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Analysis of Supply Chain Opportunities for Fuel Cell Buses Using Industrial Classifications

Andrew R. Thomas
Cleveland State University, a.r.thomas99@csuohio.edu

Iryna Lendel
Cleveland State University, i.lendel@csuohio.edu

Adam Kanter

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Prepared for:
Stark Area Regional Transit Authority

Prepared by:
Andrew R. Thomas
Iryna Lendel
Adam Kanter

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2121 Euclid Avenue Cleveland, Ohio 44115
http://urban.csuohio.edu

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About the Research Team

Andrew R. Thomas

Andrew Thomas is an Executive-in-Residence with the Energy Policy Center in the Maxine Goodman Levin College of Urban Affairs of Cleveland State University where he researches law, regulation and economics for transportation, natural gas, and electricity systems. Email address: a.r.thomas99@csuohio.edu, phone: 216-687-9304.

Iryna V. Lendel

Dr. Iryna V. Lendel is the Research Associate Professor of Economic Development and Interim Director of the Center for Economic Development at the Maxine Goodman Levin College of Urban Affairs at Cleveland State University. Her research portfolio includes projects on industrial analysis (high-tech industries, the oil and gas industry, steel industry and the re-emerging optics industry); technology-based economic development; and energy policy and economics. Email address: i.lendel@csuohio.edu, phone: 216-875-9967.

Adam Kanter

Adam Kanter is a graduate student in the Glenn College of Public Affairs at Ohio State University. Email address: Kanter.38@osu.edu.

About the Energy Policy Center

The Energy Policy Center (EPC) is housed within the Maxine Goodman Levin College of Urban Affairs at Cleveland State University. The mission of the EPC is to help overcome social and institutional barriers to the implementation of solutions to energy challenges by providing an objective channel for the free exchange of ideas, the dissemination of knowledge, and the support of energy-related research in the areas of public policy, economics, business and social science. For more information on the Energy Policy Center, use the following link: http://levin.urban.csuohio.edu/epc/

About the Center for Economic Development

The Center for Economic Development at Cleveland State University's Maxine Goodman Levin College of Urban Affairs provides research and technical assistance to government agencies, non-profit organizations, and private industry. The Center has expertise in studying ecology of innovation, entrepreneurship, performance of economic clusters, industry analysis, economic analysis of cities and regions, economic impact, economic development strategy and policy, workforce development and evaluation of economic development initiatives. The Center has served as a designated Economic Development Administration (EDA) University Center since 1985. For more information, use the following link: http://urban.csuohio.edu/economicdevelopment/.

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EXECUTIVE SUMMARY

In 2009 the United States government decided to reduce funding for research into fuel cells and the hydrogen economy. Despite this, sufficient progress has since been made into commercialization of fuel cells that niche markets have developed, most notably for battery replacement in fork lifts and in cell phone towers. In the meantime, the transportation industry, seeing the potential advantages in range and ease of refueling, has continued to invest into the technology. Automakers began in 2016 to first offer commercially available fuel cell cars.

However, the fuel cell market that today is best positioned for large scale commercial success is that of the transit bus industry. This is so because transit bus fleets can be refueled from a central location, significantly reducing the necessary investment into hydrogen refueling stations. As a result, transit buses and other fleets are likely to lead the transition to a hydrogen-based transportation economy. The shale revolution has provided additional impetus for a transition to a hydrogen economy. Hydrogen is most cost-effectively made through reforming natural gas. As a result, the long-term, low price natural gas made possibly by shale development also means likely long-term, low prices for hydrogen.

In July of 2016 there were 24 active fuel cell buses in the United States. Fuel cell bus prices have come down significantly, from around $2.4 million a few years ago, to $1.4 million in 2016, with expectations of dropping to $1.0 million with the next order of 40 buses. This trend is expected to continue as both technology improvements and manufacturing scale reduce costs. Prices will likely need to fall to below $500,000 to be competitive with diesel buses. New supply chain strategies could help the industry more readily achieve this target.

A growing fuel cell bus transit industry will provide many American suppliers with a new look at market opportunity. However, for many suppliers the opportunity may not be readily apparent. One way for suppliers to ascertain whether they have the ability to supply the fuel cell bus industry is to look at the North American Industrial Code System (NAICS) categories of fuel cell development companies. The NAICS codes provide suppliers and bus manufacturers alike with a handy catalogue for identifying who manufactures what components, and, importantly, who might be able to even if they do not do so now.

Areas of potential supply include: the bus chassis, the electric drive system, the proton exchange membrane (PEM) fuel cell, hydrogen storage tanks and batteries, among other parts. The PEM fuel cell, in turn, has many subcomponents, including bipolar plates, membrane electrode assemblies, catalysts and gas diffusion layers. Refueling stations also provide a supply chain opportunity. These include: hydrogen gas or liquid, cryogenic storage dewars, vaporizers, pipelines, regulators, fuel dispensers, compressors, hoses, nozzles and other parts.

In 2016 the PEM cell comprised about half the cost of a fuel cell bus. By ascertaining the NAICS codes applied to this industry (for example, NAICS 334413: Semiconductor and Related Device Manufacturing), fuel cell bus developers and economists can identify what companies might be

potential suppliers for the fuel cell bus industry. Likewise, the NAICS code assigned to a company could be a hint for suppliers to determine what additional business opportunities there may be from within their own sectors, and what the likely competition might be. This Study catalogues where various companies producing fuel cell buses fit within the various NAICS codes, in what industries and sectors they are primarily concentrated, and the relative cost importance of various sectors to the total cost of the fuel cell bus. The same was done, in part, for the hydrogen refueling industry.

One important limitation to using the NAICS codes is that for nascent industries deploying technology like that found in fuel cell bus manufacturing, sometimes finding the right industrial classification can be difficult. As a result, significant portions of the fuel cell industry are classified by using multiple 9s in the code. In particular, the fuel cell industry includes “99999”, for “Non-classified Establishments,” “339999,” for “All Other Miscellaneous Manufacturing,” and “335999 “All Other Miscellaneous Electrical Equipment and Component Manufacturing.” Although common, such descriptions are less helpful in identifying supplier opportunities, yet they make up around one third of the industry classification. It will be important to monitor how the fuel cell industry continues to refine its industrial categories as its products mature and market shares grow. This will enable suppliers, developers and economic development experts alike to more fully utilize NAICS codes to inform their decision making. Importantly, while the “99” codes may limit their usefulness at this time, they do speak to the nature of the fuel cell bus industry: it is new, and as such, there is significant opportunity for supply companies and regional economies to become players in it.

In addition to cataloguing the relevant NAICS codes for the industry, the Study also sets forth the status of development of fuel cell buses and refueling stations, and their component parts. The Study identifies those components that are unique to fuel cell buses and hydrogen refueling stations, and explains their roles. Supply of these components will provide the best opportunities for companies looking to play a role in this new market.

I. INTRODUCTION

A. BACKGROUND OF FUEL CELL BUS TECHNOLOGY

This Study was undertaken to help potential fuel cell suppliers better understand the opportunity to sell their products into a growing segment of the fuel cell industry: fuel cell transit buses. Many companies that could be suppliers do not know the industry well enough to understand where their products might fit. The Study provides a tool for those potential suppliers: the North American Industrial Code System (NAICS) can be used as general catalogue to help them identify where opportunity may exist. This is especially true for small suppliers, who are less likely to have the resources to follow fuel cell development or investigate the deployment process. NAICS codes can also be used in the opposite direction: fuel cell developers, especially small ones, often do not fully appreciate what companies are capable of supplying them. The is Study is intended to be a guide to help both developers and suppliers more readily identify each other.

In the mid-2000s fuel cells and the hydrogen economy were widely hailed as the best hope for ending the ongoing economic, environmental and geopolitical troubles engendered by America's dependence on oil. In 2005, American net oil imports peaked at over 12,500 barrels per day.[1] As oil prices continued to rise, Americans were spending nearly $50 billion/year for imported oil, and by 2008 over 60% of the U.S. trade deficit resulted from oil imports.[2] In the meantime, the U.S. Energy Information Agency was projecting peak oil would likely arrive by 2037[3] – and with peak oil could come economic chaos and geopolitical mischief, including potentially more wars in the Middle East over control of oil reserves.

So it was small wonder, then, that about this same time oil giant British Petroleum organized a "Hydrogen Interactive" brainstorming session between research laboratories and senior executives from major car and energy companies. The consensus from the meetings was that the future of transportation belonged to hydrogen fuel cells.[4] The most promising of the fuel cell technologies for transportation was the Proton Exchange Membrane (PEM), which is a type of fuel cell that deploys a solid polymer membrane sandwiched between an anode and a cathode. The PEM cells offered an attractive alternative to internal combustion engines running on fossil fuels: PEM cells could provide ample electric power to drive the vehicle without the use of bulky, expensive batteries that required long periods of recharging. Power Density for a fuel cell was over eight times that of the best batteries available in the early 2000s. And, importantly, the only tailpipe emission was water.[5]

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[1] U.S. Energy Information Administration, "U.S. Net Imports of Crude Oil and Petroleum Products," 5/31/2016, https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MTTNTUS2&f=A

[2] "U.S. Imports of Petroleum," United States Census Bureau, May 4, 2016, https://www.census.gov/foreign-trade/statistics/graphs/PetroleumImports.html

[3] J. Wood, et al, "Long Term World Oil Supply Scenarios," Energy Information Agency, August 18, 2004, https://www.eia.gov/pub/oil_gas/petroleum/feature_articles/2004/worldoilsupply/oilsupply04.html

[4] V. Vaitheeswaran, *Power to the People: How the Coming Energy Revolution Will Transform an Industry, Change Our Lives and Maybe Even Save the Planet,* at 223 (Farrar, Strauss and Giroux, 2003).

[5] *Id*. at 224-25.

So the U.S. government invested many hundreds of millions of dollars into developing PEM cell technology, as did the private sector. The goals of the research were to reduce the costs of manufacturing fuel cells, to improve fuel cell performance and life, and to begin to build a hydrogen-refueling infrastructure. Advances in the technology were made, however the technology was slow to develop commercially. As a result, in 2009 the U.S. Department of Energy dropped its research into fuel cells for cars. Then-DOE Secretary Steven Chu justified this decision based upon the notion that the administration's limited energy research budget needed to focus on projects that would bear fruit more quickly than would fuel cell car research, which technology "would not be practical over the next 10 to 20 years."[6]

At about this same time America began to see the first effects of the shale revolution, which in a remarkably short time resolved many of the problems that led to interest into PEM cell technology replacing the internal combustion engine. By 2014, development of the Marcellus and Utica shale formations had turned the Appalachian Basin into the nation's largest natural gas field, in the process driving down natural gas prices to historic lows. But oil was also being produced from shale in the United States: by 2014, due largely to the Bakken Shale in North Dakota, the United States had surpassed Saudi Arabia as the world's largest oil producer.[7] By late 2014, an oil surplus had developed and prices crashed to below $50/barrel due to an oversupply. By 2016, the U.S. spending on oil imports had dropped to $10 billion (on lower than 5000 barrels/day). As a result, the percentage of the trade deficit generated by oil imports had fell below 10%.[8] In short, by 2016, oil imports were 1/3 of what they were just ten years earlier, and costs were only 1/5. In the meantime, with so much untested organic shale resources around the world, neither the EIA nor the United States Geological Survey have attempted to recalculate peak oil. We simply have no idea now when it will be.

