

Hydrogen Fueling Station in Honolulu, Hawaii Feasibility Analysis

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August 2014



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SUMMARY

The *Department of Energy Hydrogen & Fuel Cells Program Plan* (September 2011) identifies the use of hydrogen for government and fleet electric vehicles as a key step for achieving “reduced greenhouse gas emissions; reduced oil consumption; expanded use of renewable power ...; highly efficient energy conversion; fuel flexibility ...; reduced air pollution; and highly reliable grid support.” This report synthesizes several pieces of existing information that can inform a decision regarding the viability of deploying a hydrogen (H₂) fueling station at the Fort Armstrong (HI0013zz) site in Honolulu, Hawaii. The hydrogen fueling station will be publicly accessible and used to fuel light-duty vehicles, including both General Services Administration fleet and non-General Services Administration fleet vehicles, and other fuel cell transportation technologies that are being deployed in the Honolulu area (such as fuel cell buses and plug-in paratransit buses).

The envisioned facility would consist of a premium covered parking lot, a roof-mounted photovoltaic solar array, and a small H₂ production and distribution station similar to other established H₂ fueling stations in California. A 1.4-acre, roof-mounted photovoltaic solar field that produces about 700 kW of power per day can sustain an electrolyzer that is capable of producing roughly 65 kg of H₂ per day without being overly dependent on the electric grid. The intent is to tie the photovoltaic solar array to the electrical grid and to one or more nearby third-party electricity consumers (i.e., most likely a co-located Federal Building) and effectively use the third-party consumer and the grid as an energy storage device. All required equipment is commercially available and can be easily procured and installed within a lead time of one calendar year.

With a 65-kg per day electrolyzer and an average demand of 80% utilization, the H₂ refueling station could support roughly 85 to 100 vehicles. About 148 government-owned electrical and gas-powered “cars” located near the proposed H₂ fueling station could easily be transitioned to H₂ fuel cell-powered vehicles. Another 293 sport utility vehicles and light-duty trucks are also candidates for transition and fueling station use, as well as a large fleet of public transportation vehicles such as busses. This makes the Fort Armstrong (HI0013zz) site very attractive.

This facility is intended to be a flagship-type installation, setting the example and establishing a renewable H₂ infrastructure in Hawaii for other government and private entities to follow. It is assumed that GSA would not own and operate the station but rather enter into a lease agreement with an entity to own and maintain the fueling station. The objective is to establish an H₂ production concept that can be replicated at other sites throughout the islands to produce affordable H₂ at a price comparable to fossil fuels and in a way that the consumer cost of H₂ per kg will not vary from station to station.

In accordance with the information and analysis contained herein, to produce an initial rate of return of 4% on the H₂ fueling station, the cost at which H₂ must be sold to recuperate capital expenditures and operations and maintenance costs, following the sale of excess solar-based power and the revenue received for covered parking, is \$13.00 per kg. In this analysis, it was assumed that a single kilogram of H₂ can power a H₂ fuel cell vehicle for ~60 miles, which is a conservative estimate. Considering that gasoline-powered vehicles average

approximately 24 miles per gallon in fuel economy, a single kg of H₂ is equivalent to more than two gallons of gasoline when fuel cell energy efficiency is considered.

Beyond the economic factors, an H₂ fueling station in Honolulu, Hawaii, offers the following important benefits:

1. Supports the President's clean energy strategy to reduce greenhouse gas emission, reduce dependence on foreign oil, and place 1 million electric vehicles on the road
2. Supports both the Hawaii H₂ Initiative (H₂I) and H₂USA, the public, private partnership launched by DOE and industry in 2013 to address the challenge of H₂ infrastructure
3. Establishes Federal/General Services Administration leadership in the zero emission vehicle and fuel cell electric vehicle arena
4. Permits the leasing of fuel cell electric vehicles by General Services Administration on Oahu
5. Informs potential stakeholders that H₂ fueling stations are real and encourages the appropriation and allocation of funds for other zero emission vehicles beyond just battery electric vehicles
6. Fort Armstrong (HI0013zz) becomes the 'anchor tenant' for fuel cell vehicle growth and catalyzes development of the Oahu infrastructure toward an initial rollout of six public H₂ fueling stations
7. Sends a serious message to fuel cell electric vehicle automakers to support the growing demand for zero emission vehicles/fuel cell electric vehicles in Hawaii.

This report was funded by GSA and the Energy Departments' Office of Energy Efficiency and Renewable Energy (EERE) and prepared by engineers from Idaho National Laboratory and National Renewable Energy Laboratory, and reviewed by experts from industry, gas providers and the utility company in HI. The effort was coordinated between EERE's Fuel Cell Technologies Office and Federal Energy Management Program Office. It is recommended that the program proceed with pursuing the detailed design and implementation of an H₂ fueling station at the Fort Armstrong (HI0013zz) site in Honolulu, Hawaii.

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ACRONYMS

FCEV	fuel cell electric vehicle
GSA	General Services Administration
H ₂	hydrogen
HECO	Hawaii Electric Company
IRR	initial rate of return
NPV	net present value
O&M	operations and maintenance
PV	photovoltaic
ZEV	zero emission vehicle

Hydrogen Fueling Station in Honolulu, Hawaii Feasibility Analysis

1. INTRODUCTION

The *Department of Energy Hydrogen & Fuel Cells Program Plan* (September 2011) identifies the use of hydrogen for government and fleet electric vehicles as a key step for achieving “reduced greenhouse gas emissions; reduced oil consumption; expanded use of renewable power ...; highly efficient energy conversion; fuel flexibility ...; reduced air pollution; and highly reliable grid-support.” The plan document also set the following milestones to achieve:

- 5,000-hour (service life of vehicle or about 150,000 miles) fuel system durability
- 300-mile driving range between fueling
- Fueling rates of 1.67 kg/minute
- Fuel costs of \$2 to 4/gasoline gallon equivalent, which can equate to as high as \$6 to 12/kg for hydrogen considering the advantages in fuel economy.

The Renewable Fuel Standard, established under the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act of 2007, mandates that fuel makers meet a minimum percentage of renewable fuel production over the next several years. The Renewable Fuel Standard lays the foundation for achieving significant reductions of greenhouse gas emissions by using renewable fuels, to reduce imported petroleum, and for encouraging the development and expansion of our nation’s renewable fuels sector.

This report synthesizes several pieces of existing information that can inform a decision regarding the viability of deploying a hydrogen (H₂) fueling station at the Fort Armstrong (HI0013zz) site in Honolulu, Hawaii. The analysis documented herein is not extremely detailed, but it identifies pieces of relevant information at a level sufficient to provide a basis for decision making.

2. ASSUMPTIONS

The following assumptions were used to conduct the feasibility analysis presented herein:

1. Fleet vehicles are replaced every 5 to 7 years, depending on the type of vehicle
2. Only those fleet vehicles operated and maintained within the immediate vicinity of the H₂ fueling station are candidates for replacement under the proposed effort
3. Fleet vehicles travel approximately 25 miles per day
4. Gas-powered vehicles can travel approximately 24 miles on one gallon of gas
5. Hydrogen-fueled vehicles can travel up to 80 miles on one kilogram of H₂
6. A contractual agreement can be reached with a third-party electrical consumer (i.e., co-located federal and state office building) to sell excess solar power at \$0.30/kWh, which is equal to the General Services Administration (GSA) price for purchasing electricity from the local power utility.

3. TECHNICAL EVALUATION

This section analyzes the technical considerations of deploying an H₂ fueling station at Fort Armstrong (HI0013zz) in Honolulu, Hawaii. The analysis provides reasonable assurance that no significant factor affecting its viability has been omitted.

3.1 Vehicle Assessment

3.1.1 Federal/State

The Federal government maintains a fleet of just over 2,700 vehicles on the island of Oahu; however, not all of the vehicles are considered “preferred” for potential replacement with an H₂-fueled vehicle to be serviced by the Fort Armstrong (HI0013zz) fueling station. Table 1 shows the agencies that have government vehicles. Those agencies shown in gray are considered less preferred under this feasibility study because the agencies are located more than 2 miles away from the Fort Armstrong (HI0013zz) site and may not participate due to the inconvenience of the fueling station.

