The cost of reforming natural gas into hydrogen – which is how 95% of hydrogen is manufactured - is comparable to making diesel fuel. Transportation and delivery costs are coming down, as the demand for refueling has been rising. Importantly, costs for carbon free hydrogen generation – primarily through electrolysis of water -- are also dropping, driven by cheap nuclear, solar and wind power. In addition, across Europe and North America the costs for electrolyzers have decreased by 40%. In China, where hydrogen has been identified as a fuel of choice, electrolyzers produced there have been found to be up to 80% cheaper than those made elsewhere. With an increase to the scale of electrolyzer manufacturing, it is predicted that hydrogen could eventually be produced for $0.8 to $1.6/kg across the globe before 2050. This cost is equivalent to gas priced at $6-12/MMBtu, making it competitive with today's natural gas prices countries such as Brazil, China, Germany and Scandinavia on an energy-equivalent basis, and overall cheaper than producing hydrogen from natural gas or coal with carbon capture and storage.[8] As described by the DOE's Alternative Fuels Data Center, 1 kg of hydrogen has 100% of the energy (on a Btu basis) of 1 gallon of gasoline; further, one gallon of diesel has 113% of the energy of 1 gallon of gasoline.[9] This indicates that it would be expected that the diesel-gallon equivalent (DGE) price to be 1.13 times as much as the price of hydrogen, or $2.26/DGE by 2030 and $1.13/DGE by 2050 according to Bloomberg's projections.

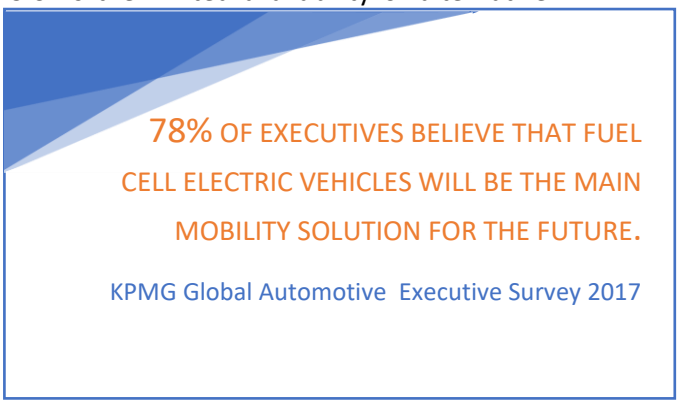
Additionally, the delivered price of hydrogen is also showing signs of future reduction. In its *Hydrogen Economy Outlook,* Bloomberg describes how the delivered cost of renewable hydrogen in China, India and Western Europe could fall to around $2/kg ($15/MMBtu) in 2030 and $1/kg ($7.4/MMBtu) in 2050.[10]

[4] https://www.marketsandmarkets.com/Market-Reports/hydrogen-storage-market-15698551.html
[5] https://www.alliedmarketresearch.com/hydrogen-fuel-cell-vehicle-market
[6] https://cafcp.org/by_the_numbers
[7] https://www.reuters.com/article/us-health-coronarivus-hydrogen-analysis-idUSKBN22K0MJ
[8] Bloomberg
[9] https://afdc.energy.gov/fuels/fuel_comparison_chart.pdf
[10] https://about.bnef.com/blog/hydrogen-economy-offers-promising-path-to-decarbonization/

The U.S. is well positioned for a successful hydrogen economy. As the global transportation market continues to move toward alternative fuels, particularly hydrogen fuel cell, the United States is doing the same. To date, 8,285 FCEVs have been sold or leased and are on the road in the U.S.[11] In fact, a recent Global Automotive Executive Survey showed that 78% of executives believe that FCEVs will be the main mobility solution for the future and more likely than BEVs to succeed in the long term.[12] Not only are fuel cells sufficiently durable, but the costs associated have also come down over the last several years and the regulations are getting more stringent. The push toward zero emission vehicles across the U.S. continues to grow every day. The California Air Resources Board (CARB) just proposed a revision to their Advanced Clean Trucks regulation. The regulation increases the sales requirements across vehicle classes 2 to 8. Under the new version of the standard at least 20% of trucks on the road in California will be electric and by 2035 this could equate to more than 17,000 class 8 trucks. This revised standard during these changing economic times confirms that the U.S. is demanding alignment of sales with the continued desire to promote carbon neutrality and meet zero emission standards for vehicles in the future.

Here, the U.S. FCEV market is currently well positioned for future market growth as fuel cell manufacturers have successfully commercialized their product as evidenced by the 60% decrease in the cost of fuel cell systems for transportation on a $/kW basis since the mid-2000s.[13] Developments in the Midwest have brought about an abundant supply of inexpensive natural gas, the primary raw material for hydrogen generation. The cost of producing hydrogen via electricity has also come down due to advancements in electrolyzer technologies. This helps confirm a commercially viable zero-emissions hydrogen pathway. The production of hydrogen for use in transportation applications is proving to be a clean, practical option for the future.