Yet even as the economic and geopolitical threats from oil depletion have abated, the environmental problems associated with burning oil as fuel have not. By 2016, concern over climate change has replaced oil depletion geopolitics as the world's greatest crisis. Further, shale development remains a finite resource, and by no means is it clearly commercial everywhere. So there continues to be an urgent need to develop commercially viable alternative fuel transportation strategies in the United States.

Fortunately, by the time federal funding was discontinued, fuel cell technology had advanced to the point where fuel cells had reached economic viability in various niche markets, such as for battery replacements in lift trucks and for cell phone towers. In addition, the transportation industry recognized that the cost of fuel cells had been sufficiently reduced such that, with some additional technology development and system engineering, the industry's goal of mass producing fuel cell electric vehicles that are cost competitive with internal combustion engine vehicles was

[6] M. Wald, "U.S. Drops Research into Fuel Cells for Cars," May 7, 2009, The New York Times, http://www.nytimes.com/2009/05/08/science/earth/08energy.html?_r=0

[7] *See e.g*. G. Smith, "U.S. Seen as Biggest Producer After Overtaking Saudi Arabia," Bloomberg, July 4, 2014, recovered from: http://www.bloomberg.com/news/articles/2014-07-04/u-s-seen-as-biggest-oil-producer-after-overtaking-saudi

[8] "U.S. Imports of Oil," note 2, *supra*, and "U.S. Net Imports of Crude Oil and petroleum Products," note 1, *supra*.

in reach. The automotive industry's commitment to fuel cells has also been driven by the realization that fuel cells continue to provide their best opportunity to mass produce an electric vehicle that would be competitive with internal combustion engine vehicles in range and refueling characteristics. Accordingly, private investment into fuel cell technology continued to be robust. Now, today, with hydrogen prices coming down, the industry appears poised to finally have commercial success in the transportation sector.[9]

Today, around 550 fuel cell electric vehicles (passenger cars and buses) are active across the globe.[10] Costs remain prohibitively high compared to conventional modes of transportation. In order to achieve success beyond the demonstration phase, the transportation sector must continue to reduce costs. While economies of scale can drive down costs, the price tag will still include certain expensive materials necessary for operation of the current technology (e.g. the platinum catalyst within the fuel cell stack). The target price for a competitive fuel cell electric vehicle should not exceed more than 15% of that for a conventional hybrid car, especially given the higher near term cost of hydrogen refueling stations.[11]

The onus of price reduction, however, need not fall squarely on the shoulders of the private companies in the fuel cell transportation industry. Effective government policy can spur private investment into fuel cell technology. Incentives can be created on both the supply and demand side of the sector, and global standards can be set in place to ease the transition towards a fully commercialized product. In addition, due to the misconceptions surrounding the danger of hydrogen fuel, public education efforts in the market introduction phase will be essential to the societal acceptance of this new technology.[12]

Yet even as fuel cells have improved in performance and price, and as cheap natural gas has generated inexpensive sources of hydrogen, fuel cell electric vehicles cannot achieve commercial success until a hydrogen-refueling infrastructure has been built. For this reason, the best way for the public and private sectors to enable the widespread adoption of fuel cell vehicles is to support the development of fuel cell fleets. Fleets that utilize predictable routes and have predictable refueling patterns can support the development of the first hydrogen refueling stations. For that reason, the following analysis considers the economic opportunity associated with the adoption of fuel cell bus fleets, which will likely make up the first commercial adoption of fuel cell vehicles. Not only are fuel cell transit buses poised to demonstrate the commercial viability of fuel cells in transportation systems, they can also demonstrate to the general public the safety of hydrogen as a fuel.

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[9] *See, e.g*. H. Greimel, "Honda, GM Set Targets for 2020 Fuel Cell Vehicles," Automotive News, March 14, 2016, http://www.autonews.com/article/20160314/OEM05/303149972/honda-gm-set-targets-for-2020-fuel-cell-vehicle. Honda introduced the *Clarity* in 2016 as its "steppingstone" to a commercial fuel cell car. *Id*.

[10] Technology Roadmap Hydrogen and Fuel Cells. (2015, June). Retrieved from https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf

[11] *Id*.

[12] *Id.*

B. State of the Industry/Technology

The next ten years will be crucial for the development of large-scale utilization of fuel cell technology in transportation, including the fuel cell bus industry. While major car companies such as Honda and Hyundai are planning the large-scale production of fuel cell electric vehicles in the near future, bus companies have been slower to develop and implement this new technology.[13] As of July 2016 in the United States there were 24 active fuel cell buses, and fuel cell power systems had accounted for more than 1 million miles of bus travel.[14] There were ongoing demonstrations in more than 8 cities across the country, including Birmingham, Alabama; Flint, Michigan; New Haven, Connecticut; and Thousand Palms, California. The San Francisco Bay Area was home to the 12 of these 24 active buses, all commissioned and operated by Alameda-Contra Costa Transit District (AC Transit). Over the next few years, additional demonstrations will begin in Canton, Ohio; Boston, Massachusetts and Ithaca, New York, with additional buses being added to the existing fleets on the West Coast.[15]

These demonstrations have shown sustained success and improvement, but have not met all of the performance targets set by the DOE and FTA. Table 1 provides a snapshot of the 2016 targets, as well as the performance measurement for the average bus in the United States fleet of fuel cell buses.

Table 1. Performance of U.S. Fuel Cell Bus Fleet

	Units of Measurement	Fleet Average (2015)	2016 Target
Bus Lifetime	Years/Miles	3.6/81,108	12/500,000
Fuel Cell/Battery Lifetime	Hours	10,102	25,000
Bus Availability	Percent of days	73	90
Road call Frequency (bus/fuel cell system)	Miles Between Road Calls	4,280/20,531	4,000/20,000
Operation time	Hours per day	11.8	20
Maintenance Cost	$/mile	1.16	.40
Range	Miles	275	300
Fuel Economy	Miles per Diesel Gas Equivalent	6.8	8

Source: Eudy, et al (2015).

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[13] *Id.*

[14] Eudy, L., Post, M., & Gikakis, C. (2015). "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2015." Retrieved from http://www.nrel.gov/docs/fy16osti/64974.pdf

[15] *Id.*

While improving, fuel cell buses are not yet ready for commercialization. Costs remain too high: a fuel cell bus in 2016 cost nearly $1,400,000 (compared to a $300,000 price tag for a conventional diesel bus). Nevertheless, the price has come down significantly in recent years, as previous versions cost as much as $2,400,000. Due to the immaturity of the industry, even a small number of additional orders for fuel cell buses will significantly reduce costs. It has been projected that an order of 40 additional buses would likely bring the costs closer to $1,000,000.[16]

The most advanced fuel cell bus technology in use today is still considered to be at a "technology readiness level" of 7 (out of 9), based upon a guide developed by the United States Government to help it assess the status of new technologies. A readiness level of 7 indicates that the technology is in "a process to validate the design, analyze the results, and reconfigure or optimize the design as needed," and requires an operational system prototype to be placed into an operational environment.[17] Once the technology meets the performance standards set in earlier readiness levels, the industry can focus more on standardization and cost reduction methods.

However, the roadblocks to commercialization are not solely centered in the readiness of the technology. Transit agencies will have to overcome some additional barriers before we will realize full commercialization of fuel cell buses. For instance, there must be a transfer of knowledge from bus and component manufacturers to the transit agency maintenance staff. Agencies currently experience issues that are highly technical and difficult to diagnose, leading to extended downtimes.[18] Maintenance must be fully transitioned to agency staff in order to achieve greater efficiency and meet the established goals for the industry. This transition will also help to constrain maintenance costs, which can spike after the initial warranty on components expires.[19] Additionally, original equipment manufacturers of buses must commit to this new technology, and include fuel cell propulsion systems as an alternative option, just as they did with electric and compressed natural gas models. For this to happen, there needs to be a strong push towards standardization of the manufacturing processes and the technology, so that the fuel cell propulsion system can be more seamlessly integrated into the standard bus build process.

II. OVERVIEW OF TECHNOLOGY AND SUPPLY CHAIN

A. Fuel Cell Transit Buses

1. Overview

Fuel cell buses provide the opportunity for clean and efficient public transportation without the sacrifice in performance that is common for other electric vehicles. Similar in size and shape to a conventional diesel bus, a fuel cell bus utilizes hydrogen fuel to generate electricity, powering the

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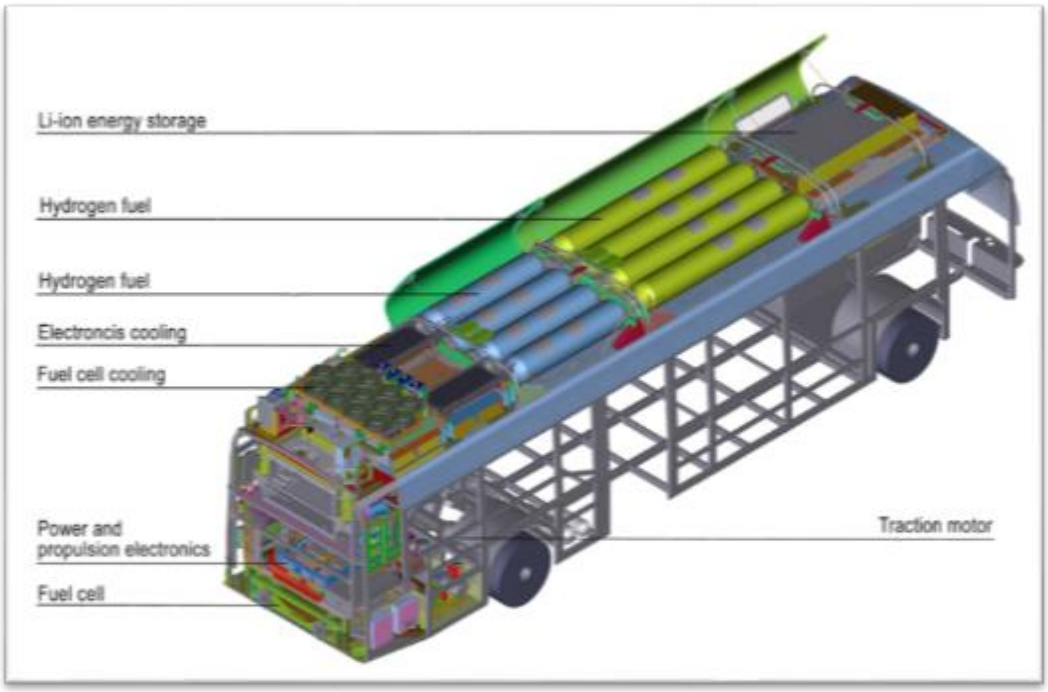
[16] *Id*.
[17] Technology Readiness Assessment (TRA) Guidance. (2011, May). Retrieved from http://www.acq.osd.mil/chieftechnologist/publications/docs/TRA2011.pdf. By comparison, the compressed natural gas transportation technology is at a readiness level of 9.
[18] Eudy, L., Post, M., & Gikakis, C. (2015), *supra* note 13.
[19] *Id*.

motor, wheels, and all electronic accessories within the bus's system.[20] Typically the fuel cell is paired with an electrical storage system, such as a lithium-ion battery, to assist with the power delivery and storage needs of the vehicle. Figure 1 provides a general overview of the key components contained within the power delivery system of a fuel cell hybrid bus (hereinafter, since nearly all commercial buses are hybrids, "fuel cell bus").