Table 1. Government agency fleet vehicles.

Agency	Vehicles in Fleet	Eligible	Potential Conversion
10 – Department of Justice	2	Y	2
12 – Department of Agriculture	64	Y	64
13 – Department of Commerce	37	Y	37
14 – Department of Interior	127	Y	127
15 – Judiciary	5	Y	5
16 – Department of Labor	24	Y	24
17 – Department of Navy	1,001	N	0
19 – Department of State	4	Y	4
20 – Department of Treasury	14	Y	14
21 – Department of Army	961	N	0
24 – Office of Personnel Management	23	Y	23
28 – Social Security Administration	1	Y	1
36 – Department of Veterans Affairs	55	Y	55
45 – Equal Emp. Opportunity	1	Y	1
47 – GSA	6	Y	6
49 – National Science Foundation	16	N	0
57 – Department of Air Force	86	N	0
68 – Environmental Protection	1	Y	1
69 – Department of Transportation	68	Y	68
70 – Department of Homeland Security	96	Y	96
73 – Small Business Administration	1	Y	1
75 – Department of Health and Human Services	5	Y	5
77 – GSA Hawaii Office	2	Y	2
80 – National Aeronautics and Space Administration	10	N	0
86 – Housing and Urban Development	1	Y	1
89 – Department of Energy	4	Y	4
96 – Corps of Engineers	56	N	0
97 – Department of Defense	54	N	0
Total	2,725		541

Table 2 shows a breakdown of the “preferred” vehicles, by type, currently in the government fleet.

Table 2. Government vehicles “preferred” for replacement.

Agency	Vehicles in Fleet	Cars	SUV/ Van	Pickup	E-car	E-Pickup	E-SUV	UNK
10 – Department of Justice	2	1	1	0	0	0	0	0
12 – Department of Agriculture	64	22	28	10	3	1	0	0
13 – Department of Commerce	37	2	15	16	0	0	1	3
14 – Department of Interior	127	13	36	72	3	0	2	1
15 – Judiciary	5	2	3	0	0	0	0	0
16 – Department of Labor	24	5	5	4	2	0	0	8
19 – Department of State	4	1	3	0	0	0	0	0
20 – Department of Treasury	14	9	4	0	0	0	0	1
24 – Office of Personnel Management	23	23	0	0	0	0	0	0
28 – Social Security Administration	1	1	0	0	0	0	0	0
36 – Department of Veterans Affairs	55	21	21	6	4	0	0	3
45 – Equal Emp. Opportunity	1	1	0	0	0	0	0	0
47 – General Services Administration	6	0	0	1	4	0	1	0
68 – Environmental Protection	1	1	0	0	0	0	0	0
69 – Department of Transportation	68	9	28	25	3	0	3	0
70 – Department of Homeland Security	96	12	45	36	1	0	0	2
73 – Small Business Administration	1	1	0	0	0	0	0	0
75 – Department of Health and Human Services	5	0	3	0	2	0	0	0
77 – GSA Hawaii Office	2	2	0	0	0	0	0	0
86 – Housing and Urban Development	1	0	1	0	0	0	0	0
89 – Department of Energy	4	0	0	2	0	1	1	0
Total	541	126	193	172	22	2	8	18

Assuming that all existing electrical and gas-powered “cars” (see columns “Cars” and “E-cars”) could be transitioned easily to H₂-powered “cars,” a minimum of 148 vehicles would need hydrogen to be provided by the proposed H₂ fueling station. Based on the presumed average distance of 25 miles per day, or about 0.4 to 0.5 kilograms of H₂ per day, the fueling station would need to produce 75 to 80 kg of H₂ each day to meet this demand. The amount of H₂ that can be produced at Fort Armstrong (HI0013zz) will be limited to the size of the site and may not be able to produce the H₂ to satisfy the demand if all 148 vehicles. The following sections provide the necessary information to determine how much H₂ can be produced at the Fort Armstrong (HI0013zz) site; this information also indicates the potential for future growth opportunities.

3.1.2 Commercial/Private

Public transportation (such as busses) is another possible user for the H₂ fueling station. A bus can consume between 25 to 35 kg of H₂ per day; therefore, they would cause greater demand on the H₂ production infrastructure.

It is assumed that the demand for H₂ production for non-GSA fleet vehicles or private vehicles could be accommodated as the H₂ infrastructure expands. For this feasibility study, it is assumed that a private vehicle and a government vehicle would be driven similar distances with the same demands. The calculations described in the following sections determine the amount of H₂ that can be produced at the Fort Armstrong (HI0013zz) site, thus projecting the number of private and government vehicles that feasibly can be accommodated.

3.2 Onsite Power Generation

Onsite power generation using renewable energy is the most preferred mechanism for H₂ production. Solar is an obvious option; however, the team also investigated the potential use of steam methane reforming and shipping H₂ from the main land. Both the steam methane reforming and shipping options were shown to be very expensive and unfeasible for the fueling station. This leaves two options for providing electricity for operation of the H₂ fueling station: (1) electrical power produced by a photovoltaic (PV) solar array or (2) electrical power purchased from Hawaiian Electric Company (HECO). It is assumed that electrical power will be required at all times, with a near constant load demand because the intent is to produce H₂ continuously. This section investigates the options of both a direct grid tie and a partnership with an assumed adjacent third-party consumer, where excess power produced by the PV array can be sold for a higher price than the price offered to sell excess power back to HECO.

3.2.1 Electricity

There is only one electric company on Oahu – HECO. HECO has six separate billing rates that are based on the “category” of customer purchasing the electricity. Electricity rates vary by category because they are based on the cost of serving each customer need. There are no adjustments for peak or off-peak usage. Average costs are calculated by dividing the total revenue by the total kWh sold for each category during the year. Average rates for each category are shown in Table 3.

Table 3. Average 2012 electricity rates for Honolulu, Hawaii.

Rate Schedule	2012 Average Cost per kWh
Residential	\$0.351
“G” Small Power Use Business	\$0.365
“J” Medium Power Use Business	\$0.317
“P” Large Power Use Business	\$0.301
“DS” Large Power Use Business, Directly Served	\$0.280
“F” Street and Park Lighting	\$0.329

According to the HECO website (www.hawaiianelectric.com), the high cost of fossil fuel used to produce electricity accounts for more than 50% of the purchase price. During 2012, fuel costs increased, resulting in a corresponding increase in the cost of electricity for the customer. Because electricity rates depend on a constantly variable fuel charge, it is nearly impossible to predict future costs; the cost follows the “spot” cost of oil.

The isolated geographic location of the Hawaiian Islands also contributes to the higher cost of electricity, because Hawaii does not have any nearby utility companies from which to draw power in the event of a problem. For system reliability, Hawaii must have reserve generating capacity and multiple distribution routes. Electricity rates include the revenue necessary to cover those costs.

The electrical power needed to operate the proposed H₂ fueling station can be purchased from HECO at a contracted GSA rate of \$0.30 per kWh, similar to the price paid by Large Power Use Businesses (see Table 3). Approximately 1,300 MWh of electricity is required per year to operate the electrolyzer. Of that, 600 MWh are provided directly from the PV panels during the day, and 700 MWh are provided by the grid during the night. The PV panels over-produce electricity by 680 MWh per year, this electricity can be used as cost avoidance for the fueling station if sold to federal facilities or 3rd party in the vicinity and then purchased back from the grid during the night. Considering the overall use the electrolyzer operates in a net-zero manner, as it uses direct solar electrons, and at night it uses time-shifted electrons via grid sales and buy backs. The proposed Fort Armstrong station does not use much net electricity from the grid; therefore the price of oil will not be a large impact to the project. In fact if

oil becomes more expensive, hydrogen could be sold at a higher price per kilogram, thus benefitting the project.