One of the key obstacles that remains prevalent in the U.S. is the limited availability of alternative refueling. Vehicle owners and fleet managers are unable to consider fuel cells as a vehicle powertrain option due to the limited access to fuel, particularly in regions such as the Midwest. Providing opportunity for this alternative fueling has proven to correlate directly to the purchase and use of hydrogen fuel cell vehicles. The 8,285 vehicles sold to date in the U.S. were purchased in areas where there is access to hydrogen fueling stations. One can be guaranteed that vehicle and fleet owners in across Michigan and Ohio, including those with fleets in surrounding states are waiting for that same infrastructure. Fleet owners are prepared to purchase FCEVs once they can be refueled along this corridor.



[11] https://cafcp.org/by_the_numbers
[12] KPMG, Global Automotive Executive Survey 2017 (Jan. 2017)
[13] "DOE Fuel Cell Technologies Office Record 17007: Fell Cell System Cost." U.S. Department of Energy. (2017). https://www.hydrogen.energy.gov/pdfs/17007_fuel_cell_system_cost_2017.pdf. See also "Fact of the Month April 2018: Fuel Cell Cost Decreased by 60% Since 2006." U.S. Department of Energy. (2018). https://www.energy.gov/eere/fuelcells/fact-month-april-2018-fuel-cell-cost-decreased-60-2006

The Midwest is well positioned to begin connecting the needs from East to West. Michigan is a recognized global leader in the automotive industry given the number of original equipment manufacturers, research and development activities and top engineering talent. Michigan offers more automotive and transportation jobs than any other states in the U.S. Their overall economy is built on the health of the automotive industry and Michigan is poised and ready to accelerate the advanced alternative technology vehicle market. Their bordering neighbor Ohio is also internationally recognized for its dynamic fuel cell technology industry and the critical role it has played in advancing the industry toward commercialization. With specialty industry resources already in place – such as an extensive fuel cell supply chain, an innovative research and development community, a technologically advanced manufacturing base, a skilled workforce, and robust programs that support workforce development – Ohio is a trailblazer in the hydrogen industry economy.[14] Several stakeholders in both states and across the Midwest region have joined forces herewith to continue to build on the strengths the region offers and work to introduce fuel cell electric vehicles into the marketplace. The Midwest is ready to set the stage for a full rollout of infrastructure and vehicles, continuing the path toward a more sustainable transportation future.

Across Michigan and Ohio, there is a growing demand for hydrogen from both industrial and transportation uses; currently demand is outpacing local hydrogen generation. Today, there are 13 FCEVs registered and on the road in Michigan and Ohio: all transit buses who have built their own infrastructure in support. Based upon a recent survey conducted by OFCC, there are many national freight hauling companies operating in the Midwest would like to convert their fleets in part to hydrogen in the near term but cannot because of the lack of access to advanced fuels.

So, what does that demand look like today, and how can it be met? To answer these questions, one first needs to understand the current market and the potential for growth in the region. The first step is to identify the interstate corridors with the heaviest traffic volume. Once the area(s) are defined, an assessment of the vehicles registered along those corridors focusing on the vehicle classes well-suited for electrification will provide guidance on potential market demand. For this study, the overall area that has been analyzed for demand can be seen in Figure 1.0 below.

[14] SARTA/CALSTART H2 Generation Report

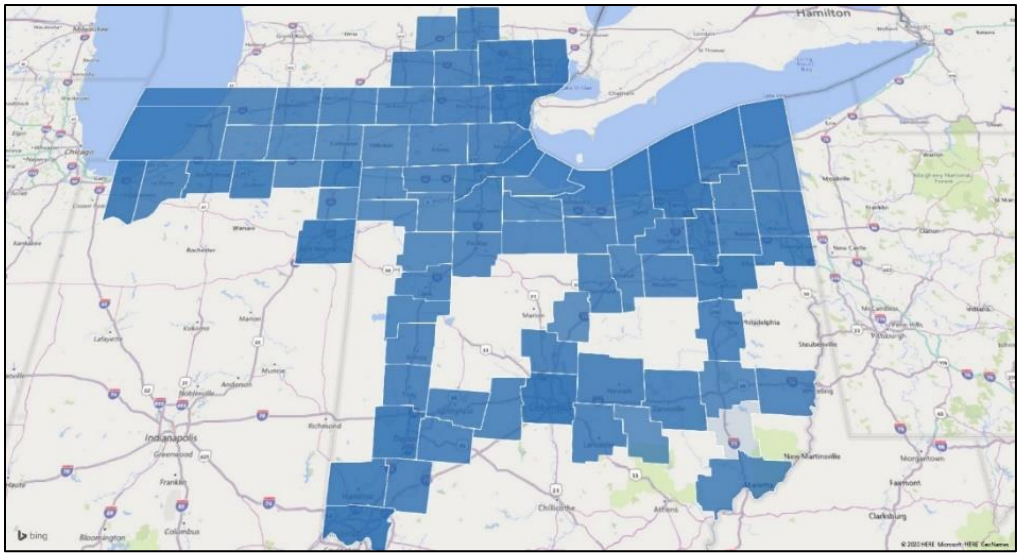


Figure 1.0: IHS Market Demand Area Across Michigan and Ohio and into Indiana

This area was defined based on recent studies run by Cleveland State University where it was determined that the most heavily travelled interstates in the Michigan and Ohio region, starting with the heaviest, are:

- **I-80/90:** An East - West interstate, a toll-road across the state of Ohio, that takes individuals and products from New Jersey to Iowa
- **I-75**: A North - South interstate that takes individuals and products from Michigan to Florida
- **I-70**: An East - West interstate that takes individuals and products from Utah to Maryland
- **I-71**: A Northeast - Southwest interstate that connects I-75/I-70 to I-80/90 across Ohio

The proposed corridors are a prime opportunity due to the fleet traffic and proximity to manufacturing facilities. Not only is the I-75 corridor the key to the Midwest manufacturing epicenter in Michigan and Ohio, but the I-80/90 and I-70 corridors also stretch from as far east as New York City and as far west as Sacramento. This provides the opening for this Midwest location to lead the way to further projects for alternative fuel infrastructure, as this would be the first piece in the puzzle ultimately connecting alternative refueling to fleets across the country. For the foreseeable future, Midwestern states are not expected to adopt California-style incentives, such as Zero Emission Medium- or Heavy-Duty Vehicle Programs which fund the early commercial implementation of zero emission trucks and buses.[15] Adoption rates will depend on identifying barriers and challenges and taking action to eliminate those quickly.

The key to drive the hydrogen and advanced alternative fleet market forward and accelerate the economies already in place in American's heartland is through the development of advanced fueling infrastructure. Today, neither Michigan nor Ohio are one of the 13 zero emission vehicle (ZEV) states in the U.S., and there is not an established revenue stream in place that supports the accelerated deployment of advanced fuel vehicle technologies. However, advanced fuel vehicle technology is critical to the growth of the area's economy and the health of its residents. Within the U.S., California and the Northeast have recognized the benefits of hydrogen and its potential to transform the transportation

[15] Alternative Fuels Data Center. "Hydrogen Laws and Incentives in California." https://afdc.energy.gov/fuels/laws/HY?state=CA

sector. The Midwest, with Michigan and Ohio's lead, stands to also gain economically from this: the hydrogen economy will expand the region's automotive OEM and supply chain industry, its fuel cell supply chain and its industrial manufacturing. The Midwest is already poised to benefit due to the local expertise around the technology and with initiatives already underway that have introduced the first stations and FCEVs to the State.[16] The states of Michigan and Ohio are critical to the U.S. transportation market as the majority of OEMs and suppliers are located in the region. Ohio specifically has a vast fuel cell supplier. Among its strengths, the region boasts a strong manufacturing base with a focus on the automotive.

Clean zero-emission hydrogen production in our own backyard. Another key ingredient to demand in the Midwest is the proximity of the Midwest nuclear fleet to high-volume hydrogen demand, both industrial and transportation. Figure 2.0 below the location of the I-80 corridor, one of the heaviest traveled roads in the nation for trucks, together with nuclear power plants and metal or chemical processing facilities that are hydrogen-intensive.

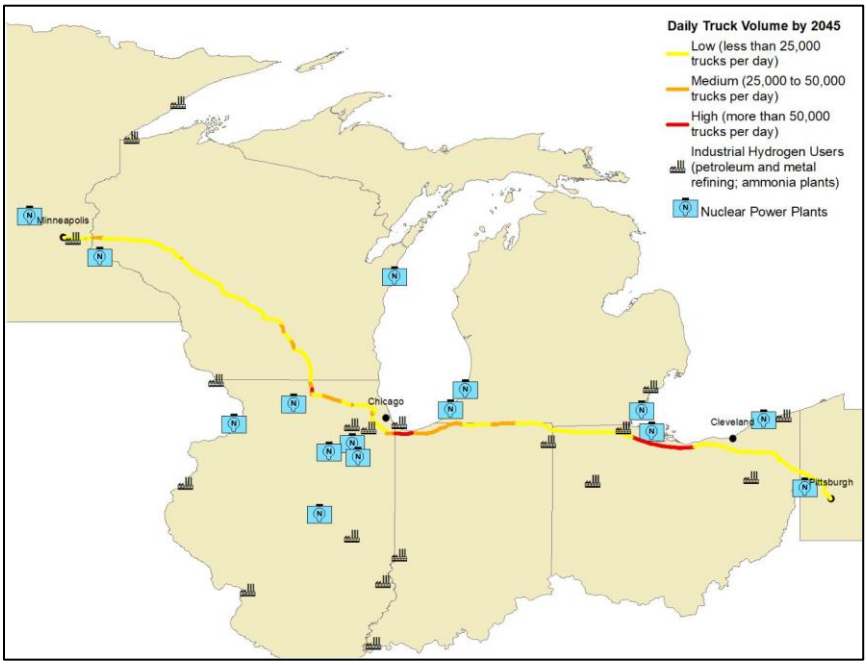


Figure 2.0: Potential Demanders and Nuclear Supply of Hydrogen[17]