Figure 1. Fuel Cell Bus Diagram



Source: BAE Systems (2016).[21]

The hydrogen fuel is stored as a highly compressed gas in storage tanks located on the roof of the bus. This compressed hydrogen is then delivered to the fuel cell stack, where it is combined with ambient air from the bus's intake. Within the fuel cell, the oxygen from the ambient air combines with hydrogen atoms, generating both an electric current and water vapor, the latter of which is expelled from the bus through an exhaust system.[22] The electric current that is generated during this process is then carried toward the electric drive system, which controls and directs the flow of electricity within the bus, assuring that the correct current is being used for the electrical components of the bus, as well as managing load delivery to the electric motor.[23]

With the exception of the fuel cell power and the fuel storage system, a fuel cell-hybrid bus is very similar to the conventional diesel bus that is commonplace in today's urban public transport

[20] "International Fuel Cell Bus Collaborative," Basics (2014). Web. 18 Mar. 2016.
[21] "American Fuel Cell Bus." Hybrid Drive. BAE Systems, 2011. Web. 22 Mar. 2016.
[22] "Hydrogen Fuel Cell Basics." Fuel Cell Basics. Department of Energy. Web. 16 Mar. 2016.
[23] "American Fuel Cell Bus." Hybrid Drive. BAE Systems, 2011. Web. 22 Mar. 2016.

systems. Some of the other significant differences include safety features and electronics, and are described herein.

2. Bus Chassis

A fuel cell bus frame, as well as the body, seats, and stanchions used on the interior of the bus, are identical to those used in the typical transit bus. Fuel cell buses pose no limitations to the body style or capabilities of today's traditional buses. Insofar as the different components contained in the fuel cell bus are generally stored on the roof, these buses are still able to utilize low-floor designs as well as accommodate wheelchair ramps to assist in para-transit passenger boarding.

The composition of the bus frame often depends on the proposed application and route for the bus being manufactured. Generally, frames are comprised of a mixture of stainless steel, carbon steel, and various aluminum alloys.[24] The proportions of these metals are dictated by the priorities of the manufacturer, especially weight, longevity, and rust-prevention. Fuel cell bus companies are often responsible for manufacturing their own frames, but there are a number of other bus frame manufacturers throughout North America that could, presumably, manufacture the fuel cell bus chassis.[25]

3. Electric Drive System

An electric drive system converts electrical energy into mechanical motion, and has a number of applications both inside and outside of the transportation sector. Electric drives are found in subway trains, railroad locomotives, washing machines, elevators, water pumps, and a myriad of other applications.[26] When applied in transportation, onboard systems manage and deliver power to the electric propulsion motors. The electric power is provided either by the power grid, in the case of subway trains or streetcars, or by an on-board power source such as batteries or fuel cells, in the case of electric vehicles. Within a fuel cell hybrid bus, the principal aim of the electric drive system is to control the energy transfer from the fuel cell and battery with maximum efficiency.[27] The system must deliver electricity from the fuel cell to the electric motor as well as all other electric accessories contained in the vehicle. These accessories include the communication and computer systems, and the lighting, HVAC system, signage, wipers, and cooling fans, among others.

There are a number of components that make up a drive system in a typical fuel cell electric hybrid vehicle. The electricity generated by the fuel cell initially passes through a DC-DC boost converter that works to step-up the voltage of the electric current. This electric current is then delivered to both the accessory power system and the propulsion control system. The accessory power system

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[24] "Building Buses with Steel, Stainless Steel and Aluminum." *National Bus Trader*. 14 June 2014. Web. 15 Mar. 2016.

[25] For a list of potential manufacturers, *see*: http://www.metroonlinedirectory.com/category/bus-manufacturers?Page=2

[26] Vodovozov, V. (2012). "Electric Drive Systems and Operation." Retrieved April 5, 2016, from http://197.14.51.10:81/pmb/ELECTRONIQUE/electric-drive-systems-and-operation.pdf

[27] Andaloro, L., Napoli, G., Sergi, F., Dispenza, G., & Antonucci, V. (2013). "Design of a hybrid electric fuel cell power train for an urban bus." *International Journal of Hydrogen Energy*, 38(18), 7725-7732. doi:10.1016/j.ijhydene.2012.08.116

converts the high voltage DC power from the fuel cell power system to lower voltage AC power that is delivered to all the electrical accessories. The propulsion control system also works as a DC to AC converter and power modulator, delivering electricity to the AC propulsion motor.[28]

The electric motor is the sole source of propulsion for the vehicle, and is typically connected directly to the standard drive shaft and rear axle.[29] Sensors and software monitor the drive system to ensure that it properly integrates fuel cell and battery operation, that it functions efficiently and that it relays safety information to the driver. This software system works to communicate within the electric drive system, managing the electrical load to respond to the changing power requirements of the electric motor. When the electric drive system requires more power than the fuel cell system can produce, the lithium-ion battery provides the energy to fill this gap. Conversely, when the power produced by the fuel cell system is more than what is needed by the drive system, the surplus electricity is used to re-charge the battery.[30]

In the fuel cell hybrid bus industry, the two most prominent electric drive system integrators are Siemens and BAE. The newest fuel cell bus demonstrations utilize the BAE HybriDrive Series-E system.[31] The individual components of the electric drive system are commonly manufactured, and the details of these manufacturers will be discussed in depth within the NAICS code industry profile found in Section V below.

4. Proton Exchange Membrane Fuel Cell

The primary source of energy for fuel cell buses comes from a Proton Exchange Membrane (PEM) Fuel Cell.[32] This form of fuel cell is utilized in transportation because of its quick startup time, low operating temperature, and desirable power-to-weight ratio. Compared to other types of fuel cells that operate at extremely high temperatures or utilize corrosive materials in the cell structure, the PEM fuel cell is an easily controlled technology well suited for transportation applications. For operation, PEM fuel cells only require a supply of pure hydrogen, ambient air and a method to remove the waste heat generated by the cells' electrochemical reactions.[33] Figure 2 provides a general overview of the process of electricity generation as well as the core components of a PEM fuel cell that is commonly used in transportation.

[28] Hybridrive® Series-E Hybrid Bus System. Retrieved April 12, 2016, from http://www.hybridrive.com/hybridrive-series-e-bus.php

[29] *Id*.

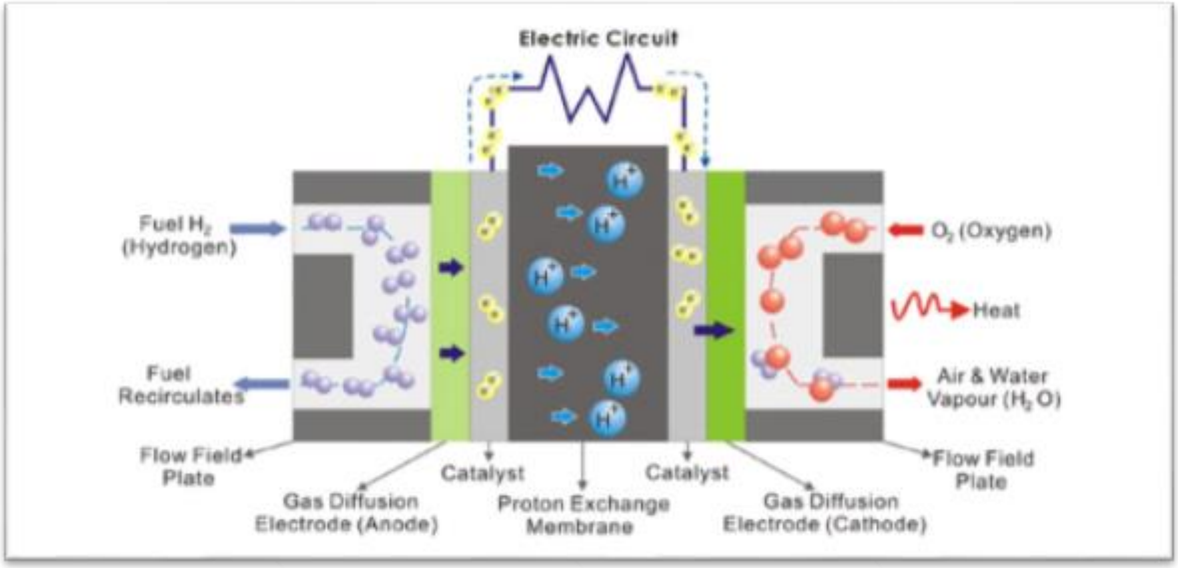
[30] Andaloro, L., Napoli, G., Sergi, F., Dispenza, G., & Antonucci, V. (2013). "Design of a hybrid electric fuel cell power train for an urban bus." *International Journal of Hydrogen Energy*, 38(18), 7725-7732. doi:10.1016/j.ijhydene.2012.08.116

[31] "American Fuel Cell Bus." Hybrid Drive. BAE Systems, 2011. Web. 22 Mar. 2016.

[32] PEM cells are also sometimes called "polymer electrolyte membrane" fuel cells.

[33] "Types of Fuel Cells." Department of Energy. Web. 23 Mar. 2016. However PEM fuel cells have stringent hydrogen purity requirements that other types of fuel cells may not. *See e.g*. "Hydrogen and material quality issues for PEM fuel cells," IEEE Xplore Digital Library (Sept. 2005) (Explaining how platinum catalyst is more susceptible to poisoning), retrieved from: http://ieeexplore.ieee.org/document/1554601/?reload=true

Figure 2. Process of Electricity Generation in PEM Fuel Cell.



