PEM Fuel Cells: Value in California

Background and Methodology

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I. INTRODUCTION

This paper presents the results of a study of the value to California residents of a large-scale deployment of distributed proton exchange membrane ("PEM") fuel cells in several stationary and off-road power generation markets. The study does not address the application of PEM fuel cells in the automotive or portable (*e.g.*, computer, cell phone) market sectors.

PEM fuel cells are predominantly fueled by hydrogen for onsite electricity generation, and are typically produced in sizes ranging from 1 to 100 kilowatts ("kW'). The resultant "building block" unit allows for deployment flexibility and can be applied in multiple units to many different size projects, potentially up to several hundred kW.

As is the case for all fuel cells, hydrogen-based PEM fuel cells are fully operational as long as air and the fuel source are available. "Green" hydrogen is produced by electrolyzing (splitting) water into hydrogen and oxygen using electricity from renewable energy sources such as wind, solar, geothermal, or hydropower. Green hydrogen has virtually no generation-related emissions. Hydrogen may also be produced from refinery and chemical off-gas streams (with resultant reduced emissions) and from reformers installed onsite. The dominant means of producing hydrogen today, however, is through natural gas-based steam methane reforming ("SMR"). [1] The SMR process currently results in emissions of carbon dioxide ("CO_2") and other criteria pollutants similar to those of a natural gas-fired central station electricity generator, though the more concentrated CO_2 emissions resulting from the SMR process will lend themselves more readily to future carbon capture and sequestration.[2] Technological development is being actively pursued to ensure that future means of hydrogen production will result in a minimum carbon and criteria pollutant footprint.

Hydrogen-based PEM fuel cells have no onsite emissions other than water vapor and heat, making them ideal for indoor electricity generation requirements. PEM fuel cells operate quietly and cause almost no vibrations. Because they operate at low temperatures, waste heat from PEM fuel cells has limited cogeneration potential, although new designs include the capability for combined heat and power operations.

Figure 1, entitled "PEM Fuel Cells: Value in California," illustrates the results of the step-by-step analysis of the value proposition of distributed PEM fuel cells that exist in commercial operations in California *today* in each of the following four onsite market applications:

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[1] Other more exotic methods of producing hydrogen also exist (*e.g.*, from algae, high temperature disassociation), but these methods today produce relatively insignificant quantities of hydrogen.

[2] See Chernyavs'ka, *et al.*, pp. 6-7 and Intergovernmental Panel on Climate Change, pp. 79-80.

- Mission-Critical Backup Power
- Distributed Baseload Power Generation
- Distributed Peak-Shaving Power Generation
- Specialty Vehicles (*e.g.*, off-road materials handling).

In the Mission-Critical Backup Power market, PEM fuel cells provide episodic on-demand backup power for customers in areas that are critical to maintain the pulse of