Nuclear plants in the Midwest along the Interstate Corridors are candidate sites for such regional hydrogen production as they are located near both major freight corridors and industrial centers, areas where potential high-volume users of hydrogen are concentrated, including transit agencies. Full capacity utilization is most likely to occur where the demand for fuel by heavy-duty vehicles is highest. The most promising sites for economical hydrogen refueling stations in this context are areas that have a history of high fuel demand, such as traditional truck stops along major freight corridors, and large transit facilities

[16] H2 Roadmap – SARTA/CALSTART

[17] Truck volume forecasts are derived from the most recent Freight Analysis Framework (FAF) produced through a partnership between the Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA); see https://ops.fhwa.dot.gov/freight/freight_analysis/faf/. Petroleum refinery and nuclear plant locations are available through the U.S. Energy Information Administration; see https://www.eia.gov/maps/layer_info-m.php. Locations for Midwest ammonia plants and direct reduced iron (DRI) facilities were identified using Google search queries.

with dense ridership. The Interstate Corridor running from Minneapolis to Pittsburgh is particularly well positioned to provide both the market for and the supply of hydrogen. This can be readily seen by comparing the existing and projected hydrogen generation capacity to the industrial hydrogen markets in the Midwest, as set forth in Table 1 below.[18]

Table 1. Current and Projected Midwest Hydrogen Consumption and Production (metric tons)

		Current[11]	*2030*	*2040*
Hydrogen Consumption	iron processing	1,699	2,086	2,696
	ammonia plants	9,144	10,714	13,060
	petroleum refining	2,707	2,990	3,385
	Total	**13,549**	**15,789**	**19,141**
Hydrogen Production	ethane crackers	763	1,516	3,572
	chlor-alkali plants	59	90	152
	on-purpose production at dedicated hydrogen plants	2,287	4,232	9,137
	Total	**3,109**	**5,838**	**12,861**
	Surplus (Shortage)	**(10,440)**	**(9,951)**	**(6,280)**

note: 1 metric ton = 1,000 kg

One strategy for optimizing station location based upon the density of existing refueling stations for heavy-duty trucks and the anticipated fuel economy of heavy-duty fuel cell electric vehicles over the next two decades is shown below in Figure 3.0.

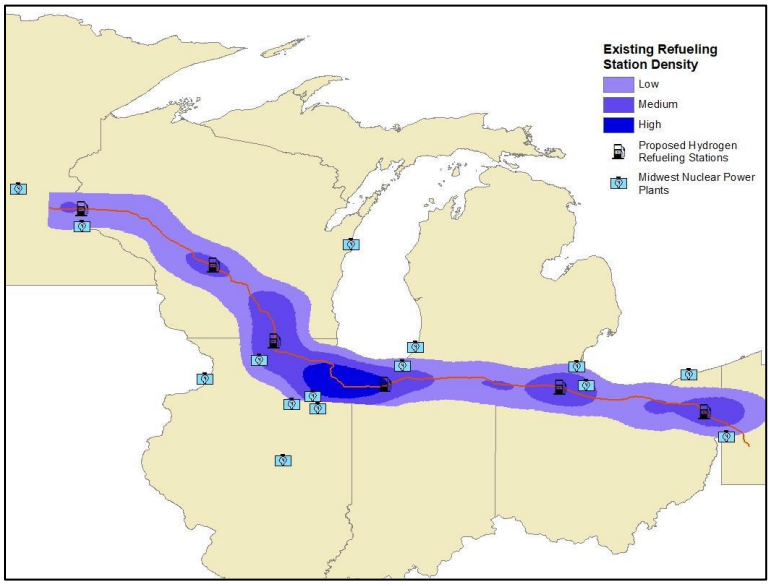


Figure 3.0: Optimized Hydrogen Refueling Station Siting and Midwest Nuclear Plants

[18] https://engagedscholarship.csuohio.edu/cgi/viewcontent.cgi?article=2650&context=urban_facpub

A vehicle market that is ready to take off. Today, every original equipment manufacturer (OEMs) has either signaled plans to make or is already manufacturing zero emission technology, including FCEVs. This market ranges from light duty passenger to heavy duty bus and truck manufacturers.

This is a growing market as major OEMs including Toyota, Honda, and Hyundai all have FCEVs available on the market for sale. Many others like Nikola, Volvo, Cummins, GM and Ford have programs under development.