Source: Nedstack (2016)[34]

The most critical component of the PEM fuel cell is the membrane electrode assembly (MEA). This component consists of catalyst embedded gas diffusion electrodes as well as the proton exchange membrane. Hydrogen gas flows through the gas diffusion electrode, and the hydrogen atoms are then split into protons (hydrogen ions) and electrons by the catalyst layer. These electrons are directed through an external circuit, which creates an electrical current. The hydrogen ions then flow through the proton exchange membrane towards the cathode, and combine with both the oxygen from the ambient air as well as electrons from the initial reaction to create water molecules. A catalyst layer of the cathode accelerates this chemical reaction. The water vapor created is then dispelled. The flow field plates (also known as bipolar plates) shown in Figure 1 are also instrumental to the operation of a fuel cell. These plates work to direct both the hydrogen towards the anode in the initial reaction, and also work to dispel the water vapor after it is formed. In addition, these flow field plates are conductive and serve as current collectors for the electric charge that is generated in the cell.[35]

One cell typically generates less than 1 volt of electricity, which, by itself, is too weak for the majority of applications. Individual cells are generally combined to create a fuel cell stack, fitted with additional plates and connections to carry the larger electrical current. The fuel cell system also includes components such as an air compressor, fans, and pumps that are together known as the “balance of plant.” These components work to support the efficient operation of the fuel cell stack. There are a number of PEM fuel cell stack manufacturers across North America, and a select few have established themselves as leaders in the fuel cell bus industry. Ballard Power Systems, located in British Columbia, is the PEM fuel cell provider for a large number of fuel cell bus

[34] "Proton Exchange Membrane Fuel Cell (PEMFC)." G-Energy Technologies. 2012. Web. 24 Mar. 2016.
[35] "About PEM Fuel Cells." Nedstack PEM Fuel Cells. 2011. Web. 28 Mar. 2016.

demonstrations in North America, Western Europe, and South America.[36] Other major PEM fuel cell manufacturers in the fuel cell bus industry are Daimler and UTC Power. In addition, there are a number of PEM fuel cell developers that have not yet entered the bus industry. Table 2 provides an overview of PEM fuel cell stack developers from around the world.

Table 2. Global PEM Fuel Cell Developers

Company Name	Location
Altergy Systems	California, United States
Cellkraft AB	Stockholm, Sweden
Doosan Fuel Cell America Inc.	South Windsor, Connecticut, United States
Elcore	Munich, Germany
EnerFuel	West Palm Beach, Florida, United States
eZelleron	Dresden, Germany
Fuel Cells Etc	College Station, Texas, United States
HelioCentris	Berlin, Germany
Horizon Fuel Cell Technologies	Singapore
Hydrogenics	Ontario, Canada
Intelligent Energy	Leicestershire, United Kingdom
Nedstack	Arnhem, The Netherlands
Nuvera	Billerica, Massachusetts, United States
Palcan Energy Corp.	Vancouver, British Columbia
PaxiTech	Rhone-Alpes, France
Plug Power Inc.	Latham, New York
PowerCell	Göteborg, Sweden
US Hybrid	South Windsor, Connecticut, United States
Tropical Green Technologies	Athens, Greece

Source: Fuel Cells 2000[37]

A number of these PEM fuel cell companies listed in the table above manufacture and assemble in-house every component of the fuel cell stack, and often sell individual components to other developers. However, there are also companies that are not fuel cell stack developers that manufacture MEAs and other fuel cell components. Generally, these are multi-national corporations with large chemical divisions that can produce the necessary materials in high volumes. Companies like DuPont, 3M, Gore, and Johnson Matthey all manufacture MEAs for a wide variety of applications. There are also smaller specialized companies that focus solely on the production of membranes, gas diffusion layers, and catalysts, such as AvCarb, Chemours, Freudenberg, PaxiTech, Sigma-Aldrich, SpectraCarb, and Toray.

Bipolar plates are distinct from the membrane electrode assembly, and form an important additional component of the fuel cell system. There are two types of bipolar plates that are used

[36] "The Power of Fuel Cells, Simply Delivered." Fuel Cell Products. Ballard Power Systems, 2015. Web. 12 Mar. 2016.
[37] "Fuel Cell Industry Top 200 Companies." Fuel Cells 2000. FuelCells.Org, 2016. Web. 27 Mar. 2016.

in PEM fuel cells: metallic and graphitic. Both materials are used in transportation, each with respective benefits and drawbacks. Metallic plates are lighter weight and thinner, but can more easily fall victim to corrosion. Graphitic plates are heavier, but combine excellent chemical erosion resistance with good electrical conductivity.[38] Manufacturers of bipolar plates range widely in size and scope, from global corporations like Dana Holding Corporation and GrafTech, to smaller more specialized companies, such as Borit and Bac2.

5. Hydrogen Storage Tanks

The onboard storage system on a hydrogen fuel cell bus must safely accept gas during refueling and then store that gas with minimal loss until needed by the power train. The overall storage system includes high-pressure storage vessels, a refueling interface, shut-off devices, hydrogen sensors, pressure and flow management mechanisms, and onboard delivery piping.[39] Figure 3 depicts a typical array of storage tanks along the roof of a Mercedes-Benz fuel cell bus.

Figure 3. Hydrogen Storage System on Roof of Fuel Cell Bus

Source: SAE International (2009).[40]

Onboard hydrogen storage is a significant technical challenge to widespread commercialization of hydrogen-fueled vehicles. The storage units must meet cost and safety requirements while

[38] Shahram Karimi, Norman Fraser, Bronwyn Roberts, and Frank R. Foulkes, "A Review of Metallic Bipolar Plates for Proton Exchange Membrane Fuel Cells: Materials and Fabrication Methods," Advances in Materials Science and Engineering, vol. 2012, Article ID 828070, 22 pages, 2012.

[39] Léon, Aline. Hydrogen Technology: Mobile and Portable Applications. Berlin: Springer, 2008. Print

[40] "Mercedes Unveils Prototype Fuel-cell Hybrid Bus." SAE International. 7 Aug. 2009. Web. 22 Mar. 2016. <http://articles.sae.org/6721/>.

maintaining capacity sufficient to support a driving range of more than 300 miles. There are four types of hydrogen storage vessels, however only those called “Type III” and “Type IV” are suitable for automotive (portable) applications, as they are much lighter than their predecessors. Both Type III and IV tanks are made up of “composites,” or a combination of two or more materials with differing physical or chemical properties.[41] Type III tanks are made up of an inner metallic liner, generally an aluminum or steel cylinder, which is encased by sheets of carbon fiber composites. This liner is key in preventing hydrogen leakage (called permeation), and the carbon fiber composite provides stability, durability, and mechanical strength. In Type IV tanks, a high-density polymeric liner replaces the metallic liner. The latter design, in addition to further preventing permeation, also reduces weight, diminishes the chances of liner cracking, and lowers cost.[42] The carbon fiber composite is the most expensive component of these tanks, and current research is focused on incorporating more lightweight polymer composite materials in order to further reduce costs.

In more recent (2016) fuel cell bus demonstrations, Luxfer-Dynetek (previously Dynetek Industries Ltd.) has been the tank provider of choice. However, other corporations such as Quantum Technologies and Hexagon Lincoln also manufacture gas storage for automotive applications. A number of the prominent gas storage vessel manufacturers focus on compressed natural gas due to the maturity and prominence of the industry. In addition to storage tank manufacturers, there are a number of companies, such as America Elements, that focus solely on chemical materials used in the polymeric liners.

6. Battery

The battery component of a fuel cell hybrid bus works to assist the fuel cell stack when power requirements exceed what it can provide. In addition, the battery stores surplus energy that is generated when power requirements are low. Currently, Lithium-Ion (Li-ion) batteries are the preferred auxiliary power source in fuel cell hybrid electric vehicles due to their high power density, high discharge rate, and relatively low cost of production.[43] The most commonly used material for cathodes in a Li-ion battery is lithium cobalt oxide, but because of safety concerns this chemical make-up is avoided in automotive applications. Other cathode materials that are currently being tested for hybrid electric vehicles include, but, are not limited to: lithium nickel, cobalt and aluminum, lithium iron phosphate, and lithium titanium. Each chemical make-up foregoes a certain amount of the five key battery attributes (power, capacity, longevity, safety, and cost), and thus, no materials have as of 2016 emerged as the clear front-runner for automotive battery technology.[44] The most recent American Fuel Cell Bus demonstrations are

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[41] Barthélémy, Hervé. "Hydrogen Storage – Industrial Prospectives." *International Journal of Hydrogen Energy* 37.22 (2012): 17364-7372. Web.

[42] *Id*.

[43] Feng, Xuning, Jianqiu Li, Languang Lu, Jianfeng Hua, Liangfei Xu, and Minggao Ouyang. "Research on a Battery Test Profile Based on Road Test Data from Hybrid Fuel Cell Buses." *Journal of Power Sources* 209 (2012): 30-39. Web.

[44] Axsen, Jonn; Burke, Andy; & Kurani, Kenneth S. (2008). “Batteries for Plug-in Hybrid Electric Vehicles (PHEVs): Goals and the State of Technology circa 2008.” Institute of Transportation Studies. UC Davis: Institute of Transportation Studies (UCD). Retrieved from: http://escholarship.org/uc/item/1bp83874

utilizing lithium iron phosphate batteries manufactured by A123 Systems as their source of auxiliary power.[45] This chemistry provides comparable performance while maintaining a higher degree of safety and exhibiting a potential for lower costs; however, lithium iron phosphate batteries still suffer challenges with energy density.[46]

As battery powered electric and hybrid-electric vehicles become more wide-spread, the number of Li-ion battery manufacturers continues to increase. Major global technology corporations such as Panasonic, Samsung, and LG are producing batteries for automotive giants such as Tesla, Fiat, and Chevrolet. However, more niche companies like A123 Systems, Valence Technology, and Johnson Matthey Battery Systems are also major players in the global Li-ion battery industry, specifically relating to automotive applications.[47]

B. Refueling Stations

The hydrogen refueling station is the key piece to the broader hydrogen infrastructure. In order for the commercialization of hydrogen vehicles to be a realistic goal, refueling stations must be prominent enough to generate demand. In the summer of 2016 there were only 23 public hydrogen refueling stations in the United States, with the majority of this infrastructure located in California.[48]

There are a variety of ways in which a hydrogen refueling station can be configured, often determined by the source of hydrogen, which can either be produced onsite or delivered via tanker or pipeline. Hydrogen is produced onsite using either steam methane reformation or the electrolysis of water. Steam methane reforming exposes methane gas to a catalyst at high temperatures, producing a mixture of carbon monoxide and hydrogen. The carbon monoxide is then typically converted into carbon dioxide and more hydrogen in an additional processing step. The carbon dioxide is vented to the atmosphere and the hydrogen generated by the two reactions is compressed and delivered to the refueling system.[49] Electrolysis utilizes electricity from the grid or an on-site power source and passes an electric current through water with an electrolyte membrane and catalysts. This process separates the hydrogen, which is then utilized for the refueling station.[50] The advantage of electrolysis over steam reforming of methane is that hydrogen can be generated with minimal carbon or other emissions when coupled with a renewable power supply, such as solar or wind. The disadvantage of electrolysis is its relatively high cost compared to steam reforming.

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[45] "American Fuel Cell Bus." Hybrid Drive. BAE Systems, 2011. Web. 22 Mar. 2016. http://www.hybridrive.com/pdfs/AllAmerFuelC.pdf

[46] Axsen, Jonn; Burke, Andy; & Kurani, Kenneth S. (2008). Batteries for Plug-in Hybrid Electric Vehicles (PHEVs): Goals and the State of Technology circa 2008. Institute of Transportation Studies. UC Davis.

[47] "Electric and Motor Vehicle Battery Industry Manufacturers Analysis 2015 Global Research Report." Digital Journal. Web. 09 October 2016. <http://www.digitaljournal.com/pr/2605564>.