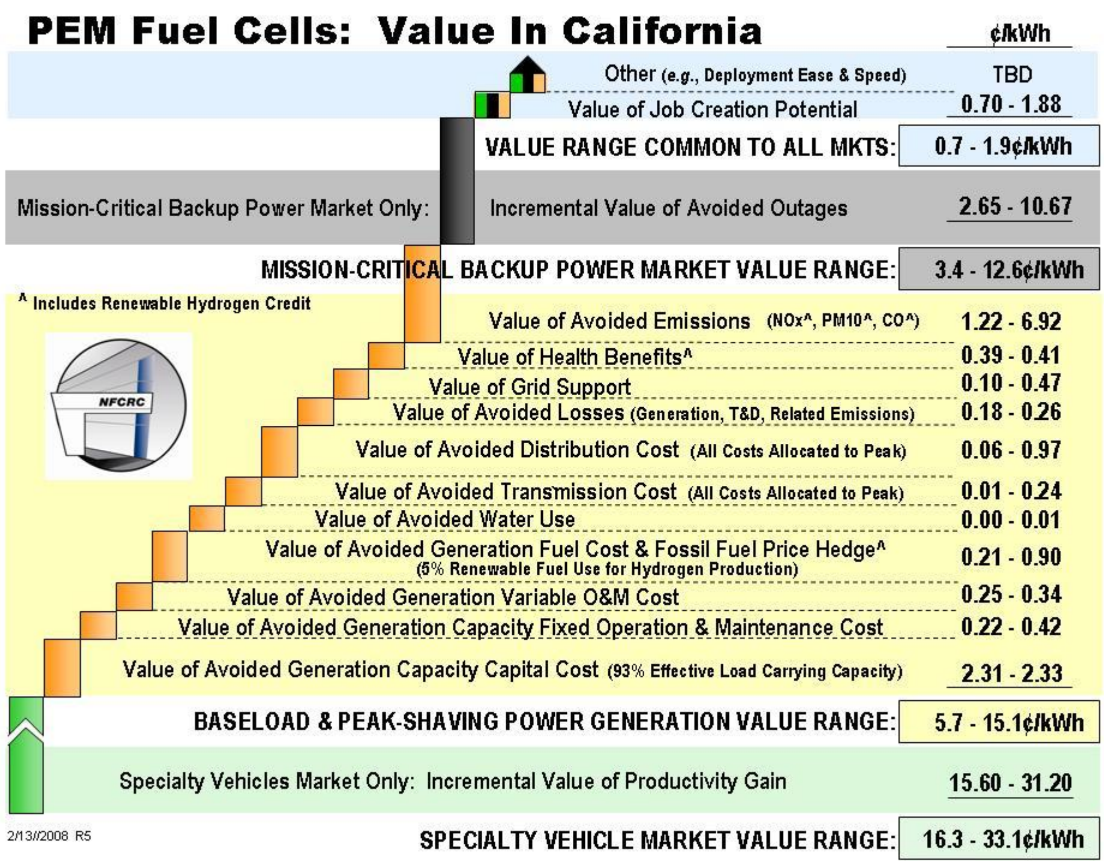

Figure 1. PEM Fuel Cells: Value in California

today's electronics-dominated economy, such as data centers, telecommunications, and electrical grid substations. The Baseload and Peak-Shaving Power Generation markets analyzed here are for PEM fuel cells in distributed generation applications, located at a customer site and operated in parallel with the electrical grid. In the Specialty Vehicles market, PEM fuel cells displace lead-acid batteries in off-road materials handling vehicles such as forklifts and airport ground support equipment.

The categories of avoided costs in Figure 1's "waterfall" chart relate to a number of distributed value elements that represent attributes of distributed generation technologies, usually when compared to a central station electricity generator. Each distributed value element quantified in Figure 1 is discussed in some detail below to enable the reader to understand the derivation of its value. Some of the avoided costs in Figure 1 are quantified based on observable market prices, and some are quantified based on values that are derived from a broad-based literature search. Additional data on fuel cell technologies, economics, and underlying assumptions was obtained from the participating organizations.

The waterfall chart in Figure 1 shows the value to California residents of PEM fuel cells in each of the market applications identified above. The top section of the waterfall chart (shaded blue) shows the range of value that is common to all four market applications. The next section (shaded gray) shows the incremental range of value specific to the Mission-Critical Backup Power market; the total value of these two markets is the sum of the values in the blue and gray sections. The third section (shaded yellow) provides the incremental and total range of value specific to the Baseload and Peak-Shaving Power Generation markets. Similarly, the fourth section, (shaded green) provides the incremental range of value specific to the Specialty Vehicles market; the total value of the Specialty Vehicles market is the sum of the value in the blue and green sections.

As seen in Figure 1, the waterfall chart indicates that:

- Regardless of market, the installation and maintenance of PEM fuel cells *today* provides California residents 0.7-1.9 cents/kWh of increased economic activity value through the Value of Job Creation Potential. Because installation and maintenance of PEM fuel cells is necessary in all markets, this value range is common to all four of the PEM fuel cell markets included in the study.

- Distributed PEM fuel cells in the Mission-Critical Backup Power market have a cumulative value range of 3.4-12.6 cents/kWh. This value range includes the Value of Job Creation Potential and the incremental value of PEM fuel cells in the Mission-Critical Backup Power market of 2.65-10.67 cents/kWh. These values are based on average commercial and industrial outage costs in California; for any specific customer, the value could be significantly higher. All California residents are considered to benefit directly or indirectly as on-demand fuel cell-based backup power units reduce utility customer costs of grid-related outages.

- Similarly, the value range for the onsite Baseload and Peak-Shaving Power Generation markets starts with the 0.7-1.9 cents/kWh of common value, and adds an incremental value of 4.96-13.27 cents/kWh, for a total average value range of 5.7-15.1 cents/kWh. PEM fuel cells in these markets avoid the need for electricity provided through the electrical grid from central station generators. As a result, California ratepayers would be the direct recipients of the components of the Baseload and Peak-Shaving Power Generation value range affecting utility bills and all Californians would benefit from the improved air quality resulting from avoided central station emissions.

- The Specialty Vehicles market value range includes the 0.7-1.9 cents/kWh of common value, and adds a market-specific incremental value proposition of 15.6-31.2 cents/kWh for increased worker productivity, for a total value range of 16.3-33.1 cents/kWh.

The details related to each market application will be described in greater detail below. Greater market penetration in any market space increases the job creation potential of PEM fuel cells within California, starting with relatively high paying fuel cell installation jobs and ultimately progressing to lower paying but longer lasting fuel cell manufacturing jobs. As fuel cell market penetration in any market space increases, customer acceptance of fuel cell technology should also increase, further increasing market penetration not only in that market space, but across all markets. As the installed capacity of fuel cells increases, manufacturing costs should decline to the point that fuel cells become a mainstream electricity generating technology in each of the four markets identified. Because of its potentially large market size, California has the opportunity to become a leader in fuel cell technology development and production.