The light duty passenger FCEV market is already well over 50 years old. After years of vehicle developments and many technical advancements, almost every global OEM is now looking to or are producing at least 1 fuel cell based vehicle platform. The Honda Clarity, Hyundai ix35, and Toyota Mirai are three of the top selling FCEVs in the U.S. today. Ford, FCA and GM each have strong FCEV programs and making their decisions based off of market demand and a demand that moves beyond the ZEV states. Honda, Hyundai and Toyota all have a strong Asian market to depend on should sales slow in the U.S.

Transit agencies have among been the first FCEV adopters. The cost of technology transition is off-set by the nature of the transit industry, as transit buses are 80% subsidized and there have been continuous investments made by the U.S. government to support the deployment of new technology which supports a better life for our citizens and improved mobility for all. Recognizing that transit buses are a perfect platform for fuel cell technology, transit OEMs that have come to market with hydrogen powered vehicles include Horizon/Hyzon, which offers its H2 40' Proton Exchange Membrane (PEM) bus. It anticipates manufacturing 2,000 units by 2023 and over 10,000 in the years to follow. Also included is New Flyer who manufactures the Excelsior CHARGE 2 (40' and 60').

On the footsteps of transit, medium and heavy duty are the next adopters of FCEV technology. Major truck OEMs including Nikola, Horizon/Hyzon, Toyota Truck, Kensworth, Navistar and Cummins, as well as qualified vehicle manufacturers like ROUSH are all producing fuel cell trucks for the market. It is also important to note that organizations such as Nikola and Horizon's Hyzon are less than 5 years old and they were established to meet the growing hydrogen fuel cell truck market – there is a market need and they are addressing the need with product. To further showcase this growing market and that it is worth the investment, in early April 2020, Daimler and Volvo, two major vehicle competitors announced the creation of a joint venture to pursue hydrogen fuel cell trucking technology. The companies said they are looking for a long-term solution for long-haul trucking that meets the vision of "sustainable transport and a carbon-neutral Europe by 2050." Both companies also sell trucks in the US. Technical advances made by manufacturers in Europe typically appear in their North American offerings.

Vehicles Types Best Suited for Fuel Cell Electrification	
Passenger Light Duty Vehicles	Step Vans
Passenger Vans	Regional Trucks

Cargo Vans	Transit Buses
Shuttle Buses	Construction Vehicles
Coach	Long Haul Trucks

Introducing the potential FCEVs owners. Passenger vehicles are likely to find high adoption among customers who want the capability to refuel quickly, drive long distances, carry heavy loads, or have more room, as these are the hallmarks of FCEVs. FCEVs may also figure prominently in higher-utilization use cases that require filling up more than once a day, such as taxis, autonomous vehicles, or delivery fleets. U.S. preferences for larger vehicles like SUVs could create an even larger market, given the fuel cell's applicability for heavier vehicles with long range.

With the introduction of the proposed availability of hydrogen refueling for hydrogen FCEVs, many fleets are preparing to move toward the purchase or conversion of vehicles to FCEVs. Based on pilot activity, purchase orders and information gathered from fleets from a recent study, many fleets have already indicated their interest and expressed that they would move forward with their plans for zero emission vehicle technology should they have access to infrastructure and fuels across Michigan and Ohio.

Fleets with Strong Sustainability Programs – Needing Access to Infrastructure			
Anhueser Busch	AT&T	FedEx	UPS
U.S. Army	Penske	Ford	Meijer
Lipari Foods	Pepsi	Frito-Lay	U.S. Express
DTE (Detroit Edison)	Consumers Energy	Ferguson Enterprises	Schneider

In 2018, Anhueser Busch, which is headquartered in St Louis, right near I-70, signed a contract with Nikola for 800[19] class 8 FCEVs which they will begin receiving production level vehicles as early as 2023, with an additional 160 supplied by Tesla. The size of each of the current fleets varies and can be seen relative to the location of the proposed alternative fuel corridor in Figure 4.0 below. In commercial fleets of small delivery trucks, buses, and medium- and heavy-duty trucks, FCEVs are estimated to make up 10% of commercial fleets and trucks sales in 2030, and 35 percent by 2050.[20] In addition to those fleets that are known to already have vehicles ripe for a new alternative fuel change, FCEVs could account for over 5 percent of passenger vehicle sales by 2030 and potentially 40 percent by 2050. Cost modeling by the National Renewable Energy Laboratory for class 8 trucks indicates a total cost of ownership in 2020 of $1.70 per mile for FCEVs compared to $5.10 per mile for battery-electric vehicles (and $0.7 per mile for diesel trucks). By 2040, class 8 FCEVs are projected to operate at a total cost of ownership that is down from $1.00 per mile greater to 50 cents per mile greater than diesel trucks ($1.3 per mile for FCEVs compared to $0.80 for diesel trucks); battery-electric class 8 trucks are projected to operate at a total cost of $3 per mile by this time. Fuel cells also offer improvements in performance: current deployments at the ports of Long Beach and Los Angeles have shown fuel cell class 8 trucks to provide a "substantial increase in torque" compared to diesel and natural gas variants.[21]