[48] "Hydrogen Fueling Station Locations." Alternative Fuels Data Center. Web. 06 May 2016. <http://www.afdc.energy.gov/fuels/hydrogen_locations.html>.

[49] Qin, Nan, and Paul Brooker. "Hydrogen Fueling Stations Infrastructure." Electric Vehicle Transportation Center. Florida Solar Energy Center, Mar. 2014. Web. 2 May 2016. <http://fsec.ucf.edu/en/publications/pdf/fsec-cr-1986-14.pdf>. This is currently how hydrogen is made commercially for the chemical commodities business.

[50] *Id*.

Because small-scale hydrogen reformation is generally not commercially viable, delivery via truck is the most common source of hydrogen for refueling stations. The hydrogen is produced offsite, and then delivered in either gaseous or liquid form. Liquefied hydrogen has superior volumetric densities compared to gaseous hydrogen, allowing for greater quantities to be delivered using one tanker. This method is usually more cost-effective and also works to reduce the carbon footprint associated with the use of hydrogen refueling stations.[51] Since it is the more prevalent form of delivery, the discussion herein will consider only liquid hydrogen, as it is used in typical refueling stations.

Once the liquid hydrogen filled tanker arrives at the refueling station, it is connected via its delivery system to a large vacuum cryogenic storage dewar (tank), which varies in size depending on the scale of the refueling station. These dewars have multi-layered walls often made up of stainless steel, which provides strength, durability, and thermal insulation. The hydrogen must be kept at extremely low temperatures and/or high pressures to retain its liquid state within the dewar.[52] When hydrogen is needed for the refueling system, a cryogenic pump pulls hydrogen from the dewar, greatly increasing the pressure of the liquid hydrogen. The liquid is then drawn through vacuum jacketed piping to ensure it stays in liquid form, and is delivered to a vaporizer, which gasifies the compressed liquid hydrogen and raises the temperature to a negative 20 degrees Fahrenheit.[53]

From the vaporizer, the compressed gaseous hydrogen is then piped to smaller buffer storage tanks in order to maintain the fuel's high pressure and low temperature. Connected to these buffer tanks are high-pressure, insulated pipelines that deliver the hydrogen gas to the fuel dispenser system. A pressure regulator and an electronic solenoid valve then control the flow of hydrogen into the fuel dispenser.[54] Depending on the station, and the type of vehicles being serviced, the fuel dispenser will operate at either 5,000 or 10,000 psi. The dispenser system is very similar in appearance to a typical gasoline dispenser, as the hydrogen fuel flows out of a nozzle at the end of an insulated, flexible hose. [55] An air compressor is used to operate pneumatic valves that connect the numerous components contained in the network of storage vessels and pipelines.[56]

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[51] Dikeos, John, Jordan Haas, Jesse Maddaloni, Tom Owen, Tara Smolak, Ron Songprakorp, Pedrum Sodouri, Louise St. Germain, and Amando Tura. "Hydrogen Refueling Station." Www.h2fuelstation.com. University of Victoria, 3 Mar. 2004. Web. 3 May 2016.

[52] *Id*.

[53] *Id*.

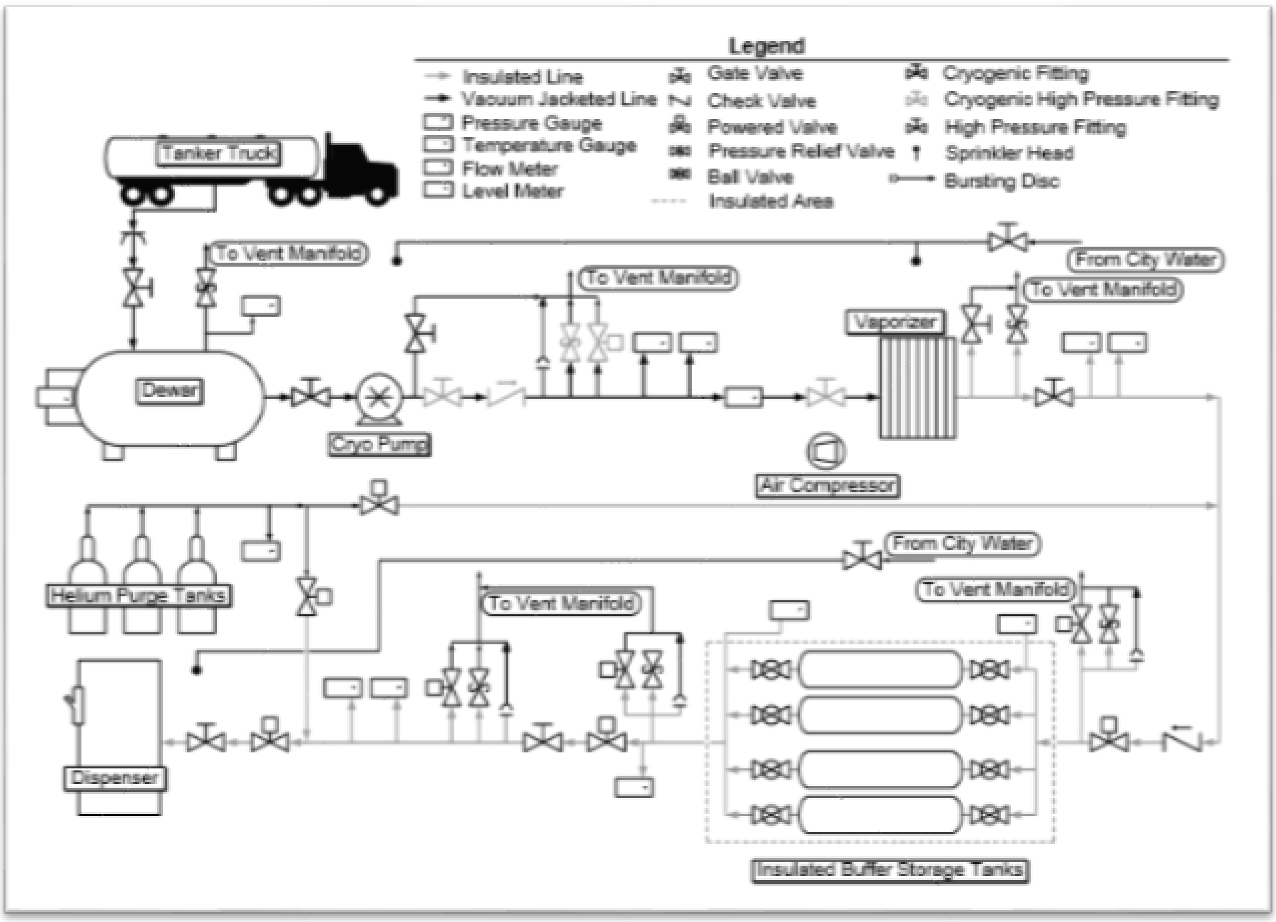
[54] *Id.*

[55] "Hydrogen Refueling & Storage Infrastructure." *Information Resource for Highlands & Islands Enterprise*, E4Tech, Element Energy, PURE. Web. 4 May 2016. *See:* <http://www.hi-energy.org.uk/Downloads/Hydrogen Fuel Cell Resource/3b-Hydrogen refueling and storage infrastructure.pdf>.

[56] Dikeos, John, Jordan Haas, Jesse Maddaloni, Tom Owen, Tara Smolak, Ron Songprakorp, Pedrum Sodouri, Louise St. Germain, and Amando Tura. "Hydrogen Refueling Station." Www.h2fuelstation.com. University of Victoria, 3 Mar. 2004. Web. 3 May 2016.

Throughout the refueling station system there are vent stacks above each core component. Each vent leads to a broad venting manifold, which safely disperses any lost hydrogen above and away from the refueling station and neighboring structures. There are also a number of additional safety features required for a refueling station. Beyond regulations and coding than ensures safe distance and processes, hydrogen and temperature sensors are also integrated throughout the station, as well as flame detectors, sprinklers, and flow meters to allow for the monitoring of the system's processes. The following diagram (Figure 4) depicts a comprehensive refueling station system utilizing liquid hydrogen delivery. [57]

Figure 4. Diagram of Liquid Hydrogen Delivery Refueling Station



Source: Dikeos, et al (2016).

[57] *Id*.

III. SUPPLY CHAIN OPPORTUNITIES AND INDUSTRIAL CLASSIFICATION

A. INDUSTRY ANALYSIS

1. Industrial Profile for Fuel Cell Buses

Industrial analysis based on the North American Industry Classification System (NAICS)[58] is an analytical tool helpful to economists who seek to understand the structure of a regional economy, including supply chain and manufacturing trends. NAICS classifies business establishments into groups of industries for the purpose of collecting, analyzing, and publishing statistical data and for administrative and tax purposes. NAICS is described by the Census Bureau as "an industry classification system used by statistical agencies to facilitate the collection, tabulation, presentation, and analysis of data relating to establishments."[59] The NAICS system is continuously evolving through the addition of new or changing industries, and through clarifying definitions designed to keep current with industry trends. In addition, the NAICS system is updated every 5 years to reflect changes in the U.S. economy. Industries are classified on the basis of their production (or supply function): "establishments using similar raw material inputs, capital equipment, and labor are classified in the same industry."[60]

Industrial system helps analysts understand structure of the economy, including what industries exist in the region, where they are located, what inputs they use, what outputs they produce, and what markets they serve. It may also illustrate the organization of production units and degree of their vertical integration for marketing goods and services.

Each business establishment is classified into a NAICS code based upon the activity in which it is primarily engaged. NAICS uses a vertical hierarchical classification scheme that employs increasing specificity, with 20 categories at the top (2 digit) level and 1175 categories at the finest level (6 digit). The 6-digit level provides *U.S. industry*, which is then grouped into higher levels of: *NAICS industry* (5-digit), *industry group* (4-digit), *subsector* (3-digit) and finally *sector* (2-digits).

One way for suppliers to ascertain whether they have the ability to supply the fuel cell bus industry is to look at the NAICS categories of fuel cell development companies. The NAICS codes provide suppliers and bus manufacturers alike with a handy catalogue for identifying who manufactures what components, and, importantly, who might be able to manufacture components even if they do not do so now.

By ascertaining the NAICS codes applied to this industry (for example, NAICS 334413: Semiconductor and Related Device Manufacturing), fuel cell bus developers and economists can identify what companies might be potential suppliers for the fuel cell bus industry. Likewise, the NAICS code assigned to a company could suggest to suppliers additional business opportunities

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[58] NAICS system was developed under the auspices of the Office of Management and Budget (OMB) and adopted in 1997 to replace the Standard Industrial Classification (SIC) system.

[59] U.S. Census Bureau, Glossary. https://www.census.gov/glossary/

[60] Murphy, J. Introducing the North American Industry Classification System. Monthly Labor Review, July 1998, p.44.

that may exist within their own sectors, and what the likely competition might be therefore. Groups of NAICS codes assigned to most of the companies producing fuel cell buses and their component parts could then be considered as a NAICS profile for this nascent industry.