II. MARKETS AND VALUE PROPOSITION COMPONENTS

The value proposition offered by PEM fuel cells is determined largely by the market in which these fuel cells operate. Figure 1 provided a summary of the value proposition of PEM fuel cells in California within four major markets: (1) Mission-Critical Backup Power; (2) Baseload Power Generation; (3) Peak-Shaving Power Generation; and, (4) Specialty Vehicles. In each of these markets, the PEM fuel cells considered in this study are assumed to operate as an onsite distributed energy resource.

A. Mission-Critical Backup Power

As the global economy becomes increasingly reliant on high-speed electronic technology, electricity reliability issues become more and more critical. Much of today's electronic equipment is intolerant of even very small electricity "blips." PEM fuel cells offer the Mission-Critical Backup Power market (i) quick ramp-up and (ii) extended operations for as long as fuel is available. The latter takes on increased significance in light of the recent Federal Communications Commission ("FCC") ruling that cell phone towers must have at least 8 hours of onsite backup capability.[3] This ruling was made largely in response to telecommunications outages along the Gulf Coast in the wake of Hurricanes Katrina and Rita in 2005.

Hurricanes, rolling black-outs and brown-outs are all examples of events that disrupt the electrical grid that powers the telecommunications networks. For critical sites, the economic impact of electrical outages can be significant, making reliable backup power a

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[3] *Recommendations of the Independent Panel Reviewing the Impact of Hurricane Katrina on Communications Networks*, Order, 22 FCC Rcd 10541 (2007). *See also* 47 C.F.R. § 12.2.

pressing concern for the industry. PEM fuel cells are receiving increased industry attention for mission critical backup power applications as market needs change and evolve.

PEM fuel cells are a solid state backup power solution that incorporates the best attributes of combustion generators and batteries, while avoiding the weaknesses of each of those technologies. Although they have a higher first cost, PEM fuel cells offer improved system reliability, predictable performance across a broad range of climates, a reliable service life, and near zero onsite emissions. Valve-regulated lead acid batteries are temperature sensitive, too heavy for rooftop installations and other outdoor applications, and often unable to keep pace with the energy demands of outdoor plant technology (*e.g.*, in telecommunications). Generators present their own challenges, such as combustion emissions, noise, and high maintenance requirements (especially problematic for remote sites, such as cell towers).

The FCC reports that there were 29.7 million mobile wireless telephone subscribers in California at the end of 2006, up over 16 percent from the previous year and almost double the number of subscribers at the end of 2001.[4] Using an industry-wide average of 1,100 subscribers per cell tower,[5] the number of cell towers in California is estimated to be over 27,000 and growing as the number of subscribers continues to increase. Each cell tower typically has multiple carriers (*i.e.*, cell phone companies), and each carrier maintains its own backup power device, often an over-sized 20 kW diesel generator. As thousands of new cell towers are constructed in California to accommodate subscriber growth, these diesel generators often provide baseload power during installation of the cell tower as power lines are extended to tower sites.

The use of PEM fuel cells operating on hydrogen eliminates nearly all of the onsite emissions associated with backup power, which can be a significant benefit compared to the highly polluting backup generators currently in place in many locations. The potential magnitude of onsite annual avoided emissions for PEM fuel cells in this market is shown in Figure 2 (below) and was calculated assuming that:

- PEM fuel cells replace 20 kW back-up diesel generators at 40 percent of the estimated 27,000 cell towers in California.

- All onsite emissions are avoided through PEM fuel cells displacement of diesel generators, with average diesel generator emissions based on U.S. Environmental Protection Agency standards.[6]

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[4] *See* Federal Communications Commission, 2007, Table 14, p. 17.

[5] Five-year rolling average derived from CTIA-The Wireless Association, 2007, pp. 3-4.

[6] *See* U.S. Environmental Protection Agency, April 2004, Table 1, pp. 4-5.

- Backup power units operate for an average of 53 hours per year, both for backup use and for maintenance and testing.

As grid reliability concerns increase and as backup diesel generators proliferate in response to the FCC ruling noted above, the increased use of PEM fuel cells provides an excellent opportunity to satisfy the FCC's 8-hour backup requirement while also reducing onsite emissions in the Mission-Critical Backup Market.