3.2.2 Solar

An important component of this feasibility study is the generation of H₂ using electricity produced by an array of PV solar cells. Hawaii is located near the equator and experiences approximately 274 sunny days a year. This fact alone makes PV solar power a viable option for providing electricity to the H₂ fueling station. Assuming that the majority of the primary parking area at the Fort Armstrong (HI0013zz) site (approximately 1.4 acres) is available and could be used for covered parking with roof-mounted PV solar panels, the resulting array would yield about 700 kW of usable electric power. A conceptual view of this can be found in Section 3.3.1.

However, two notable short-comings limit the potential use of solar power at the fueling station: (1) solar power can only be accessed during daylight hours, and (2) the size of the lot limits the amount of H₂ that can be produced given the energy production potential of the resulting 1.4-acre PV solar array. Grid-based electricity also will be incorporated into the design to facilitate 24-hour H₂ production and to meet the additional electrical demands of the station. The photovoltaic (PV) array is rated at 700 kW, and the electrolyzer capacity is 187 kW. If the electrolyzer is working at full power and the solar is at full output, 513 kW of access power would be produced. The worst case would be if H₂ storage is full (i.e., electrolyzer is off), while the PV is producing 700 kW, that would be offloaded to the grid. Rather than sell the excess power back to HECO at a reduced rate of \$0.20/kWh to turn around and buy the same power back at night at a higher rate, it is assumed that an adjacent consumer facility would be available and willing to establish a partnership to buy the excess PV power for the same or lower price that they are buying power from HECO (i.e., \$0.30/kWh). By making this arrangement with an adjacent facility, the H₂ fueling station would sell about 683,000 kWh of power to the consumer facility, while buying that same amount of power back to operate the electrolyzer during the night. This would save the station about \$86,300 per year (given the exchange rate with HECO), while not costing the adjacent consumer facility anything^a.

The impact of installing a PV solar array on the cost of the fueling station is significant; however, it is an environmentally friendly alternative that will reduce dependence on fossil fuel. Integration of PV solar technology will also increase the public's perception of renewable H₂ production as a viable alternative to traditional H₂ production, entice local government entities, and help garner the political support of environmentally sensitive federal agencies.

3.3 H₂ Station Design (Conceptual)

A 1.4-acre parking lot and adjacent land area at Fort Armstrong (HI0013zz) has been identified as the preferred site for the proposed H₂ fueling station in Honolulu, Hawaii (see Figure 1). Fort Armstrong (HI0013zz) is adjacent to Ala Moana Boulevard (i.e., the main route to Waikiki), downtown Honolulu, Honolulu International Airport, and almost all state and local government offices. This includes the Offices of State Judges, State Senators and Representatives, most State Agencies, the Governor's Office, the U.S. Postal Service, and the Prince Jonah Kuhio Kalaniana'ole Federal Building, which houses the U.S. District Court for the State of Hawaii; the Offices of Federal Judges, U.S. Senators and Representatives; and the Branch Offices of numerous Federal Agencies. Ala Moana Boulevard is also near the bus parking lot and is a main route for tourist buses, trolleys, and taxis. This site is ideal for both paid parking to offset the cost of H₂ and for providing maximum public exposure to an all renewable H₂ fueling station.

^a This approach will require an interconnect requirements study



Figure 1. Fort Armstrong site illustrations.

3.3.1 High-Level Station Configuration (Conceptual)

As noted above, the H₂ fueling station will be powered by a combination of a roof-mounted fix-tilt PV solar array and an integrated connection to the Hawaii electrical grid. To facilitate the use of PV solar technology to produce H₂, the project proposes utilizing the unused space of the nearly 1.4-acre lot at Fort Armstrong (HI0013zz) for publically accessible covered parking. Covered parking would allow continued use of the lot for premium parking, while still providing the solar footprint needed to produce the H₂. It is estimated that the resulting structure could produce approximately 1,288 MWh of electricity per year as a power source for the fueling station, while also serving as a potential revenue source (i.e., paid parking structure) to recover capital and operating expenses.

A 1.4-acre PV solar field producing about 700 kW peak power per day can sustain an electrolyzer that is capable of producing roughly 65 kg of H₂ per day. With this conceptual design, the PV solar array will produce enough power during the day to continually operate the electrolyzer. As noted above, the intent is to tie the PV solar array to the grid and to one or more nearby, third-party electricity consumers (most likely a co-located Federal building). This would be done so that when excess power is produced, it can be sold to a third-party at the same rate it would cost them to purchase power from the utility, then the H₂ fueling station can repurchase the electricity from HECO (as needed) during non-sunlight hours. This approach allows the H₂ fueling station to use the third-party consumer and the grid as an energy storage device.

The envisioned station itself is expected to be similar to other established H₂ fueling stations and will occupy a very small fraction of the Fort Armstrong (HI0013zz) site beneath the PV solar array. The station consists of power electronics that receive and modulate electricity from the PV solar array and provide it to the electrolyzer. Potable water is assumed to be available onsite and will be piped to the electrolyzer, where it is first purified then separated using electrolysis into hydrogen and oxygen gas. The hydrogen stream is fed to a series of hydrogen bulk storage tanks, which, in turn, feed a refueling pump that is used to fill H₂-powered vehicles. The oxygen stream is vented to the atmosphere as a harmless gas. With a 65-kg per day electrolyzer and an average demand of 80% utilization, the refueling station could support roughly 85 to 100 vehicles, assuming they burn between 0.5 and 0.6 kg of H₂ per day. Figure 2 provides a high-level schematic of the envisioned facility.

No water storage is required onsite because it is assumed the water utility is accessible and has sufficient storage. The system can consume potable water and will consume about 45,000 gallons of water per year and according to the board of water supply website (www.hbws.org/cssweb) the cost water is \$4.95 per 1,000 gallons. This equates to about \$225 in water cost per year and is therefore negligible at this point.

This concept of a fueling station is intended to be designed as an autonomous fueling station in order to minimize the cost of personnel to man the station. An operation and maintenance contract will be required to ensure continued operation but there will not be an attendant at the location once sufficient training is completed. The cost of this training is incorporated into the annual O&M costs.