The NAICS profile of a fuel cell hybrid electric bus consists mainly of manufacturing industries belonging to NAICS sector 31-33. This sector is comprised of "establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products," as well as organizations that assemble the component parts of manufactured products.[63] Identifying an affiliation for each company with 6-digit U.S. NAICS industry code enables us to discern a detailed description of the activity in which it is primarily engaged. Mapping the U.S. NAICS industry vertically allows us to identify 5-digit NAICS industries (comparable to international industrial classifications), industry groups (4-digit NAICS), and subsectors (3-digit NAICS).[64] For example:

- **U.S. Industry** NAICS 335991 - Carbon and Graphite Product Manufacturing. This U.S. industry is composed of establishments that are primarily engaged in manufacturing carbon, graphite, and metal-graphite brushes and brush stock; carbon or graphite electrodes for thermal and electrolytic uses; carbon and graphite fibers; and other carbon, graphite, and metal-graphite products. This 6-digit U.S. industry belongs to NAICS 33599.
- **International industry** NAICS 33599 – All Other Electrical Equipment and Component Manufacturing. This industry is composed of establishments that are primarily engaged in manufacturing electrical equipment (except electric lighting equipment, household-type appliances, transformers, motors, generators, switchgear, relays, industrial controls, batteries, communication and energy wire and cable, and wiring devices). In turn, this industry belongs to an industrial group NAICS 3359.
- **Industrial group** NAICS 3359 - Other Electrical Equipment and Component Manufacturing. This industry is composed of establishments that manufacture electrical equipment and components (except electric lighting equipment, household-type appliances, transformers, switchgear, relays, motors, and generators). This industrial group is part of a subsector NAICS 335.
- **Subsector** NAICS 335 - Electrical Equipment, Appliance, and Component Manufacturing. This industry is a part of Manufacturing sector NAICS 31-33. It includes industries that manufacture products that generate, distribute and use electrical power. Electric Lighting Equipment Manufacturing establishments produce electric lamp bulbs, lighting fixtures, and parts. Household Appliance Manufacturing establishments make both small and major electrical appliances and parts. Electrical Equipment Manufacturing establishments make goods, such as electric motors, generators, transformers, and switchgear apparatus. Other Electrical Equipment and Component Manufacturing establishments make devices

[63] U.S. Census Bureau, 2017 North American Industry Classification System. http://www.census.gov/cgi-bin/sssd/naics/
[64] *Id*.

for storing electrical power (e.g., batteries), for transmitting electricity (e.g., insulated wire), and wiring devices (e.g., electrical outlets, fuse boxes, and light switches).

Grouping industries through vertical hierarchy allows us to assess common suppliers, business services and agglomerations within the regional economies that create a necessary condition for developing innovation and, ultimately, for developing new industries stemming from the strength of existing ones.

Since there is no "fuel cell bus" NAICS category, a NAICS code profile analysis for fuel cell buses should focus on major components and respective sub-components: proton exchange membrane fuel cell, hydrogen storage tanks, electric drive system, and lithium-ion battery. However, because of the industry is relatively immature, 6-digit NAICS codes for these components are not always easy to categorize.

The companies involved in fuel cell manufacturing are broken down into two main groups: (1) those that manufacture and/or assemble the entire fuel cell system as a product and (2) those that manufacture the individual components to be used by others in integrating the fuel cell system. Most commonly, companies that manufacture and assemble the whole fuel cell system as a unit are categorized within the NAICS code 334413, defined as "semiconductors and related device manufacturers."[65] However, other fuel cell manufacturers, such as Plug Power Inc., which acquires component parts and integrates them into their design, are grouped in with the NAICS code 335999, defined as "all other miscellaneous electrical equipment manufacturing." Due to the immaturity of the industry, other manufacturers of fuel cells or component parts have been placed into the category of "Unclassified Establishments" (NAICS code 999990).[66]

Nascent industries using novel technologies and uncommon production processes often are classified within the closest manufacturing industries group or NAICS industry with ending digit 99. The description of these industry groups or industries starts with the word "Others," highlighting the dissimilarity of this industry's production process to more mature manufacturing sectors. Typically, the companies classified within "Other" industries illustrate higher than average sector productivity and fast growth. It is important for regional economists to note that the broader NAICS groups (4-digit) and subsectors (3-digit) can identify industries that support development and expansion of a new manufacturing industry within the region.

Significant portions of the fuel cell industry are classified by using multiple 9s in the code. In particular, the fuel cell industry includes "99999", for "Non-classified Establishments," "339999," for "All Other Miscellaneous Manufacturing," and "335999 "All Other Miscellaneous Electrical Equipment and Component Manufacturing." Although common, such descriptions are less helpful in identifying supplier opportunities. Yet they make up around one third of the industry classification. It will be important to monitor how the fuel cell industry continues to refine its industrial categories as its products mature and market shares grow. This will enable suppliers,

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[65] U.S. Census Bureau, 2017 North American Industry Classification System. https://www.census.gov/cgi-bin/sssd/naics/naicsrch

[66] *Id*.

developers and economic development experts alike to more fully utilize NAICS codes to inform their decision making. Importantly, while the “99” codes may limit their usefulness at this time, they do speak to the nature of the fuel cell bus industry: it is new, and as such, there is significant opportunity for supply companies and regional economies to become players in it.

The individual components of a proton exchange membrane fuel cell come from a wide range of NAICS codes. While global corporations such as DuPont and 3M are key players in the manufacturing of membrane electrode assemblies, catalysts, and gas diffusion layers, due to their size and the diversity of their products, their respective primary NAICS codes do not tell us much about the nature of their fuel cell component manufacturing. However, niche companies can provide a clearer profile. Manufacturers of membrane electrode assemblies and gas diffusion layers often fall within NAICS codes 325180 — “other basic inorganic chemical manufacturing” — and 333999 — “all other miscellaneous manufacturing.” Platinum catalyst manufacturers are identified as NAICS code 325998: “all other miscellaneous chemical product and preparation manufacturing.”[67] Again, because this industry is still young, more specific NAICS codes have not been created, and thus a number of the companies involved in fuel cell manufacturing are grouped in with “other” or “miscellaneous” manufacturing. Some companies, such as Giner, Inc., are involved in manufacturing, but are at this stage primarily research and development corporations, and therefore are classified within the NAICS code 54171: “research and development in the physical, engineering, and life sciences.”[68]

Bipolar plate manufacturers fall into separate categories from those involved in the membrane electrode assembly. The primary NAICS code for most manufacturers of bipolar plates is 335991: “carbon and graphite product manufacturing.” However, this code does not encompass all plate manufacturers. Others can be found in NAICS code 325998, defined as “all other miscellaneous chemical products and preparation manufacturing,” as well as 424690, “other chemical and allied product merchant wholesalers.”[69]

Hydrogen storage tank manufacturers fall more neatly into two distinct NAICS codes. First, companies like Luxfer-Dynetek, are labeled as NAICS code 332420, metal tank (heavy gauge) manufacturing. However, as discussed in previous sections, today’s hydrogen storage tanks also include polymer liners to lower weight and reduce permeation. So, companies identified as NAICS code 325211 — “plastics material and resin manufacturing” — are also involved in storage tank manufacturing.[70] Assignment of companies making the same product into two different NAICS affiliations suggests a similarity of production processes between the two manufacturers in a part of their business responsible for this product. It also suggests that more than 50% of their products relate to different production processes, and in this instance, that production of hydrogen storage tanks is not a majority of their business. This creates an opportunity for broader affiliation of industries that can support production of hydrogen storage tanks within the regional

[67] *Id*.
[68] 2017 NAICS Definition. U.S. Census Bureau. https://www.census.gov/cgi-bin/sssd/naics/naicsrch
[69] *Id.*
[70] *Id.*

economy, thereby creating more potential for future growth in those regions with strong specialization in both industries, NAICS 332420 and 325211.

The battery system of a fuel cell hybrid electric bus can be manufactured using a number of different chemical compositions. However, regardless of the makeup, all manufacturers of rechargeable storage batteries for automotive applications fall under the NAICS code 335911: "storage battery manufacturing."[71]

The electric drive system is comprised of many common electrical system components, such as converters, inverters, and voltage regulators. The manufacturers of these components are most commonly classified within NAICS code 33599: "all other electrical equipment and component manufacturing."[72] The manufacturers of electric motors used in electric drive systems are classified separately within NAICS code 335312: "motor and generator manufacturing."[73] Lastly, companies involved in manufacturing sensors and instruments used to manage voltage and collect information on the efficiency and effectiveness of the electric drive system are categorized under NAICS code 334515, defined as "instrument manufacturing for measuring and testing electricity and electric signals."[74]

For those considering entering the fuel cell bus supply chain, knowledge of the approximate costs of the various components is useful. The California electric vehicle collaborative CALSTART has compiled total average 2016 costs of fuel cell bus components and made them available for this study.[75] Table 3 sets forth CALSTART's estimated costs for the various fuel cell bus components, with corresponding relevant NAICS codes.

Table 3. 2016 Relative Price of Fuel Cell Bus Components

Bus Component	Estimated Cost	Percentage of Total Bus Cost	Relevant NAICS Codes
Electric Drive System	$60,000	4%	335999, 334419, 335312, 335999, 334419
Battery	$7,500	0.5%	335911
PEM Fuel Cell	$705,000	52%	334413, 335999, 325180, 339999, 325998, 335991, 54171, 999990
Hydrogen Storage	$100,000	7.4%	332420, 325211, 326199

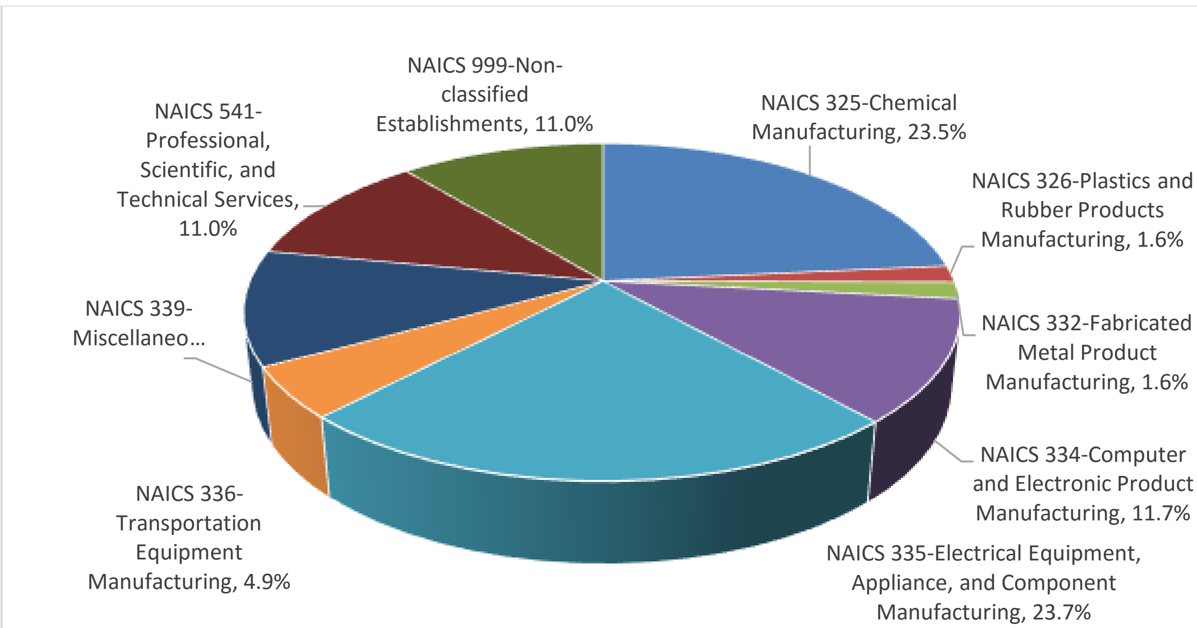
71 *Id.*
72 *Id.*
73 *Id*.
74 *Id*.I
75 *See*: http://calstart.org/Homepage.aspx. CALSTART is a member-based organization dedicated to supporting clean energy transportation technology development. Fuel cell electric vehicles are one of a number of technologies it supports.