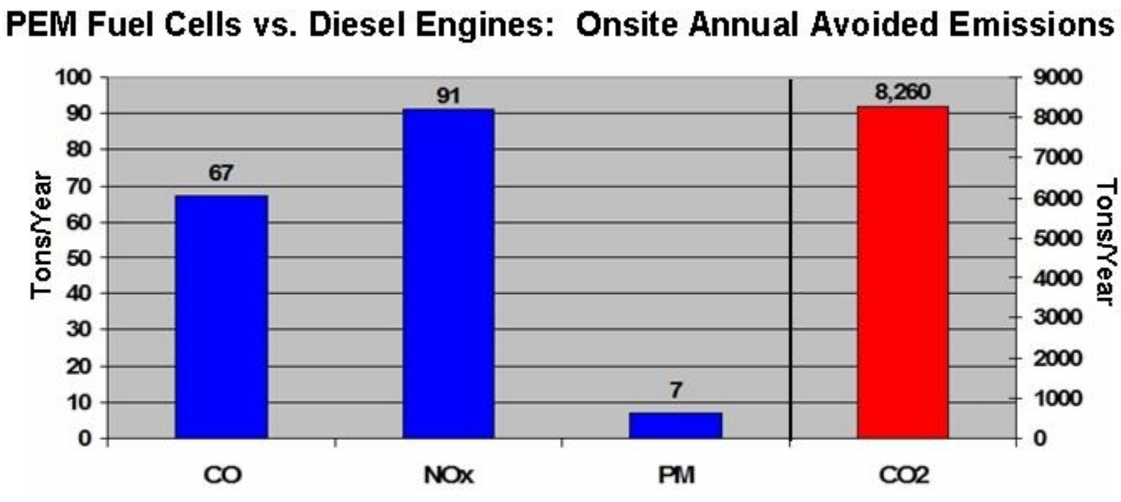

Figure 2. PEM Fuel Cells vs. Diesel Engines: Onsite Annual Avoided Emissions

PEM fuel cells in the Mission-Critical Backup Power market not only avoid onsite emissions, but also allow customers to avoid electrical outages during periods of grid failure. The Value of Avoided Outages is calculated in the first instance based on a study by Lawrence Berkeley Laboratory ("LBL") that calculated an annual cost of electricity outages of $8.1 billion for California's electricity users, approximately $8.0 billion of which was incurred by commercial and industrial ("C&I") electricity users.[7] Dividing this annual cost of outages to California's C&I electricity users by annual consumption data from EIA for these same customers indicates that California's commercial customers incur a 2.65 cent/kWh outage cost "premium," while for California's industrial customers the outage cost premium is 10.67 cents/kWh of electricity usage.

The mission-critical aspect of backup power is perhaps better reflected by calculating the Value of Avoided Outages in terms of the avoided cost per kWh of *outage* (*i.e.*, per kWh not delivered due to grid failure), rather than per kWh of electricity *usage*. Using annual outage date for California from the same LBL study cited above, the cost per kWh of *outage* for California's commercial customers is $72.84, while the cost for industrial customers is $293.84 per kWh of *outage*.

[7] *See* LaCommare and Eto, p. 28.

Because they are averages, even these much larger values per kWh of outage mask the enormous cost of electrical outages to specific industries. Table 1 shows outage costs per hour for a select number of industries, as reported by the U.S. Department of Energy.[8]

Table 1. Selected Outage Costs

Industry	Average Cost of Downtime (Per Hour)	
	(Constant 1996$)	(Constant 2007$)
Cellular Communications	$41,000	$54,120
Telephone Ticket Sales	$72,000	$95,040
Airline Reservations	$90,000	$118,800
Credit Card Operations	$2,580,000	$3,405,600
Brokerage Operations	$6,480,000	$8,553,600

Thus, if these customers can avoid electricity outages through the use of PEM fuel cells for mission-critical backup power, these outage cost premiums–however they are calculated–can be avoided. These direct customer-specific benefits in the commercial and industrial sectors can be expected to spill over indirectly to all Californians who use the products and services of the positively impacted companies.

B. Baseload and Peak-Shaving Power Generation

The whole electrical grid–including generation, transmission, and distribution–is built to satisfy peak electricity demand. Distributed (*i.e.*, onsite) generation technologies that reliably reduce the amount of on-peak electricity that needs to be delivered from the electrical grid can reduce the need for an even greater amount of central station generation, transmission, and distribution (given the losses inherent in the electrical grid). Due to their quick ramp-up and reliable operations, distributed PEM fuel cells can provide on-peak power that not only benefits the grid but that also reduces utility demand (and energy) charges for the onsite customer. PEM fuel cells that operate in peak-shaving mode relieve pressure on the grid by reducing the need for natural gas-fired peaking generation, which would normally be a combustion turbine. Thus, the avoided generator in the peak-shaving power generation market space would be one located at or near the top of the economic dispatch stack.

Baseload power generation by PEM fuel cells also benefits the grid by relieving the amount of on-peak electricity that needs to be delivered from the grid, this time from a generator closer to the bottom of the dispatch stack. The avoided central station generator in this case will be a baseload unit, rather than a peaking unit, but the benefits with respect to avoided transmission and distribution ("T&D") are identical to the benefits provided by a PEM fuel cell operating in peak-shaving mode.

8 *See* U.S. Department of Energy, September 2000, Table 1, p. 7.

Note that there is no fundamental difference between the baseload and the peak-shaving power generation market value proposition. PEM fuel cells in either market reduce the quantity of electricity being transmitted through and delivered by the electrical grid during the peak demand period; the avoided T&D value proposition to ratepayers as a whole is the same whether the PEM fuel cell operates in baseload or peak-shaving mode. In contrast, the aggregate value of the avoided generator will differ based on the avoided generator technology, which is assumed to be a natural gas combined cycle plant for the baseload power generation market and a natural gas-fired combustion turbine for the peak-shaving power generation market.