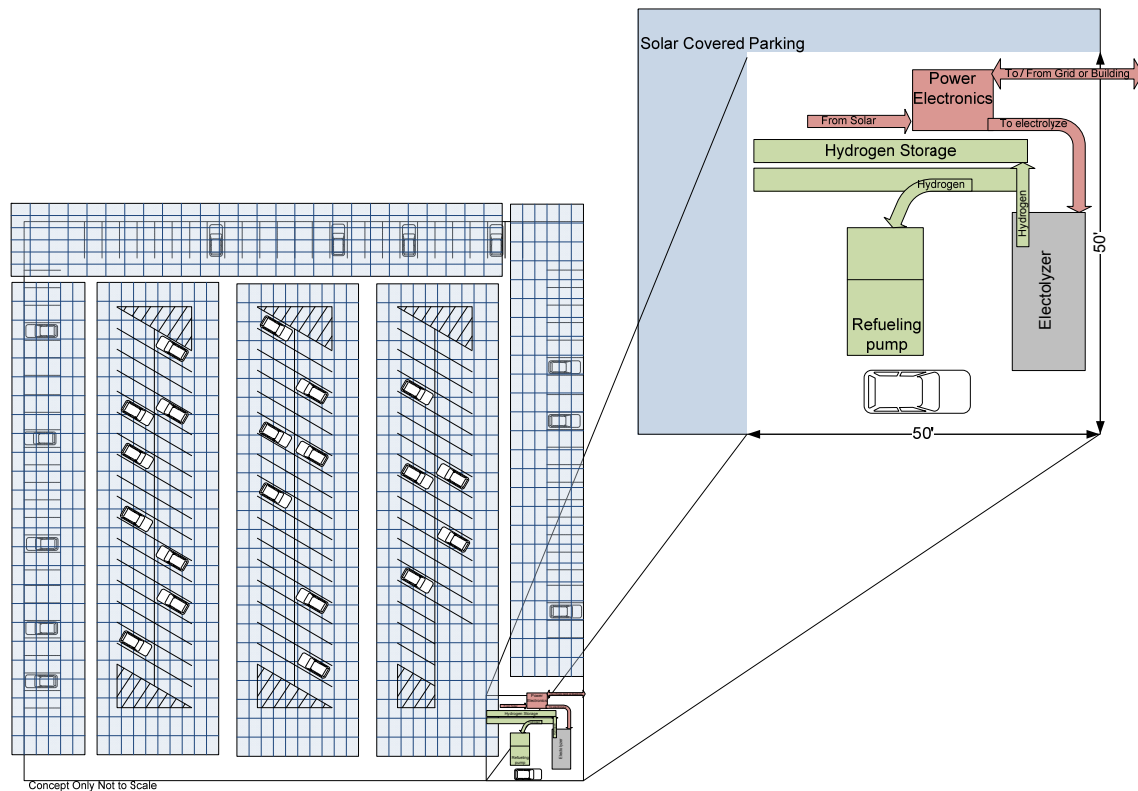


Figure 2. High-level schematic of the proposed H₂ fueling station.

This facility is intended to be a flagship-type installation, setting the example and establishing a renewable H₂ infrastructure in Hawaii for other government and private entities to follow. The objective is to establish an H₂ production concept that can be replicated at other sites throughout the islands to produce affordable H₂ at a price comparable to fossil fuels and in a way that the cost of H₂ will not vary from station to station.

3.3.2 Equipment Needs and Commercial Availability

Simply constructed, the H₂ production, storage, and fueling facility will consist of the following:

1. A 1.4-acre covered parking lot
2. A 700-kW capacity array of roof-mounted fixed tilt PV solar panels over the Fort Armstrong (HI0013zz) parking lot, with integrated connections to the H₂ production capability and to the HECO electrical grid
3. A polymer electrolyte membrane electrolyzer capable of generating up to 65 kg of H₂ per day
4. One or more 70-kg H₂ storage tanks, including all necessary piping to move H₂ from the electrolyzer to the tanks and from the tanks to the dispensing station
5. Hydrogen compressor to move H₂ from the electrolyzer to the bulk H₂ storage tanks

6. A single, dual-pressure, fast-fill dispenser with chiller capable of dispensing H₂ at 350 and 700 bar pressure (provisions will also be made for additional future pump(s) as demand increases).

All required equipment is commercially available, can be easily procured, and installed within a lead time of one calendar year.

4. ECONOMIC EVALUATION

4.1 Capital Equipment and Facility Development Costs

The necessary equipment identified in Section 3.3.2 constitutes the capital equipment needed to build the H₂ fueling station. Capital expenses are calculated based on the cost required to produce a single kW of power. For the PV solar panels, that is \$4,000 per kW at a capacity of 700 kW for a total capital cost of **\$3,150,000**. For the electrolyzer, that is \$3,500 per kW at a capacity of 187 kW for a total capital cost of **\$655,000**. The other identified pieces of equipment are at their net present purchase price (shown in Table 4). Total capital equipment and facility development costs are estimated at **\$4,920,000**.

Table 4. Estimated capital equipment costs.

Capital Equipment	Estimated Cost
Solar panels	\$3,150,000
Electrolyzer	\$655,000
Storage	\$70,000
Dispenser + chiller	\$350,000
Compressor	\$300,000
Installation & Permitting	\$370,000
Parking meter	\$25,000
Total capital	\$4,920,000

4.2 Operations and Maintenance Costs

Operations and Maintenance (O&M) costs for the H₂ fueling station are calculated as the total estimated annual maintenance costs for each piece of capital equipment. As shown in Table 5, annual O&M costs are estimated at \$150,000 per year.

Table 5. Estimated operations and maintenance costs.

Capital Equipment	Estimated O&M Cost
Solar panels	\$21,000
Electrolyzer	\$32,700
Storage	\$700
Dispenser & chiller	\$17,500
Compressor	\$15,000
Parking meter	\$5,000
Training & Operation Labor	\$58,100
Total capital	\$150,000

4.3 Parking Analysis

The location of the Fort Armstrong (HI0013zz) lot is ideal for paid parking, especially with the current concept of covered parking in Oahu that can be sold for a premium. It is presumed that a parking

lot of 1.4 acres can provide 175 stalls that could be made available for parking. It is estimated that a \$0.50/hour rate with a maximum of \$6/day would be a reasonable price to pay for such parking. Currently, there is no covered parking at the Fort Armstrong (HI0013zz) site; however, Prince Jonah Kuhio Kalanianaʻole covered parking is sold for \$2,760 per year (*i.e.*, a prorated price of \$7.56 per day rate). For this analysis, it is presumed that revenue generated with the parking would go to the project net present value (NPV) and the initial rate of return (IRR). Figure 3 shows the NPV and IRR based on the percentage of stalls occupied per year.

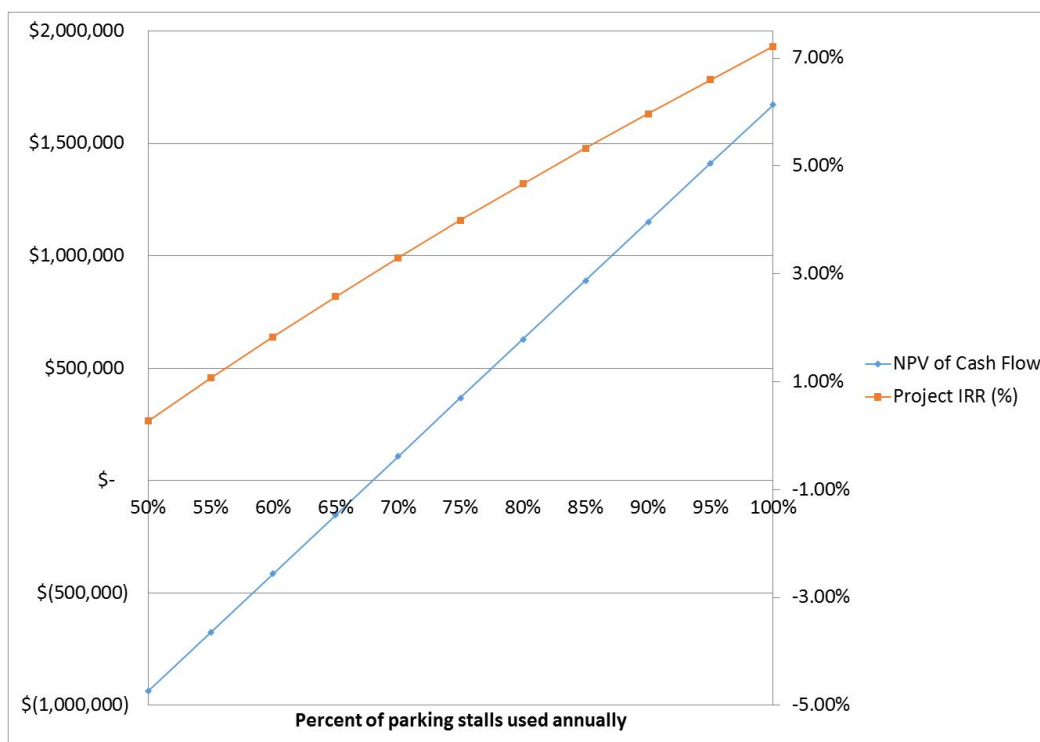


Figure 3. Estimated net present value and initial rate of return versus the percentage of annual parking stalls used.

