Economic Analysis of Hydrogen Energy Station Concepts:

Are “H_2E-Stations” a Key Link to a Hydrogen Fuel Cell Vehicle Infrastructure?

Final Report

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This research project has also been benefited by grants from the University of California Energy Institute, the U.S. EPA, and the Energy Foundation. These grants allowed us to construct the original CETEEM model, upon which this analysis and report are fundamentally based.

Executive Summary

Fuel cell vehicles (FCVs) powered with onboard hydrogen (H_2) will need access to an H_2 refueling infrastructure. For this reason, most direct-H_2 FCVs introduced prior to 2008-2010 are likely to be placed in fleets where they can be centrally refueled. However, access to additional refueling sites would increase the usefulness of these early FCVs, and once FCV commercialization spreads to the general public, consumers will require at least a minimal H_2 refueling infrastructure in order to make FCV use feasible.

One option for expanding the infrastructure for FCVs beyond fleet refueling applications, or potentially even for forming the basis of central refueling stations, is the concept of the "hydrogen energy station"(or H_2E-Station hereafter in this report). These H_2E-Stations would be either dedicated refueling facilities or a key component of the energy production, use, and management portion of a commercial or industrial facility. The energy station component would consist of a natural gas reformer or other H_2 generation appliance, a stationary fuel cell integrated into the building with the potential capability for combined heat and power (CHP) production, and an H_2 compression, storage, and dispensing facility.

In essence, the H_2E-Station seeks to capture synergies between producing H_2 for a stationary fuel cell electricity generator that provides part or all of the power for the local building load (as well as the capability to supply excess electricity to the grid), and refueling FCVs with additional high-purity H_2 that is produced through the same H_2 generation system. In principle, many different H_2E-Station concepts and designs are possible, including:

- "service station" type designs that are primarily intended to produce H_2 for FCV refueling;

- "office building" based designs that primarily provide electricity and waste heat to the building but also include a small off-shoot for FCV refueling; and

- "distributed generation" facilities that are primarily intended to supply excess electricity to the power grid, but that also include some provision for FCV refueling.

In addition, FCVs parked near the H_2E-Station for any sizable length of time could in principle supply electricity to the building or grid, since they would have access to a fuel supply.

Project Goals

This project expands on a previously conducted, preliminary H_2E-Station analysis in a number of important directions. This additional analysis, based on an integrated Excel/MATLAB/Simulink fuel cell system cost and performance model called CETEEM, includes the following:

- Inclusion of several energy station designs based on different sizes of fuel cell systems and hydrogen storage and delivery systems for service station and office building settings;

- Characterization of a typical year of operation based on seasonally varying electrical load profiles for office building H_2E-Station cases, rather than a single daily load profile;

- More careful specification of input variables, including "high" and "low" cost future cases and hydrogen sale prices of \$10/GJ, \$15/GJ, and \$20/GJ;

- Sensitivity analysis of key variables including natural gas prices, fuel cell costs, reformer system costs, and other capital and operating costs; and

- Examination of greater numbers of FCVs per day supported, up to 75 per day, and examination of additional cases with station design and operational variations.