Avoided T&D costs are based on California-specific calculations performed by Energy and Environmental Economics, Inc. ("E3") for the California Public Utilities Commission ("CPUC"). E3 calculates avoided T&D costs by planning region and by climate zone for each of the investor-owned utilities Pacific Gas & Electric ("PG&E"), Southern California Edison ("SCE"), and San Diego Gas and Electric ("SDG&E"). The 0.06-0.97 cents/kWh value range for the Value of Avoided Distribution Cost and the 0.01-0.24 cents/kWh value range for the Value of Avoided Transmission Cost reflect the minimum and maximum range of avoided T&D values calculated by E3. The Value of Avoided Losses of 0.18-0.26 cents/kWh reflects the value of the 6 percent of central station generation lost to T&D between the point of generation and the point of delivery.

PEM fuel cells used for baseload power generation may also provide additional grid support benefits through the provision of ancillary services (*e.g.*, regulation up, regulation down). The Value of Grid Support of 0.10-0.47 cents/kWh is also based on E3's California-specific avoided cost analysis for the CPUC, which values the cost of ancillary services per MW of load at 2.84 percent of total energy commodity costs.[9]

As indicated above, the avoided baseload generator is assumed to be an in-state natural gas combined cycle unit, and the range of value for the baseload power generation market is based on avoided capital and operations and maintenance ("O&M") costs developed by the CPUC for a newly-constructed natural gas combined cycle unit. This unit is referred to by the CPUC as the 2006 Market Price Referent ("MPR") proxy plant. The avoided peaking generator is assumed to be an in-state natural gas combustion turbine, with the range of value for avoided capacity and O&M costs based on electricity generating technology costs developed by the U.S. Department of Energy's Energy Information Administration ("EIA") for its *2007 Annual Energy Review*.

The Value of Avoided Generation Fuel Cost & Fossil Fuel Price Hedge is calculated assuming that only 5 percent of the hydrogen used by PEM fuel cells in California today is produced from renewable energy sources. Note that the availability of renewable-based hydrogen should increase steadily over time as additional renewable energy resources are brought on-line. The current dominance of natural gas-derived hydrogen

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9 *See* Kempton, *et al.*, for an analysis of fuel cell vehicle potential to provide ancillary services to the California electrical grid.

should thus be viewed as an important transitional step, without which the current development of California's hydrogen infrastructure would be greatly impaired.[10]

Use of renewable fuel for hydrogen production displaces absolute natural gas use and provides a hedge against volatile natural gas prices.[11] The range of avoided natural gas prices underlying the Value of Avoided Generation Fuel Cost & Fossil Fuel Price Hedge is based on the 2004-2007 range of monthly natural gas futures contract settlement prices on the New York Mercantile Exchange ("NYMEX") of $4.20-15.40/MMBtu.[12]

The Value of Avoided Emissions is also calculated only for the 5 percent of hydrogen use by PEM fuel cells assumed to be produced from renewable fuel. This is because hydrogen produced from natural gas (through SMR) creates approximately the same amount of emissions as a natural gas-fired generator, resulting in no avoided emissions. For the 5 percent of renewable-derived hydrogen, the Value of Avoided Emissions is determined by the physical quantity of avoided CO, NO_x, and PM10 per kWh, valued at in-state California emissions allowance prices. The Value of Health Benefits associated with the renewable-based avoided emissions is based in part on an epidemiological study by Abt Associates that attaches a monetary value specific to California for reduced emissions of NO_x and SO_x. The Value of Health Benefits for reduced PM10 emissions is based on an analysis by the California Environmental Protection Agency ("Cal EPA") and the California Air Resources Board ("CARB").

As noted above, the components of the 5.6-15.1 cent/kWh Baseload and Peak-Shaving Power Generation value range related to avoided generation and T&D capacity would accrue directly to California ratepayers; the components of the value range related to avoided emissions and related health benefits would be more broadly distributed among all California residents.

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[10] Increasing availability of renewable energy resources for hydrogen production in California is embodied in Senate Bill 76 ("SB 76"), the implementing legislation for the California Hydrogen Highway Network Blueprint Plan. Under SB 76, 20 percent new renewable energy resources must be used at the outset to produce hydrogen at the hydrogen fueling station demonstration projects; by 2010, the renewable requirement increases to 33 percent. *See* http://www.HydrogenHighway.ca.gov/facts/sb76fs.pdf.

[11] *See* Bolinger, *et al.*, for analysis of the hedge value of renewable fuels.

[12] No cost adjustment has been made to reflect the value of transportation from the NYMEX delivery point at the Henry Hub in Louisiana to California, since this transportation value (known as the "basis") is highly volatile, varies seasonally, and may be either positive or negative.