4.4 Income and Expenditure Projections (15 years)

Expenditure projections for the H₂ fueling station consist of three items: (1) up-front capital equipment costs (\$4,920,000; see Table 4), (2) O&M costs (\$150,000/year; see Table 5), and (3) the cost of purchasing electricity from HECO for H₂ production, escalated over a 15-year period. The amount of energy needed to produce 1 kg of H₂ is estimated at about 70 kWh/kg. The station will not be fully utilized during the first year, but it is expected that the demand for H₂ would ramp up as more vehicles begin to fuel at this location. The demand is projected to reach 52 kg/day (18,980 kg/year) and require 1,300 MWh of electricity. This is the same amount of power available from the 700-kW solar array, which yields 1,300 MWh/year. To minimize capital expense, a 190-kW electrolyzer system will be used instead of a 700-kW electrolyzer. This system operates directly from solar power during the day, with the remaining power (*i.e.*, 680 MWh) supply generated by the solar array being used by an adjacent facility. At this facility, the solar power displaces energy use at a cost of \$0.30/kWh, yielding a revenue of \$200,000 annually, assuming 2% escalation (see Appendix A for the cash flow calculation). The 190-kW electrolyzer will operate continuously, and at night, would consume 700 MWh from the grid at a cost of 30¢/kWh, yielding an expense of \$211,000 per year. The system effectively is a net-zero grid power consumer because it overproduces the same amount of daytime energy that it consumes at night. The

revenue from electricity sales matches the expense from grid electricity purchases throughout the year. Total anticipated expenditures over a 15-year period are shown in Table 6.

Income to the project comes from three sources: (1) the sale of excess, solar-based electricity to a third-party electricity consumer at the same price they would pay to buy electricity from HECO, (2) the sale of H₂ to government and public consumers, and (3) premium covered parking. The third-party consumer is anticipated to purchase about 683,000 kWh of solar-based electricity per year to meet facility needs. At the HECO equivalent price of \$0.30 per kWh, this equates to a revenue of \$204,900 once the fueling station is at capacity, with an expected annual revenue increase of 2% each year thereafter for a total of about \$6,684,219 in net cash flow after 15 years. Electricity demand profiles indicate that the excess electricity that could be sold to the grid at \$0.197 per kWh is negligible (i.e., on the order of less than 10 kW/year) -- thus it is an immaterial source of potential income. Assuming that 75% of the lot is full on a continuous basis, premium covered parking will produce \$287,438 annually for a 15-year total of \$4,311,563. The sale of H₂ accounts for the remaining revenue. The estimated sale price of H₂ is addressed in Section 4.5, with the total anticipated revenue and net cash flow from all sources over a 15-year period being shown in Table 7. It is anticipated that the sales of H₂ will increase each year for the first 2 years, showing the transition from gasoline-powered vehicles to fuel cell electric vehicles (FCEVs). It is worth noting that the net cash flow decreases as H₂ sales ramp up. This is because, per kWh of solar power, it is more profitable to sell electrons directly than to produce and sell H₂.

Table 8 is for reference and is used to support the expenditure and income tables; it also shows the assumed energy flow for each year.

4.5 Price Point of H₂

The price point of H₂ for this study is \$13.00/kg. That cost is based upon a comparable price of gasoline for same amount of miles driven. Both the NPV and IRR are sensible at this price point as well. It represents a reasonable cost at which H₂ must be sold to recuperate both capital expenditures and O&M costs following the sale of solar-based power to the grid and the revenue received for parking. Total capital expenses and remaining net O&M costs are calculated considering the Federal Guidance discount rate of 3% over a 15 year period. Given the anticipated expenditures and revenues (shown in Tables 6 and 7), the desire to make the sale of H₂ a profitable business alternative seems to be achievable.

Table 6. Total anticipated expenditures (U.S. dollars).

Source	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12	Yr 13	Yr 14	Yr 15
Grid to H ₂	-	\$51,992	\$114,842	\$219,603	\$223,995	\$228,475	\$233,045	\$237,706	\$242,460	\$247,309	\$252,255	\$257,300	\$262,446	\$267,695	\$273,049	\$278,510
Cost of Maintenance	-	\$150,000	\$153,000	\$156,060	\$159,181	\$162,365	\$165,612	\$168,924	\$172,303	\$175,749	\$179,264	\$182,849	\$186,506	\$190,236	\$194,041	\$197,922
Equipment Expense	\$4,919,063	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-	\$-
Total Expenditures	\$4,919,063	\$201,992	\$267,842	\$375,663	\$383,176	\$390,840	\$398,657	\$406,630	\$414,763	\$423,058	\$431,519	\$440,149	\$448,952	\$457,931	\$467,090	\$476,432

Table 7. Total anticipated income (U.S. dollars).

Source	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12	Yr 13	Yr 14	Yr 15
H ₂ Sales	-	\$82,247	\$167,783	\$256,708	\$261,842	\$267,079	\$272,421	\$277,869	\$283,427	\$289,095	\$294,877	\$300,775	\$306,790	\$312,926	\$319,184	\$325,568
Parking	-	\$287,438	\$293,186	\$299,050	\$305,031	\$311,132	\$317,354	\$323,701	\$330,175	\$336,779	\$343,514	\$350,385	\$357,392	\$364,540	\$371,831	\$379,268
PV to 3 rd Party	\$-	\$307,392	\$241,998	\$213,207	\$217,471	\$221,821	\$226,257	\$230,782	\$235,398	\$240,106	\$244,908	\$249,806	\$254,802	\$259,898	\$265,096	\$270,398
Total Revenues	\$-	\$677,077	\$702,967	\$768,965	\$784,344	\$800,032	\$816,032	\$832,352	\$849,000	\$865,980	\$883,299	\$900,966	\$918,984	\$937,364	\$956,111	\$975,234
Net Cash Flows	\$ (4,919,063)	\$475,085	\$435,125	\$393,302	\$401,168	\$409,192	\$417,375	\$425,722	\$434,237	\$442,922	\$451,780	\$460,817	\$470,032	\$479,433	\$489,021	\$498,802

Table 8. Analysis of H₂ fueling station (reference).

Analysis/Year	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12	Yr 13	Yr 14	Yr 15
Price of hydrogen (\$/kg)	12.75	13.00	13.26	13.53	13.80	14.07	14.35	14.64	14.93	15.23	15.54	15.85	16.16	16.49	16.82	17.15
Price of electricity to grid (\$/kWh)	0.193	0.197	0.201	0.205	0.209	0.213	0.218	0.222	0.226	0.231	0.235	0.240	0.245	0.250	0.255	0.260
Price of electricity to building (\$/kWh)	0.294	0.300	0.306	0.312	0.318	0.325	0.331	0.338	0.345	0.351	0.359	0.366	0.373	0.380	0.388	0.396
Hydrogen sales (kg/day)	-	17	35	52	52	52	52	52	52	52	52	52	52	52	52	52
Hydrogen sales (kg/year)	-	6,327	12,653	18,980	18,980	18,980	18,980	18,980	18,980	18,980	18,980	18,980	18,980	18,980	18,980	18,980
PV output (kWh/year)	-	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678	1,288,678
PV to electrolyzer (kWh/year)	-	263,220	497,756	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576
PV to 3 rd party (kWh/year)	-	1,024,641	790,843	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093
H ₂ production (kg/year)	-	436,528	873,056	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162	1,309,162
H ₂ from PV (kg/year)	-	263,220	497,756	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576	605,576
H ₂ from grid (kg/year)	-	173,308	375,299	703,586	703,586	703,586	703,586	703,586	703,586	703,586	703,586	703,586	703,586	703,586	703,586	703,586
Net grid power (kWh/year)	-	7,907,850	8,344,378	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484	8,780,484
Electricity from grid (kWh/year)	-	7,908,667	8,344,456	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492	8,780,492
Building demand (kWh/year)	-	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000	8,760,000
PV to building (kWh/year)	-	1,024,641	790,843	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093	683,093
Grid to building	-	7,735,359	7,969,157	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907	8,076,907

Figure 4 illustrates the relationship between the NPV and the IRR on the y-axis and the percent of parking occupancy on the x-axis, while holding the cost of H₂ constant at \$13.00/kg. The NPV is \$370,000 and the IRR is 4%. It is presumed that the parking will be at a 75% occupancy rate. Additionally, the NPV and the IRR are highly dependent on the parking revenue. Therefore, when parking occupancy rises, the NPV and IRR become more attractive.