[19] https://www.theverge.com/2018/5/3/17314606/anheuser-busch-budweiser-hydrogen-trucks-zero-emission-startup-nikola

[20] https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf

[21] CSU Study

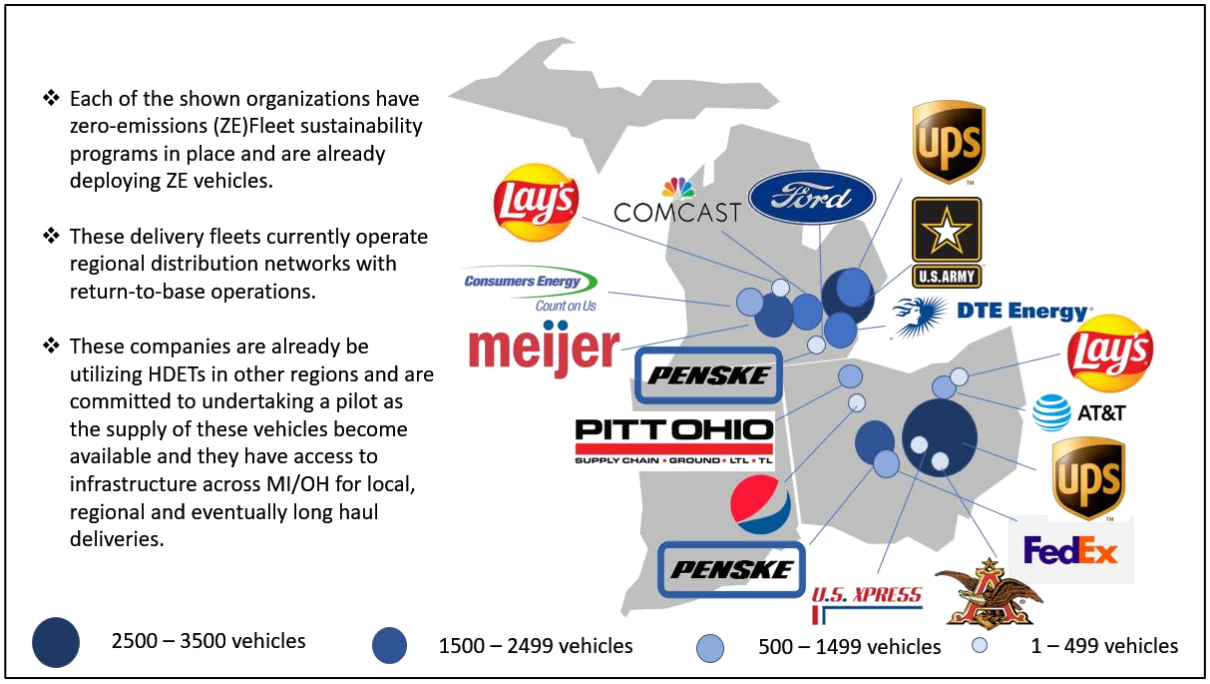


Figure 4.0: Fleets with Zero Emission Sustainability Vehicle Programs Wanting to Electrify

The proof of current success with hydrogen FCEVs lies with the first adopters of hydrogen transportation in the Midwest. Transit agencies have been strengthened by the availability of federal funding for zero-emission vehicles in public transportation and by California mandates to deploy more zero-emission buses that will likely drive down vehicle costs for agencies in all states. Fuel cell buses have a similar range to conventional buses. Battery electric buses typically require charging during scheduled routes, where fuel cell electric buses (FCEBs) do not usually need to be refueled as often. One would fuel an FCEB is the same manner a diesel bus is currently refueled today and within the same timeframe. FCEBs currently have higher startup costs than battery electric buses, however adding FCEBs to an established FCEB fleet may not require adding additional refueling infrastructure. This is often a hurdle when adding battery electric buses to a fleet. Additionally, maintenance costs for FCEBs in early deployments are much more competitive with diesel buses as transit agency staff gains experience with the technology. As agencies deploying both conventional and new propulsion technologies, the cost per mile related to replacement parts has been lowest for FCEBs in evaluations performed by the National Renewable Energy Laboratory. According to the U.S. Energy Information Administration (EIA), hydrogen use by transit buses and freight trucks is projected to be around 0.01% of total transportation energy use (within each mode) in 2020. By 2050, hydrogen-powered FCEVs are forecast by the CEOs of leading energy and transport companies to compose 35% market share and 22% market share for buses and trucks, respectively.[22] This represents a compound annual growth rate in market share between now and 2050 of about 29.5% for buses and 28% for heavy-duty trucks.[23] Given these figures, the Study Team projected market penetration in 2030 and 2040 for FCEVs in the two heavy-duty modes, seen below in Table 2 below[23].