C. Specialty Vehicles

The Specialty Vehicles market considered in this analysis includes non-automotive off-road vehicles that are primarily used for materials handling, such as forklifts and airport ground support equipment. Hydrogen-based PEM fuel cells are used in this market to replace the main battery in already-electrified specialty vehicles, with the following benefits:

- PEM fuel cells operate at full power output capacity between refueling; there is no power output capacity loss, as is experienced when batteries discharge.
- Hydrogen refueling time is minimal compared to battery recharging time and is significantly shorter than the time required to swap out battery packs.
- Swapping out of heavy and bulky battery packs is eliminated, as is the risk of injury and workmen's compensation claims related to battery pack handling.
- The amount of lead-acid batteries required is minimal, eliminating the need for large-scale battery disposal and associated risks of liability.
- Battery charging and storage space requirements are significantly reduced, freeing up facility space for other productive uses.

The lead-acid batteries typically used in specialty vehicles continually lose power output capacity as they are operated, with a resultant loss of productivity. The fact that PEM fuel cells operate at full power output capacity between refueling results in a specialty vehicle productivity gain (relative to battery-only operations) of approximately 3.5 percent.[13] Calculated over an eight-hour shift with the specialty vehicle operator being paid $26/hour, the Value of Productivity Gain alone provides a value proposition of 14.56 cents/kWh of avoided electricity use. This value proposition is based on the avoided 50 kWh of utility-provided electricity required to fully charge a lead acid battery, electricity that is now being provided by the hydrogen-based PEM fuel cell.[14] If the 14.56 cents/kWh Value of Productivity Gain is (conservatively) assumed to be the upper end of the range, half of that value is estimated as the lower end of the range, which could reflect lower wages, lower productivity gain, more efficient battery charging, or any combination of the three.

Hydrogen refueling provides an additional source of productivity gain in the Specialty Vehicles market due to (i) less time being required for hydrogen refueling of fuel cells than for changing out battery packs, and (ii) refueling of fuel cells being required less often than recharging of battery packs. The magnitude of these two sources of productivity gain is approximately 4 percent, more than doubling the upper end of the cumulative Value of Productivity Gain to 31.20 cents/kWh of avoided electricity use.[15]

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[13] Productivity gain based on industry estimates.

[14] *See* Curtis Instruments, Inc., Section 3.

[15] Productivity gain based on industry estimates.

The lower end of the cumulative Value of Productivity Gain is again estimated at half of the upper end of the range, that being 15.60 cents/kWh of avoided electricity use.

The Specialty Vehicles market space offers significant opportunity for increased PEM fuel cell penetration, particularly given California's ongoing efforts to promote electric drive technologies in key applications, including electric forklifts. In their jointly released December 2007 "State Alternative Fuels Plan," the CARB and the California Energy Commission include as a strategic objective to "maximize alternative fuels in early adopter market niches, such as…off-road vehicles…in the near and mid term."[16] For every doubling of PEM fuel cell capacity, it is anticipated that manufacturing costs will decline by 15 percent.[17] [18] The CARB forecasts that the population of electric forklifts alone in California will increase under "business as usual" assumptions to over 60,000 units by 2022.[19] Assuming that PEM fuel cells capture approximately 25 percent of the California electric forklift market by 2020, the installed capacity of PEM fuel cells in the Specialty Vehicles market will double more than 10 times from today's installed capacity. This level of PEM fuel cell penetration in the Specialty Vehicles market space in California could lead to a market transformation in customer acceptability and elicit manufacturing cost reductions of up to two-thirds of today's cost as a result of increased production, based on a 15 percent learning coefficient. This reduction in PEM fuel cell manufacturing costs would benefit each of the four markets identified in this study.

In addition, as hydrogen-based PEM fuel cells increasingly penetrate the Specialty Vehicles market in California, less and less electricity will be required from the electrical grid to charge the displaced batteries. Although the CARB anticipates that the impact on central station generation and grid-related T&D from battery replacement in the Specialty Vehicles market will be insignificant, the increased PEM fuel cell capacity that would result from a true market transformation could potentially result in avoided costs similar to those attributed to the Baseload and Peak-Shaving Power Generation markets. The proliferation of PEM fuel cells in the Specialty Vehicles market will have an equally beneficial effect on both stationary and mobile power sources. The resultant collective demand for hydrogen will reduce localized emissions and move the state forward toward

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[16] *See* CARB and California Energy Commission, page 5. The "State Alternative Fuels Plan" states on page 1 that it "meets the requirements of Assembly Bill 1007 (Pavley, Chapter 371, Statutes of 2005) to develop and adopt a plan to increase the use of alternative fuels without adversely affecting air quality or water quality, or causing negative health affects."

[17] Laitner *et al.*, p. 6, expresses the learning curve as a power function in the equation $Cost_t = Cost_0 \times Output^b$, where *Output* is an index of the cumulative number of units produced from year *0* to year *t* divided by the cumulative units produced in year *0*, and *b* is a learning parameter that measures the rate that costs are reduced as cumulative output increases.