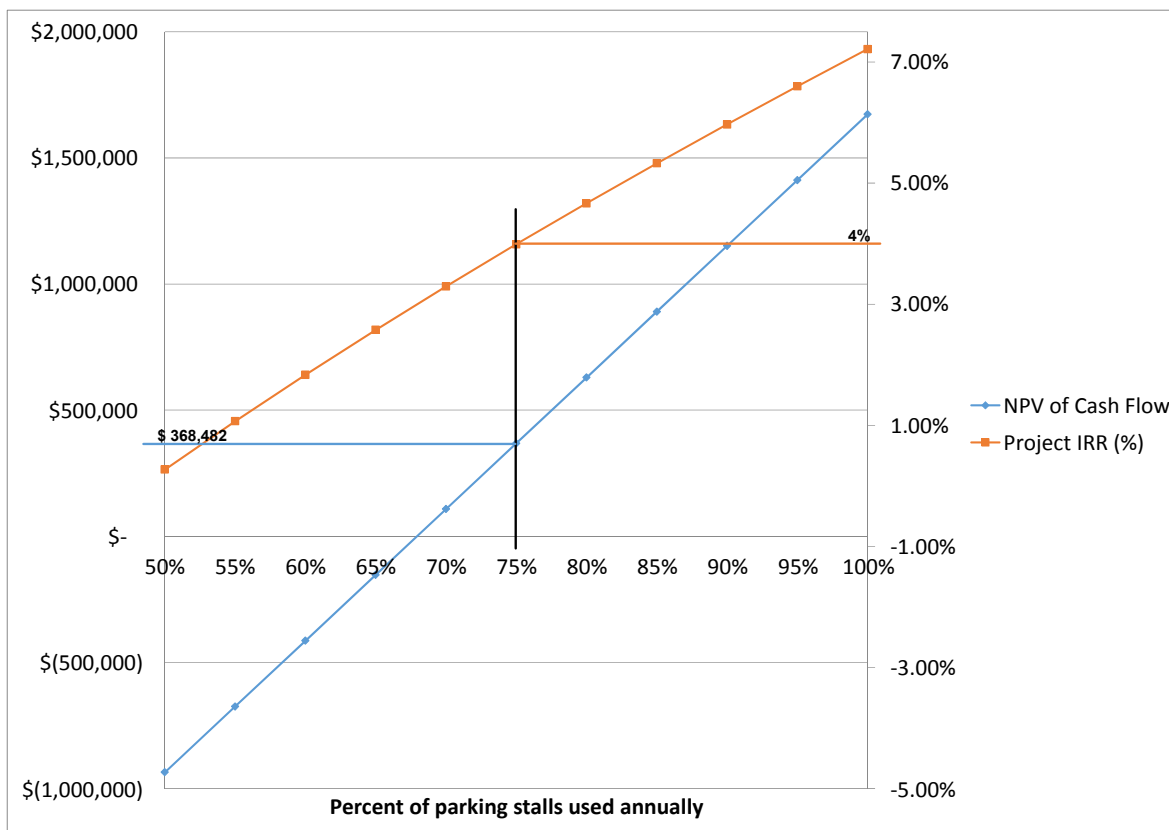


Figure 4. The net present value and initial rate of return for 75% parking occupancy.

4.6 Anticipated Cost to Customer

As discussed in Section 4.5, the anticipated cost to the customer for H₂ produced at the proposed H₂ fueling station at Fort Armstrong (HI0013zz) is \$13.00/kg. A single kg of H₂ will power an H₂ fuel cell vehicle approximately 80 miles. Considering that gas-powered cars average approximately 24 miles per gallon in fuel economy, a single kg of H₂ is roughly equivalent to 3.3 gallons of gasoline. The current average price of unleaded gasoline in Honolulu, Hawaii is about \$4.35/gallon (HonoluluGasPrices.com, 2014). At \$13.00/kg, H₂ has a gasoline gallon equivalent price of \$3.90 per gallon. This makes filling a vehicle with H₂ slightly less expensive than traditional gasoline under the fueling station concept and configuration presented herein. This type of savings can encourage consumers to purchase and drive H₂ powered vehicles.

4.7 Additional Non-Economic Benefits

Beyond the economic factors associated with H₂ production and distribution, an H₂ fueling station in Honolulu, Hawaii, offers the following important benefits:

1. Supports the President's clean energy strategy to reduce greenhouse gas emissions, reduce dependence on foreign oil, and place 1 million electric vehicles on the road

2. Supports the State of Hawaii Hydrogen Roadmap (2011)
3. Supports both the Hawaii H₂ Initiative (H₂I) and H₂USA, the public, private partnership (PPP) launched by DOE and industry in 2013 to address the challenge of H₂ infrastructure
4. Establishes federal/GSA leadership in the zero emission vehicle (ZEV) and FCEV arena
5. Permits the leasing of FCEVs by GSA on Oahu
6. Informs potential stakeholders that H₂ fueling stations are real and encourages the appropriation and allocation of funds for other ZEVs beyond just battery electric vehicles
7. Fort Armstrong (HI0013zz) becomes the ‘anchor tenant’ for fuel cell vehicle growth and catalyzes development of the Oahu infrastructure toward an initial rollout of six public H₂ fueling stations
8. Sends a serious message to FCEV automakers to support the growing demand for ZEVs/FCEVs in Hawaii.

5. CONCLUSION/RECOMMENDED PATH FORWARD

It is recommended that the program pursue the detailed design and implementation of an H₂ fueling station at the Fort Armstrong (HI0013zz) site in Honolulu, Hawaii.

5.1 Further Analyses Needed

Further analysis is needed before going into the detailed design of the H₂ fueling station. The following is a list of topics that need further analysis:

- Coordinate with HECO to ensure the grid tie with the PV solar array is acceptable
- Study the options and possibility of partnering with an adjacent Federal facility to determine if that assumption is accurate
- Validate the other assumptions used in this assessment
- Further analyze the rollout and demand for H₂ vehicles, including partnering with vehicle manufacturers
- Further analyze cost information by talking to equipment suppliers
- Study options for required permitting.

5.2 Project Schedule (Notional)

Table 9 shows a preliminary and notional schedule for the detailed design and construction of an H₂ fueling station at the Fort Armstrong (HI0013zz) site in Honolulu, Hawaii.

Table 9. Preliminary schedule.

Project Schedule	FY 2014		FY 2015				FY 2016				FY 2017			
Tasks	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Planning														
Design														
Siting														
Solar Design														
Electrical Design														
H ₂ System Design														
Preliminary Design														
Final Design														
Procurement														
Construction														
Parking Lot Construction														
Solar Construction														
Electrical Construction														
H ₂ System Construction														
System Integration														
Estimated Substantial Completion														
Turn Over – Final Completion														
Operation														

Appendix A

Financial Analysis of an H₂ Fueling Station at Fort Armstrong (HI0013zz)

This appendix discusses the analysis steps taken to assess the anticipated financial performance of a renewable H₂ fueling station at Fort Armstrong (HI0013zz). The analysis performs the following general steps:

- Time-of-day data incorporation (i.e., fueling demand, solar demand, and building load demand)
- Equipment sizing (i.e., solar panels, electrolyzer, and hydrogen storage)
- Multi-year hourly energy analysis (i.e., accounts for demand ramp-up over time)
- Revenue and expenses tracking
- Multi-year financial analysis.