[22] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/hydrogen-the-next-wave-for-electric-vehicles
[23] https://engagedscholarship.csuohio.edu/cgi/viewcontent.cgi?article=2650&context=urban_facpub

Table 2. Projected Market Penetration of Fuel Cell Vehicles by Mode

Mode	*2030*	*2040*
Transit buses	0.20%	2.64%
Class 8 trucks	0.15%	1.85%

A leading example of success. A key example of FCEB at-scale deployment success in the Midwest is the Stark Area Regional Transit Authority (SARTA). SARTA operates the third largest Hydrogen Fuel Cell Electric Bus (FCEB) transit fleet in the Western Hemisphere. The current fleet will have (11) 40-foot FCEBs in operation, with the last two being delivered, and one additional FCEB to be ordered. An additional order for five (5) fuel cell paratransit vehicles is being finalized. The fleet is refueled from delivered liquid hydrogen (LH_2) stored on site in a 2,400 kg liquid hydrogen tank. The refuel island has two dispensers (two refuel positions) with H35 (350 bar or 5,000 psi) refuel nozzles. The refuel island is being expanded to four dispensers (4 refuel positions for FECBs) and a separate dispenser that could host a H70 (700 bar or 10,000 psi) nozzle.

A strong future-outlook. Market-wide adoption of any new vehicle powertrain technology does not generally increase evenly from year to year. During the growth phase of an innovative technology, business advancements can move rapidly in a short period. In heavy-duty applications of hydrogen transportation, planning refueling station locations that maximize capacity utilization are critical to realizing low cost refueling.[23] FCEV deployment success depends on the intelligent introduction of commercial hydrogen stations.

As of 2019, in the focused corridor area, there were a total of 532,744 registered vehicles ranging from class 2B to class 8 vehicles that included the following types of vehicles set forth in Table 3 and Chart 1 shown below. Table 3 separates the vehicles into classes 2 through 8 and indicates the vehicle types shown in each class. The projections are then separated into near-term (2025), mid-term (2030) and far-term (2050). Each projection shows the percentage of vehicle market that is calculated to convert to fuel cell vehicles, the corresponding number of vehicles that percentage represents and the kilograms of hydrogen fuel those vehicles would consume. This table represents light-duty, medium-duty and heavy-duty vehicles and clearly shows how hydrogen demand will expand across all classes of vehicles, indicating a strong need to build the infrastructure necessary to allow these vehicles to refuel in the Midwest corridor.

Category	Class	Gross Vehicle Weight Rated (GVWR)	Vehicle Platform Examples	Total Registered Vehicles (IN, MI, OH)	Market Demand Projections								
					Near-Term			Mid-Term			Far-Term		
					2025			2030			2050		
					% Market	# of vehicles	Est. Annual Fuel Usage[25-26] (H2kg)	% Market	# of vehicles	Est. Annual Fuel Usage[25 26] (H2kg)	% Market	# of vehicles	Est. Annual Fuel Usage[25 26] (H2kg)
Light-duty (LD)	2	6001-10,000		213,434	0.01-0.02%	21-43	14,190	0.1-0.25%	213-533	175,890	20-22%	42,886-47,175	15,567,750
	3	10,001-14,000		32,770	0.03-0.055%	9-19	47,291	0.1-0.3%	32-98	243,922	20-22%	6,554-7,209	17,943,201
Medium-duty (MD)	4	14,001-16,000		46,519	0.02-0.04%	9-18	37,413	0.04-0.08%	18-36	74,826	20-22%	9,308-10,234	21,271,369
	5	16,001-19,500		7,332	0.01-0.02%	7-14	13,293	0.2-0.4%	14-28	26,586	20-22%	1,466-1,613	1,531,544
	6	19,501—26,000		37,222	0.05-0.1%	18-37	52,085	0.1-0.25%	37-93	130,916	22-25%	8,188-9,305	13,098,648

Category	Class	Gross Vehicle Weight Rated (GVWR)	Vehicle Platform Examples	Total Registered Vehicles (IN, MI, OH)	Market Demand Projections								
					Near-Term			Mid-Term			Far-Term		
					2025			2030			2050		
					% Market	# of vehicles	Est. Annual Fuel Usage[25] [26] (H2kg)	% Market	# of vehicles	Est. Annual Fuel Usage[25] [26] (H2kg)	% Market	# of vehicles	Est. Annual Fuel Usage[25] [26] (H2kg)
Heavy-duty (HD)	7	26,001—33,000		24,517	0.05-0.15%	12-36	282,261	0.15-0.3%	36-73	572,364	22-25%	5,393-6,129	48,055,037
	8	33,001+		170,950	0.05-0.01%	85-170	1,385,500	0.1-0.25%	170-427	3,480,050	30-35%	51,285-59,832	48,753,300
				Total Registered Vehicles	Near-Term – 2025			Mid-Term - 2030			Far-Term -2050		
						# of vehicles	Fuel (H2kg)		# of vehicles	Fuel (H2kg)		# of vehicles	Fuel (H2kg)
GRAND TOTALS				532,744		161-337	1,832,033		337-795	4,705,004		125,080-141,497	166,220,849