[18] A 15 percent value for the learning parameter for fuel cells is referenced at IEA, p. 86, and is somewhat conservative compared to the 16 to 19 percent learning coefficients for other modular technologies referenced at Imperial College Centre for Energy Policy and Technology, p. 59.

[19] *See* CARB, 2007, p. ES-5.

achievement of Governor Schwarzenegger's California Hydrogen Highway Network objectives.

III. PROJECTED 2020 PEM FUEL CELL CAPACITY IN CALIFORNIA, BY MARKET SEGMENT

PEM fuel cells today are commercially deployed predominantly in the Mission-Critical Backup market and in the Specialty Vehicles market, with smaller numbers deployed in the Baseload and Peak-Shaving Power Generation markets. The Mission-Critical Backup and Specialty Vehicles markets are expected to continue their dominance going forward, with significant market penetration expected over the next 10-15 years in each of the four identified markets. Figure 3 shows the projected PEM fuel cell installed capacity in California in 2020 for each of the four markets discussed above. These projections are based on data provided by the participating organizations.

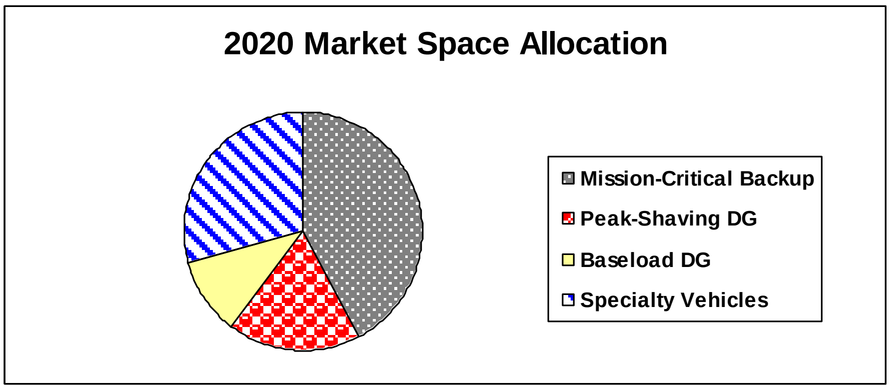

Figure 3. 2020: Installed PEM Fuel Cell Capacity in California, by Market Segment

IV. CONCLUSIONS

As demonstrated by the waterfall chart in Figure 1, commercially deployed PEM fuel cells provide significant value *today* to California in the Mission-Critical Backup Power market, in the Baseload and Peak-Shaving Power Generation markets, and in the Specialty Vehicles market. A specific example of the potentially significant onsite avoided emissions associated with PEM fuel cell displacement of diesel generators in the Mission-Critical Backup Power market for telecoms was shown in Figure 2. With the proper incentives, PEM fuel cells are expected to increase their market penetration in each of these markets, with projected 2020 market shares as indicated in Figure 3. As the early deployment markets, the Mission-Critical Backup market and the Specialty Vehicles market provide an ideal opportunity for a market transformation brought about by a dramatic increase in market penetration. In both markets, this market transformation will be driven by the enhanced performance characteristics of PEM fuel cells compared to incumbent technologies; in the Specialty Vehicles market, market transformation prospects will be enhanced by California's existing push to increase the number of electric drive specialty vehicles. The benefits to California will increase as the market penetration of the PEM fuel cell technology increases in all four of the identified markets, particularly with respect to the Value of Job Creation potential.

V. ACKNOWLEDGEMENTS

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Attachment A

Fuel Cells: Technology and General Attributes

INTRODUCTION

Fuel cells can be made to suit a wide variety of applications or market sectors, including stationary, transportation and portable applications. This study addresses the use of proton exchange membrane ("PEM") fuel cells for a number of stationary applications, including baseload and peak-shaving power generation, episodic mission-critical backup power, and battery replacement for off-road specialty vehicles. To serve these markets, component systems ranging in capacity from one to five kilowatts are now available, which may be combined to serve customers requiring larger capacity systems.

In its most basic form a fuel cell is an electrochemical device in which a fuel and an oxidant are combined to produce electricity and heat. With two electrodes separated by an electrolyte, a fuel cell is similar to a battery, except that it will not run down as long as fuel and air are supplied. To generate useful quantities of electricity, individual cells must be connected together in series to build voltage, and the size and number of cells in a cell stack or module will determine its electric generating capacity. Because the conversion of the fuel to electrical energy takes place electrochemically, without combustion, the process is highly efficient, clean and quiet. Perhaps confusingly, the term "fuel cell" can refer to an individual cell itself, to a cell stack, to a module consisting of a number of cells, or to the entire electrical system.