Analysis for this project requires consideration of the time dependence of the solar resource and fueling demand. For this reason, a detailed model was produced to account for not only financial performance, but to ensure that time dependencies are addressed. Fueling demand for light-duty vehicles is dependent on time of day. The analysis model used Chevron's fueling stations demand profiles to forecast H₂ demand over time. The resulting profile is found in Figure 5 as follows:

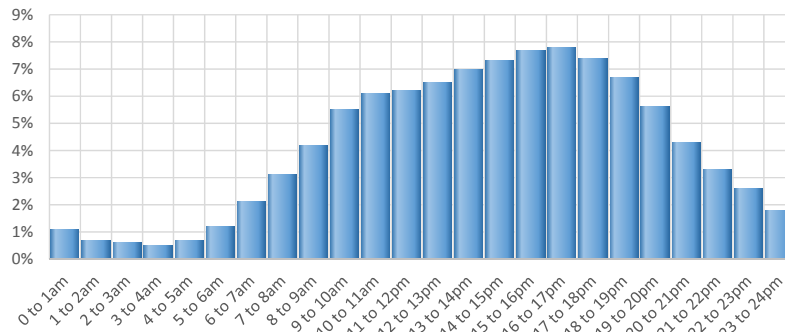


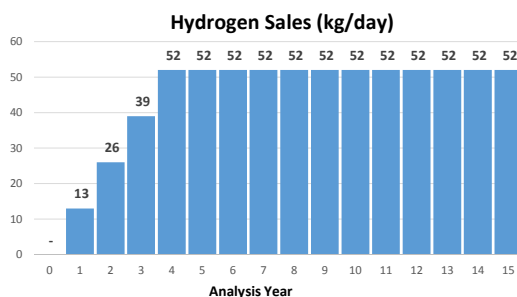
Figure 5: Hourly Demand as Fraction of Daily Hydrogen Demand

As shown, most of fueling would be expected between 4 and 5 pm each day, with very little fueling after 10 pm. The profile is repeated each day of the week throughout the year, and also includes variation due to weekly fueling behavior differences, as follows:

Sunday	101%
Monday	94%
Tuesday	96%
Wednesday	100%
Thursday	105%
Friday	108%
Saturday	96%

These projections indicate that most fueling occurs on Fridays, although the analysis includes consideration for a larger H₂ buffer (in case of production equipment outage) or extended times of elevated H₂ demand due to special events (such as nearby station outage or traffic abnormalities).

Considering the site constraints described below, the site was estimated to be able to support a total of 65 kg/day of H₂ production (where 1 kg is equivalent to the energy content of 1 gallon of gasoline). Utilization of H₂ was assumed to ramp up to full capacity over the first 3 years of operation, with a maximum anticipated utilization of 80% (52 kg/day).



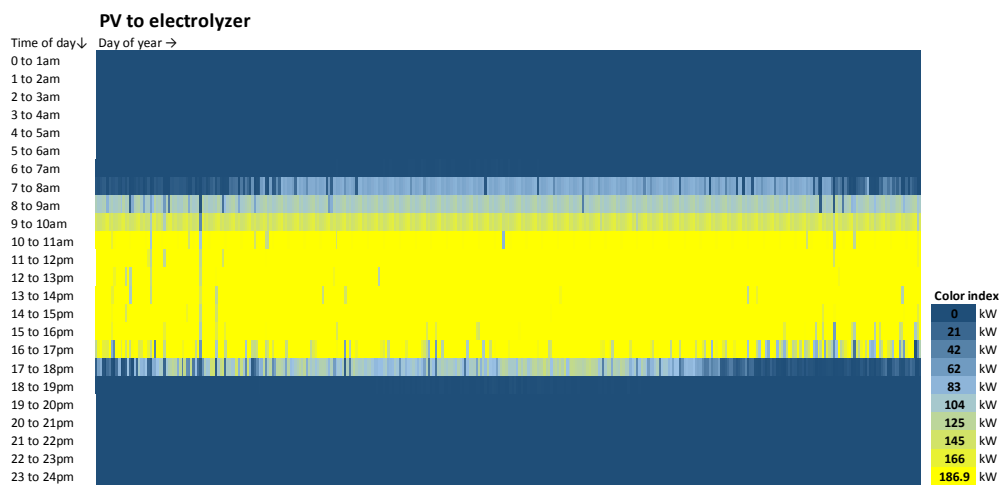
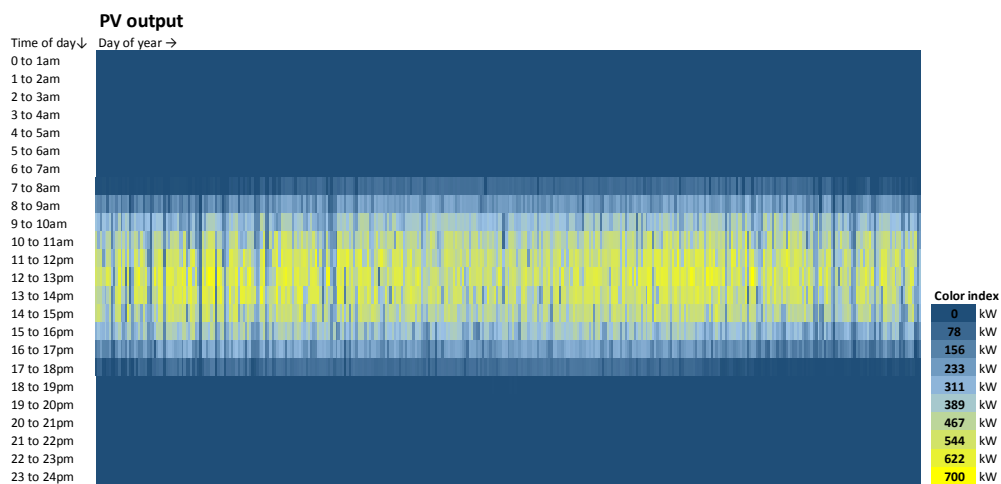
Because the station relies on solar energy for H₂ production, data for solar availability was acquired from a weather station at the Honolulu Airport, which is representative of solar availability for this adjacent location. The analysis evaluated fixed-mount panels and single-axis tracking panels. While the tracking system resulted in better electricity production efficiency, it also resulted in less production for the Fort Armstrong (HI0013zz) site. This is due to a higher installation density of fixed panels because they do not shade each other in the mornings and evenings. With the footprint limits of the site, 700 kW of solar installation was deemed possible. Alternatively, a single-axis tracking system would have yielded only 290 kW of power for the site and would not have been feasible for a covered parking installation (thus eliminating the potential for parking revenue).