Table 3: Future Market Demand Based on Vehicle Registrations Across Corridor Demand Study Area

25https://afdc.energy.gov/data/10308

26Using annual GGE and the efficiency factor https://afleet-web.es.anl.gov/afleet/ efficiency

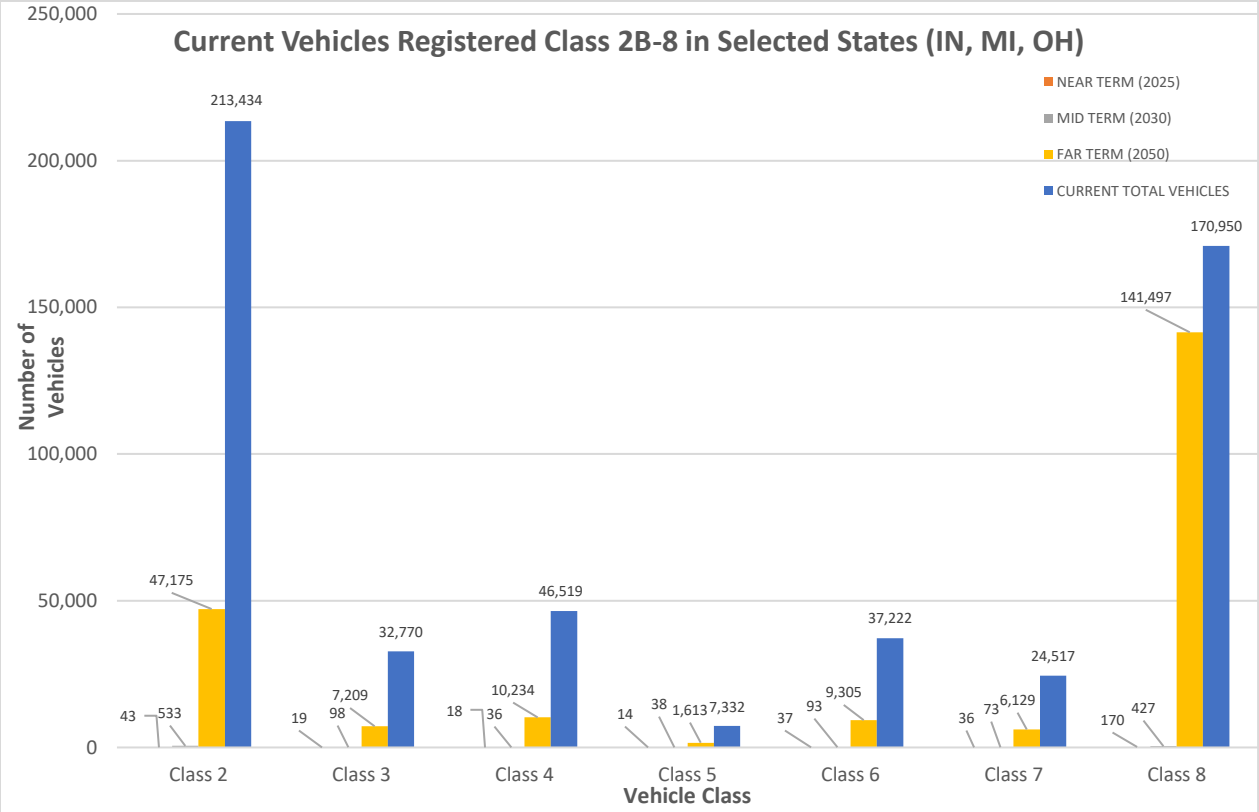


Chart 1: Current Vehicles Class 2B-8 in Selected States (OH, MI, IN)

These future market demand numbers will never be met nor surpassed without action and moving the levers of change. These critical levers of change include:

- **Championship:** The most ambitious goals are met through championship of hydrogen as an economic growth driver.
- **Mitigation:** Through collaborative relationships, barriers of adoption need to be prioritized and addressed with state and regional support for FCEVs.
- **Leadership:** Business leaders need to embrace this opportunity to achieve their sustainability and decarbonization goals; fleets shall set strong goals.
- **Policy:** Federal, state and local policies need to be in place to drive the market to greater decarbonization in the US.

The biggest champions in the Midwest for hydrogen are Ohio Fuel Cell Coalition and the Renewable Hydrogen Fuel Cell Coalition, of whom SARTA and Cleveland State University are both strong members. Altogether, they have prioritized the needs to advance the hydrogen economy and are now actively addressing the infrastructure challenge of providing access to hydrogen. They are seeking funding to carry out the first critical steps of planning for the infrastructure to ensure that access is located where the demand is, or will be, the greatest. Business leaders and consumers are watching the market and are interested in the new hydrogen vehicle products. They are ready to jump in and make the purchase decisions but cannot move forward without access to fuel. ■