While the basic principles of all fuel cells are the same, the electrolytes, conducting ions and operating temperatures differ greatly between fuel cell types. Five major types of fuel cells have been (or are being) developed, generally identified according to the type of electrolyte used. In ascending order of operating temperature, the five major types of fuel cells are: (1) Alkaline ("AFC," ~70^{o}C); (2) Proton Exchange Membrane ("PEM fuel cell," ~80^{o}C); (3) Phosphoric Acid ("PAFC," ~200^{o}C); (4) Molten Carbonate ("MCFC," ~650^{o}C); and, (5) Solid Oxide ("SOFC," 800-1000^{o}C). With some exceptions, higher temperature fuel cells (*i.e.*, PAFC, MCFC, and SOFC) tend to be better suited to larger applications, while lower temperature systems (*i.e.*, AFC and PEM fuel cells) are considered better suited to smaller applications.

HOW A FUEL CELL OPERATES

PEM fuel cells combine hydrogen and oxygen to produce electricity and water. Hydrogen is fed into the anode of the PEM fuel cell. Air provides the oxygen and enters the PEM fuel cell at the cathode. Encouraged by a platinum-based catalyst, the hydrogen is split into two streams: positive hydrogen protons and negative electrons. The hydrogen proton stream passes through the electrolyte to the cathode. The electron stream is the useful stream, and is created once an external circuit is provided, forming an electric current. This electric current can be utilized before the electrons return to the cathode to combine with the hydrogen proton stream to keep the fuel cell's electrochemical process going. The reconstituted hydrogen atoms combine with the oxygen at the cathode to create water. An overview of the entire electrochemical process is illustrated below in Figure A-1.

TYPES OF FUEL CELLS

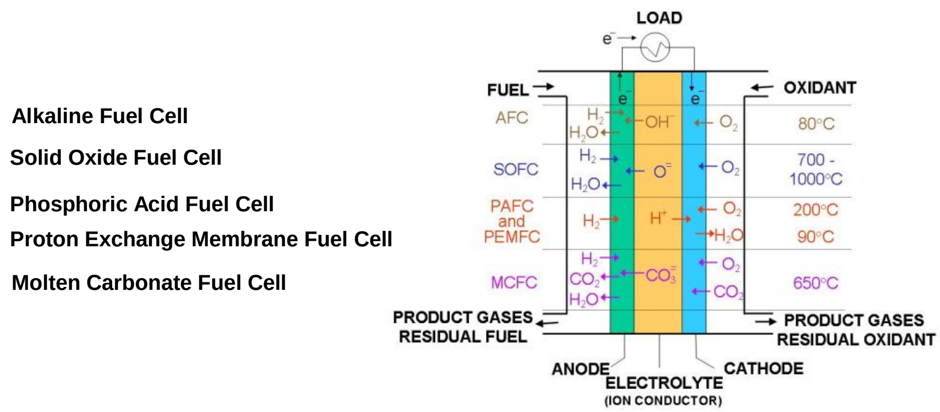

Figure A-1.

ELECTRICAL EFFICIENCY

Electrical efficiency is a measure of how well fuel input is converted to electrical power. The higher the electrical efficiency, the lower the amount of fuel input required per kilowatt-hour ("kWh") of electricity generated. High electrical efficiency is an important benefit of fuel cells from the viewpoints of both the cost of operation and environmental impact.

PEM fuel cells have demonstrated gross plant electrical efficiencies above 60 percent on a lower heating value ("LHV") basis, with limited ability for cogeneration due to their low operating temperature.

ENVIRONMENTAL IMPACT

PEM fuel cells that operate on hydrogen produce only water vapor in their exhaust, making them ideal for inside applications such as materials handing. However, because most hydrogen is today produced from natural gas through steam-methane reforming, the overall environmental impact is similar to that of a natural gas-fired electricity generator. The lowest environmental impact results from hydrogen produced from renewable energy sources such as wind, solar geothermal, hydropower, or digester gas from wastewater treatment plants, landfill gas, and biofuels.

FUEL CELLS FOR STATIONARY APPLICATIONS

Among stationary applications, different types of fuel cells are better suited to serve different market segments, based on size and customer needs (especially for heat and/or cooling), fuel availability, *etc.*

PEM fuel cells are well suited for backup power and intermittent power demand (*e.g.*, peak load shaving) compared to incumbent combustion-based generating technologies for the following reasons:

- Lowest environmental impact of any power generation system using similar fuels
- High quality power produced
- Ease of siting at or near the point of use
- Unattended operation, low maintenance, high availability
- Readily turned on and off as required on demand
- Minimal licensing, permitting and installation time.

PAFCs, MCFCs, and SOFCs are well suited for continuous, baseload generation of electricity and heat compared to incumbent combustion-based generation technologies for the following reasons:

- Highest electrical efficiency of any comparable-sized system
- Lowest environmental impact of any power generation system using similar fuels
- Amenable to operation on natural gas, industrial waste hydrogen, digester gas and other biofuels fuels; do not need pure hydrogen
- High quality power produced
- Ease of siting at or near the point of use
- Unattended operation, low maintenance, high availability
- Minimal licensing, permitting and installation time
- Some are air-cooled, most need limited water during normal operation
- Cogeneration (with options for chilled water, steam) or electric-only options.