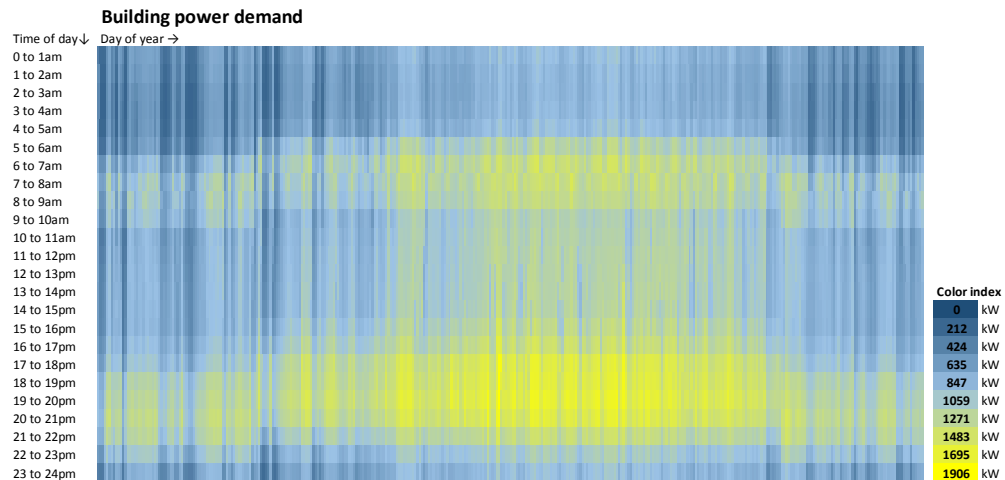
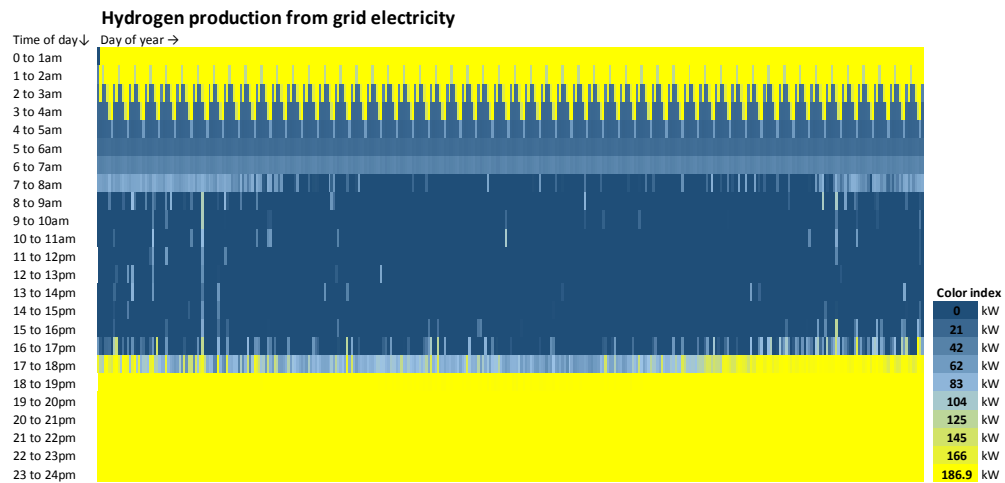
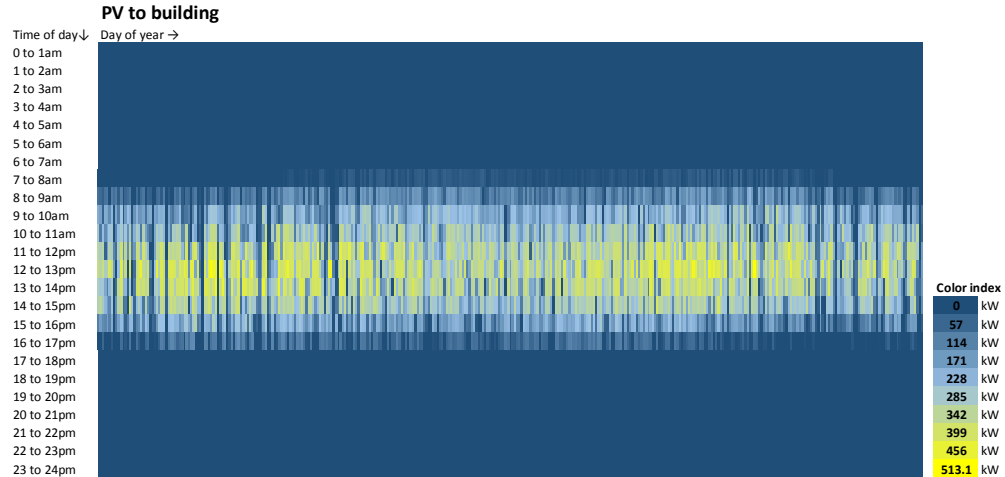
At times, the solar power exceeds the electrolyzer energy demand and at other times is not sufficient. When solar availability exceeds H₂ production requirements, electricity is exported from the site. When electrolyzer demand exceeds solar availability, electricity is purchased from the grid. However, excess electricity cannot be sold back to the grid at the retail rate. Commercial grid electricity costs \$0.30/kWh, but selling back to the grid yields only \$0.20/kWh (according to net metering arrangements established by HECO). To improve the value of excess electricity, this project will pursue a power sharing arrangement with a neighboring facility (possibly a Federal facility). Instead of selling excess electricity to the grid for a reduced price, the power would be used to displace grid purchases by a neighboring building, thus yielding \$0.30/kWh of avoided costs.

For analysis purposes, a 1,000-kW average demand building load was assumed, with an hourly demand profile consistent for an office building in the appropriate climate type. Hourly energy analysis was performed for each year of the project. The following are examples of analysis outputs for key energy flows, because they vary throughout one analysis year.

Capital cost estimates were made for each system component, as shown in the following table. The component cost estimates reflect recent costs communicated to the National Renewable Energy Laboratory from field installations and maintenance costs experienced by those installations.

	Capital costs		O&M	
Solar pannels	\$	3,150,000	\$	21,000 \$/year
Electrolyzer	\$	3,500	\$/kW	
Electrolyzer	\$	654,063	\$	32,699 \$/year
Storage	\$	70,000	\$	700 \$/year
Dispenser + chiller	\$	350,000	\$	17,500 \$/year
Compressor	\$	300,000	\$	15,000 \$/year
Installation & permitting	\$	370,000	\$	58,101 \$/year
Parking Meter	\$	25,000	\$	5,000 \$/year
Total capital	\$	4,919,063	\$	150,000 \$/year





Revenues and expenses were quantified for each project analysis year. Parking revenues were estimated by assuming that, on average, the parking would be 75% occupied for 12 hours per day at a rate of \$0.50/hour for any of its 175 parking spots. This results in an annual income from parking fees of \$287,000. Hydrogen would be sold for \$13/kg, which is roughly equivalent to \$3.90/gallon of gasoline fuel cost.

Analysis year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenues																
Hydrogen sales	-	82,247	167,783	256,708	261,842	267,079	272,421	277,869	283,427	289,095	294,877	300,775	306,790	312,926	319,184	325,568
PV to grid	-	161	16	2	2	2	2	2	2	2	2	2	2	2	2	2
Parking	-	287,438	293,186	299,050	305,031	311,132	317,354	323,701	330,175	336,779	343,514	350,385	357,392	364,540	371,831	379,268
Pv to building	\$ -	\$ 307,392	\$ 241,998	\$ 213,207	\$ 217,471	\$ 221,821	\$ 226,257	\$ 230,782	\$ 235,398	\$ 240,106	\$ 244,908	\$ 249,806	\$ 254,802	\$ 259,898	\$ 265,096	\$ 270,398
Total revenues	\$ -	\$ 677,237	\$ 702,983	\$ 768,967	\$ 784,346	\$ 800,033	\$ 816,034	\$ 832,355	\$ 849,002	\$ 865,982	\$ 883,301	\$ 900,968	\$ 918,987	\$ 937,367	\$ 956,114	\$ 975,236
Expenditures																
Grid to H2	-	51,992	114,842	219,603	223,995	228,475	233,045	237,706	242,460	247,309	252,255	257,300	262,446	267,695	273,049	278,510
Cost of maintenance	-	150,000	153,000	156,060	159,181	162,365	165,612	168,924	172,303	175,749	179,264	182,849	186,506	190,236	194,041	197,922
Equipment expense	\$ 4,919,063	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Total expenditures	\$ 4,919,063	\$ 201,992	\$ 267,842	\$ 375,663	\$ 383,176	\$ 390,840	\$ 398,657	\$ 406,630	\$ 414,762	\$ 423,058	\$ 431,519	\$ 440,149	\$ 448,952	\$ 457,931	\$ 467,090	\$ 476,432
Net cash flows	\$ (4,919,063)	\$ 475,245	\$ 435,142	\$ 393,304	\$ 401,170	\$ 409,193	\$ 417,377	\$ 425,725	\$ 434,239	\$ 442,924	\$ 451,783	\$ 460,818	\$ 470,035	\$ 479,435	\$ 489,024	\$ 498,805
NPV of cash flows	\$ 368,482															
Project IRR	3.99%															

Note that in this analysis, equipment is owned and operated by a government entity. This implies that taxes are not paid, thus financial analysis does not require evaluation of depreciation. NPV for the project was evaluated using a discount rate of 3% and yielded \$300,000. The project IRR was calculated at 3.9%.