Base Vehicle	$310,000	23%	336211

Source: CALSTART (2016). Fuel cell buses have approximately $130,000 of "other" costs (about 13% of the total cost).[76]

The relative percentage of total bus cost is distributed among a variety of industries capable of producing fuel cell bus components. Accordingly, Table 4 illustrates the relative importance of corresponding NAICS industrial profiles supplying the fuel cell bus industry. Aggregating NAICS categories to industrial sectors provides a profile across seven manufacturing and a total of nine industry subsectors, as shown in Table 5.

Figure 5. Diagram of Liquid Hydrogen Delivery Refueling Station



Appendix A attached hereto provides a complete list the NAICS codes for companies involved in manufacturing components for fuel cell buses, along with a list of suppliers of the main components.

[76] *Id*. The data was provided through communication with CALSTART.

Table 4. Relative Cost Importance of U.S. NAICS industries to the Fuel Cell Bus Industry (2016).

Code of U.S. NAICS Industry	Name of U.S. NAICS Industry	Description of U.S. NAICS Industry	Relative Cost Importance
335999	All Other Miscellaneous Electrical Equipment and Component Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing industrial and commercial electric apparatus and other equipment. This industry includes power converters, power supplies, surge suppressors, and similar equipment for industrial-type and consumer-type equipment.	11.8%
325180	Other Basic Inorganic Chemical Manufacturing	This industry comprises establishments primarily engaged in manufacturing basic inorganic chemicals.	11.0%
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing chemical products.	11.0%
334413	Semiconductor and Related Device Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing semiconductors and related solid state devices. Examples of products made by these establishments are integrated circuits, memory chips, microprocessors, diodes, transistors, solar cells and other optoelectronic devices.	11.0%
335991	Carbon and Graphite Product Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing carbon, graphite, and metal-graphite brushes and brush stock; carbon or graphite electrodes for thermal and electrolytic uses; carbon and graphite fibers; and other carbon, graphite, and metal-graphite products.	11.0%
339999	All Other Miscellaneous Manufacturing	This U.S. industry comprises establishments primarily engaged in miscellaneous manufacturing.	11.0%
54171	Research and Development in the Physical, Engineering, and Life Sciences	This U.S. Industry comprises establishments primarily engaged in conducting research and experimental development	11.0%
999990	Non-classified Establishments	Non-classified Establishments	11.0%
336211	Motor Vehicle Body Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing truck and bus bodies and cabs and automobile bodies. The products made may be sold separately or may be assembled on purchased chassis and sold as complete vehicles.	4.9%
325211	Plastics Material and Resin Manufacturing	This U.S. industry comprises establishments primarily engaged in (1) manufacturing resins, plastics materials, and nonvulcanizable thermoplastic elastomers and mixing and blending resins on a custom basis and/or (2) manufacturing noncustomized synthetic resins.	1.6%
326199	All Other Plastics Product Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing plastics products.	1.6%
332420	Metal Tank (Heavy Gauge) Manufacturing	This industry comprises establishments primarily engaged in cutting, forming, and joining heavy gauge metal to manufacture tanks, vessels, and other containers.	1.6%
334419	Other Electronic Component Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing electronic components.	0.8%
335312	Motor and Generator Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing electric motors, power generators, and motor generator sets. This industry includes establishments rewinding armatures on a factory basis.	0.8%
335911	Storage Battery Manufacturing	This U.S. industry comprises establishments primarily engaged in manufacturing storage batteries.	0.1%

Table 5. Relative Cost Importance of NAICS Subsectors to the Fuel Bus Industry (2016).

Code of NAICS Subsector	Name of NAICS Subsector	Description of NAICS Subsector	Relative Cost Importance
325	Chemical Manufacturing	The Chemical Manufacturing subsector is based on the transformation of organic and inorganic raw materials by a chemical process and the formulation of products.	23.5%
326	Plastics and Rubber Products Manufacturing	Industries in the Plastics and Rubber Products Manufacturing subsector make goods by processing plastics materials and raw rubber.	1.6%
332	Fabricated Metal Product Manufacturing	Industries in the Fabricated Metal Product Manufacturing subsector transform metal into intermediate or end products, other than machinery, computers and electronics, and metal furniture, or treat metals and metal formed products fabricated elsewhere.	1.6%
334	Computer and Electronic Product Manufacturing	Industries in the Computer and Electronic Product Manufacturing subsector group establishments that manufacture computers, computer peripherals, communications equipment, and similar electronic products, and establishments that manufacture components for such products	11.7%
335	Electrical Equipment, Appliance, and Component Manufacturing	Industries in the Electrical Equipment, Appliance, and Component Manufacturing subsector manufacture products that generate, distribute and use electrical power.	23.7%
336	Transportation Equipment Manufacturing	Industries in the Transportation Equipment Manufacturing subsector produce equipment for transporting people and goods.	4.9%
339	Miscellaneous Manufacturing	Industries in the Miscellaneous Manufacturing subsector make a wide range of products that cannot readily be classified in specific NAICS subsectors in manufacturing.	11.0%
541	Professional, Scientific, and Technical Services	Industries in the Professional, Scientific, and Technical Services subsector group establishments engaged in processes where human capital is the major input.	11.0%
999	Non-classified Establishments	Non-classified Establishments	11.0%

2. NAICS Codes Specific to Hydrogen Fueling Stations.

Much like for fuel cell buses, the industry profile for hydrogen refueling stations remains inchoate. The alternative refueling station industry is still new, and component supply chains are immature. Limitation in choices of suppliers in turn limits the available information from which to build a comprehensive NAICS code catalogue.[77] Also, as was the case for fuel cell buses, the majority of relevant NAICS codes are found within the manufacturing sector. The following refueling station components were considered in analyzing industry profiles: hydrogen gas/liquid fuel, vacuum storage tanks (dewars), vaporizers, buffer storage tanks, vacuum jacketed piping, cryogenic pumps, hydrogen fuel dispensers, valves, ventilation, air compressors, sensors, and fire suppression systems.

Many of the more active companies involved in building hydrogen refueling stations operate overseas, and as a result fall outside of the North American Industrial Classification System. However, some major international corporations have branched into the North American market. Both Air Liquide and Linde are multinational corporations with European origins that have expanded their reach into North America. However, some domestic companies have emerged as leaders in the American hydrogen refueling industry. U.S.-based companies such as Air Products, Plug Power, and General Hydrogen are recognized participants in the hydrogen gas and refueling station industry.

Each of these companies is categorized under the NAICS code 325120: "industrial gas manufacturing."[78] However these corporations do more than manufacture hydrogen: they also assemble and integrate the individual components used to build the refueling station. Because of the immaturity of the supply chain to this industry, there are no 6-digit NAICS codes for these types of system integrators. Instead, since their operations relate primarily to the production of industrial gas, these corporations tend to be classified along with other industrial gas manufacturers.

The dewars and buffer storage tanks are both manufactured by companies that fall under the NAICS code 332420: "metal tank (heavy gauge) manufacturing."[79] Within this code, the companies involved in manufacturing vessels for hydrogen refueling stations focus on cryogenic tanks, which allow for liquid and gaseous storage at extremely cold temperatures. The initial liquid hydrogen storage tank is multi-layered, with vacuum sealing and heavy insulation to keep the hydrogen below negative 424 degrees Fahrenheit (the gas's boiling point in liquid form).[80] The

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[77] Element Energy Corp., & Innovate UK Technology Strategy Board. (2015, July). Installing Accessible Hydrogen Refueling Stations: A Best Practice Guide. Retrieved May 2, 2016, from http://www.element-energy.co.uk/wordpress/wp-content/uploads/2015/07/Installing-accessible-HRS-best-practice-guide_July-2015.pdf

[78] U.S. Census Bureau, 2017 North American Industry Classification System. https://www.census.gov/cgi-bin/sssd/naics/naicsrch

[79] *Id*.

[80] Bentor, Y. Chemical Element.com – Hydrogen. Web. 10 May 2016 <http://www.chemicalelements.com/elements/h.html>

buffer storage tanks must still be heavily insulated, but because the hydrogen is in gaseous form in these tanks, the temperature does not have to be maintained at such extreme levels. Companies that fall under the very broad NAICS code 333249, encompassing all “other industrial machinery manufacturing,” manufacture the industrial vaporizers used to gasify the liquid hydrogen.[81]

Two other main components of the refueling station system require the ability to maintain extreme temperatures. The cryogenic pump, used to draw the hydrogen from the large dewar, is manufactured by companies within the NAICS code 333912, defined as “air and gas compressor manufacturers.” This includes those manufacturers that produce industrial vacuum pumps.[82] Companies classified within code 331210 manufacture the vacuum-jacketed piping used in the refueling station to transport liquid hydrogen: “iron and steel pipe and tube manufacturing from purchased steel.”[83] These pipes, much like the hydrogen storage tanks, must be multi-layered and vacuum-sealed in order to maintain the necessary temperatures to prevent the liquid hydrogen from boiling off. While the 331210 NAICS code is very general, companies that focus on transporting cryogenic material will be most apt to manufacture piping suitable for hydrogen refueling stations.

Although a main goal of a refueling station is to maintain efficient transportation of the liquid hydrogen with minimal loss, there are instances in which hydrogen is lost or must be released to maintain appropriate pressure. Such hydrogen is channeled through ventilation ducts in order to ensure safety. The manufacturers of these ventilators are categorized under NAICS code 333413, described as “industrial and commercial fan and blower and air purification equipment manufacturing.”[84] The valves used to release this hydrogen, as well as the valves used to control the flow of liquid hydrogen within the refueling station, are manufactured by companies with the NAICS code 332911: “industrial valve manufacturing.”[85] A number of these valves are operated by an air compressor that is separate from the main refueling station system, which, like the cryogenic pump, is manufactured by companies classified in the NAICS code 333912,” “air and gas compressor manufacturing.”

Additional safety measures are necessary for refueling stations, including hydrogen gas and pressure sensors, as well as a fire suppression system. The sensors are manufactured by companies within the NAICS code 334513, labeled as “instruments and related products manufacturing for measuring, displaying, and controlling industrial process variables.” Fire suppression unit manufacturers can be found in multiple NAICS codes, but are most commonly categorized within 238220 (plumbing, heating, and air conditioning contractors) or 922160 (fire protection services). [86]

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81 U.S. Census Bureau, 2017 North American Industry Classification System. https://www.census.gov/cgi-bin/sssd/naics/naicsrc
82 Id.
83 Id.
84 Id.
85 Id.
86 Id.

At the tailgate of the refueling station system, the consumer must be able to refuel his or her vehicle with compressed hydrogen fuel through a dispenser system. These dispensers are much like those used at conventional gas stations, and are manufactured by measuring, dispensing, and other pumping equipment manufacturing companies, assigned the NAICS code 333914.[87]

While the above industry profile lays out the main components for a refueling station that utilizes liquid hydrogen delivery, there are other methods to obtain the necessary hydrogen. These include onsite hydrogen production through electrolysis or steam methane reformation. Both an electrolyzer and a methane reformer fall into the category of "other industrial machinery manufacturing," NAICS code 333249.

Appendix B attached hereto provides a complete list the NAICS codes, along with suppliers, for the main components of a hydrogen refueling station.

B. Opportunities for Fuel Cell Suppliers Using NAICS codes

Discerning a NAICS profile for the nascent fuel cell bus industry enables businesses and economic development experts to assess the prospects of expansion of that industry into specific geographies. Regions with high concentrations of manufacturing industries within the relevant NAICS categories will be good candidates for housing this industry as it grows. Analysts can also use the NAICS profile to look for potential suppliers to the fuel cell bus industry and the corresponding demand for labor. With this information they can identify competitive advantages for each region, as well as address potential shortages in the supply chain and workforce occupations with relevant public policies. Such analysis can also point to the regions that would be potential competitors to house future expansion of the fuel cell bus industry, or potential collaborators in production of component supplies.

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A future analysis might compare the NAICS profiles for the fuel cell bus industry established in this paper with the concentration of the critical NAICS industries in a specific region (e.g. metropolitan area or state), thereby providing insight into a region's ability to develop a fuel cell bus manufacturing or supply chain industry. An analysis of the NAICS profile of the fuel cell bus industry also can help to identify key suppliers and critical components for support services, as well as to reveal regional competitive advantages across the critical industries. Moreover, the NAICS profile of the fuel cell bus industry can inform economists about workforce occupations and skills necessary to establish or expand the industry and/or its suppliers. Ultimately the analysis can illustrate a region's potential to form an industrial cluster centered upon fuel cell and components manufacturing and the prospects for expanding relationships with industry's suppliers, customers, and various enabling institutions. Such a study can lead to developing research-informed public policies aimed at creating economic prosperity rooted in support to new manufacturing.

[87] Id.

IV. CONCLUSIONS

Fuel cell bus manufacturers and their component suppliers have made a good deal of progress in recent years both in bringing down costs and in improving performance. Continuing progress will be necessary before the industry fully develops commercially. Much of this progress will be accomplished by manufacturers identifying component suppliers or identifying companies that could be component suppliers. NAICS codes can be a useful tool for manufacturers to identify companies that might be part of their supply chain. This could be especially useful for companies that may feel constrained by their options among suppliers.

However, there will likely be some limitations placed upon such inquiries due to the nascent nature of the fuel cell business. Many companies and component manufacturing processes have been or will be placed into a “99” NAICS category – indicating miscellaneous activities within a manufacturing sector. This is a common practice in NAICS classification for the manufacturing of new products. The NAICS classification is based upon mature products found in the marketplace. Therefore, during the nascent stage of product development and during the phase of gaining market share in sales, an industry is usually classified among “Others” within the closest manufacturing sector. Every five years the NAICS system is updated and industries that have reached sufficient sales or product development will be assigned into separate and often new NAICS codes.

Nevertheless, even for a new industry like fuel cell bus manufacturing, the NAICS codes provide companies and experts with a sense of the opportunities that may be available at this time. And it could be a starting point for the investigation of knowledge, products, processes, skills, and occupations that might secure a company’s place in the supply chain. A future study that might be more useful could make links to industrial, occupational or skill profiles within a specific region to quantitatively assess the economic opportunity to form a new production cluster for fuel cell bus (and other fuel cell vehicle) manufacturing.

For economic development agencies looking to understand potential industry growth or cluster aggregation, these tools can also be useful. Economic development experts can, after identifying relevant NAICS code categories, determine what companies in the region fall into those categories. Having made that identification, the experts can approach those companies to determine their level of capacity and interest in becoming a supplier. The classification of aspects of the industry within “other” NAICS code categories may limit the ability of experts to readily ascertain possible inclusion of a company in the supply chain, but it also illustrates the opportunity to start a new industry within the region.

V. APPENDICES

Appendix A. Fuel Cell Bus Critical NAICS Code Categories (2016).

Component	Supply Chain	NAICS Code	NAICS Code Description	Potential Suppliers
Electric Drive System	Converter, Inverter, Voltage Regulator, Current Sensor	334419	Other Electronic Component Manufacturing	Lenco Electronics, Gems Sensors & Controls, Electronetics, Switch Controls & Converters, TFK-Lambda Americas Inc., Integrated Power Design
		335999	All Other Miscellaneous Electrical Equipment Manufacturing	Tamura Corp. of America, Neeltran Inc., REO-USA, Falcon Electric
Battery	Lithium-Ion Battery	335911	Storage Battery Manufacturing	A123 Systems, EnerDel Inc., LG Chem Power Inc., XALT Energy
Hydrogen Storage	Onboard Hydrogen Storage Tanks	332420	Metal Tank (Heavy Gauge) Manufacturing	Luxfer-Dynetek, Quantum Technologies
	Polymer Liner	325211	Plastics Material and Resin Manufacturing	Flexi-Liner, Royal Liner, Champion Plastics, Micor, Rhino Linings
		326199	All Other Plastics Product Manufacturing	Protective Industrial Polymers, APR Allen Plastics Fabricating, Custom Service Plastics, AmTech
PEM Fuel Cell	PEM Fuel Cell	334413	Semiconductors and Related Device Manufacturing	Doosan Fuel Cell America, Siemens Corporation, Altergy Systems
		335999	Al Other Miscellaneous Electrical Equipment Manufacturing	Tamura Corp. of America, Neeltran Inc., REO-USA, Falcon Electric
		999990	Unclassified Establishments	Nuvera Fuel Cels
	Membrane Electrode Assembly	325180	Other Basic Inorganic Chemical Manufacturing	The Chemours Company, Cabot Corp, BASF
		339999	All Other Miscellaneous Manufacturing	Fuel Cell Etc., Electrochem Inc.
		54171	Research and Development in the Physical, Engineering, and Life Sciences	Giner
		999990	Unclassified Establishments	Entegris, Akron Polymer Systems, Coors Tek Inc., Environmental Technology Advancement and Energy Corp., Teledyne Energy Systems, Bettergy
	Bipolar Plates	325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	Sigma-Aldrich Corp
		335991	Carbon and Graphite Product Manufacturing	Graf Tech International Holdings, Toray Carbon Fibers, SGL Carbon Corp., Schunk Graphite Technology, Asbury Graphite Mills
	Platinum Catalyst	325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	Sigma-Aldrich Corp., Anco Catalysts Ltd., Albemarle Catalysts International, pH Matter LLC

		339999	All Other Miscellaneous Manufacturing	Powder Processing & Technology LLC
Hydrogen Storage	Onboard Hydrogen Storage Tanks	332420	Metal Tank (Heavy Gauge) Manufacturing	Luxfer-Dynetek, Quantum Technologies
	Polymer Liner	325211	Plastics Material and Resin Manufacturing	Flexi-Liner, Royal Liner, Champion Plastics, Micor, Rhino Linings
		326199	All Other Plastics Product Manufacturing	Protective Industrial Polymers, APR Allen Plastics Fabricating, Custom Service Plastics, AmTech
Base Vehicle	Bus Chassis	336211	Motor Vehicle Body Manufacturing	Van Hool, New Flyer, El Dorado

APPENDIX B. REFUELING STATION CRITICAL NAICS CODE CATEGORIES (2016).

NAICS Code	NAICS Code Description	Potential Component(s) Supplied	Unique to Hydrogen Station?	Potential Supplier
325120	Industrial Gas Manufacturing	Hydrogen, Refueling Station Integration	Critical	Air Liquide, Linde, Air Products, General Hydrogen, Hydrogen Frontier, Sutton-Garten
334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables	Hydrogen Sensor	Unique	Nexceris
334519	Other Measuring and Controlling Device Manufacturing			Advanced Chemical Sensors
333914	Measuring and Dispensing Pump Manufacturers	Hydrogen Dispenser	Unique	Gilbarco, Bennett Pump
999990	Unclassified Establishments	Electrolyzer, Steam Methane Reformer	Unique	Hydrite Chemical Co., Treadwell Corp
332420	Metal Tank (Heavy Gauge) Manufacturing	Dewar, Buffer Hydrogen Storage Tank, Cryogenic Pump	Not-Unique	Down River Cryogenics, Taylor-Wharton Cryogenics, Cryostar, Cryogenic Industries, Macomber Cryogenics, Wessels Co., Kenned Tank & Manufacturing Co.
332410	Power Boiler and Heat Exchanger Manufacturing	Vaporizer	Not-Unique	API Heat Transfer Inc,. Trumbo Inc., Cryogenic Experts, Multitherm LLC
333912	Air and Gas Compressor Manufacturing	Air Compressor	Not-Unique	Ariel Corp., Air and Gas Technologies, Central Air Compressor Corp, Price Compressor Corp, Universal Air and Gas Production Corp, Warren Equipment
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	Vacuum Jacketed Pipes	Not-Unique	Salzgitter Mannesmann International, Perma-Pipe, Pacific Corrugated Pipe Corp, Thermacor Process Inc.
333413	Industrial and Commercial Fan and Blower and Air Purification Equipment Manufacturing	Ventilation System	Not-Unique	Compas Cryogenics, Industrial Ventilation Systems, American Warming & Ventilating
332911	Industrial Valve Manufacturing	Valves	Not-Unique	Engineered Control International, Pentair Valves and Controls, M&H Valve Co., Everest Valve Company
334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables	Temperature Sensor, Pressure Sensor	Not-Unique	Comptrol Inc., Endress & Hauser, Proportion-Air Inc., Johnson Controls Inc.
334519	Other Measuring and Controlling Device Manufacturing			Mid-West Instrument, Pyromation Inc., Thermocouple Technology, Capacitec, Tavis Corp, Hampshire Controls, Schneider Electric, Sierra Monitor Corp, Enmet Corp., Sierra Montior Corp.
238220	Plumbing, Heating, and Air Conditioning Contractors	Fire Suppression System	Not-Unique	Gemini Fire Protection, Allied Fire Protection, A&B Fire Protection and Safety, Coastal Plumbing and Fire Protection, Firetronics LLC
333914	Measuring and Dispensing Pump Manufacturers	Hydrogen Dispenser	Unique	Gilbarco, Bennett Pump