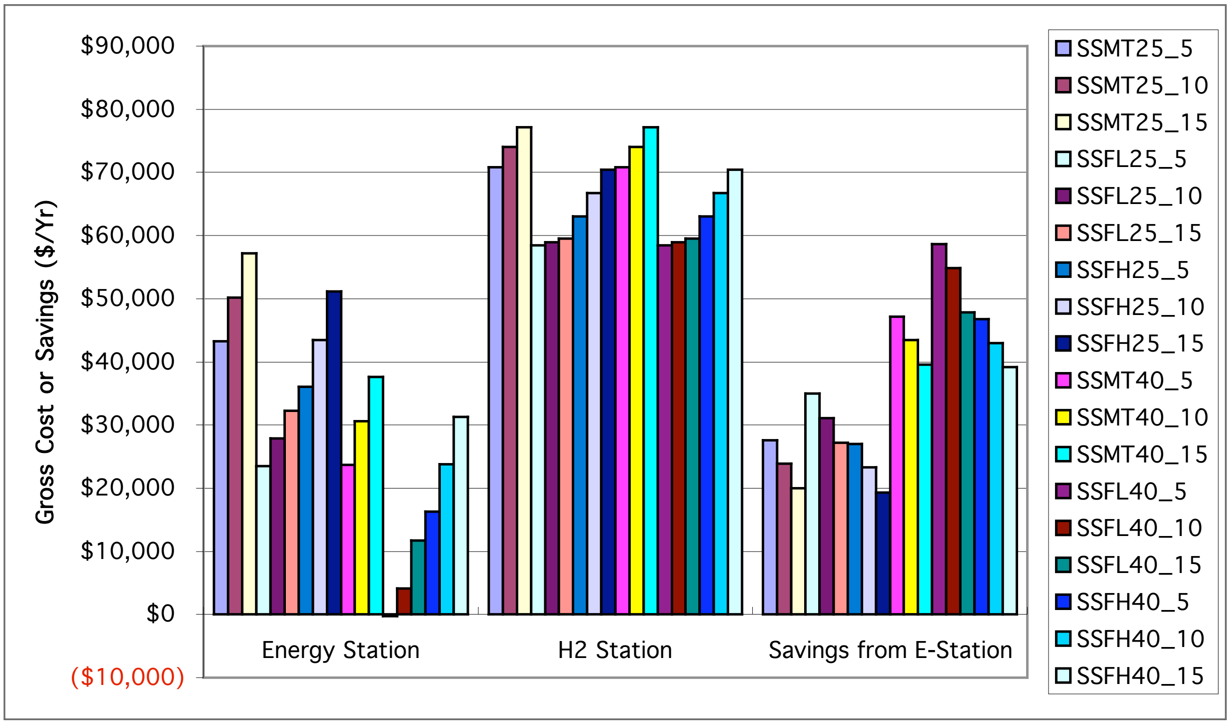
This expanded analysis allows for a more complete feasibility analysis of the H_2E-Station concept. There are, however, many more energy station design concepts that are possible, and additional facets of this concept that will be explored in future analysis.

Synopsis of Results

In general, and particularly in the low-cost future cases, the H_2E-Station design that appears to be the most economically attractive is the office building setting where relatively large fuel cells in the 100-250 kW size displace significant electricity purchases in the form of electricity energy and demand charges. These avoided electricity costs help to cover the costs of producing hydrogen for FCVs, and the economics of these stations tend to look better than those of H_2E-Stations based at gasoline service stations. However, even these H_2E-Stations at gasoline stations are more attractive than simply adding hydrogen dispensing infrastructure to a gasoline station without co-producing electricity, and this generally reinforces the potential attractiveness of the hydrogen energy station scheme in both office building and service station locations.

Figures ES1 through ES4 present many of the key findings of the analysis. Figure ES1 compares the costs of operating H_2E service stations with 25-kW and 40-kW fuel cells and 5-15 vehicles per day supported, with the costs of operating a simpler "H_2 station" that simply adds a hydrogen production, compression, storage, and dispensing system to an existing gasoline service station (i.e., with no fuel cell and larger reformer). As shown in the figure, in all cases there is a benefit from the energy station design; however, in all of these cases with only small amounts of hydrogen sold at a price of \$10/GJ, none of the H_2E-Stations or H_2 stations can be operated without a net annual cost.

Figure ES1: Estimated Annual Costs of H_2E-Stations with 25 and 40 kW Fuel Cell and 5-15 FCVs Refueled per Day, Compared with Costs of Dedicated H_2 Stations (H_2 price of $10/GJ)



Note: FL = future low cost case; FH future high cost case; MT = medium term case; SS = service station; X_Y = Fuel Cell Size in kW_# of FCVs per Day refueled.

Figure ES2 shows that when the number of FCVs supported expands to 50 and 75 vehicles per day at "service station" locations with a 40-kW fuel cell, the economics begin to look attractive with relatively high H_2 sales prices of around $20 per GJ. At this H_2 price, a 10% ROI target can be achieved with about 50 FCVs per day supported, again under a "future high cost case" that essentially takes future fuel cell, reformer, and other H_2 equipment high-volume manufacturing cost estimates and marks them up 25% to be more conservative.

Figure ES2: Estimated Profit (or Loss) from H_2E-Service Station with 40 kW Fuel Cell and 5 to 75 FCVs Refueled per Day (w/approx. 10% ROI target)

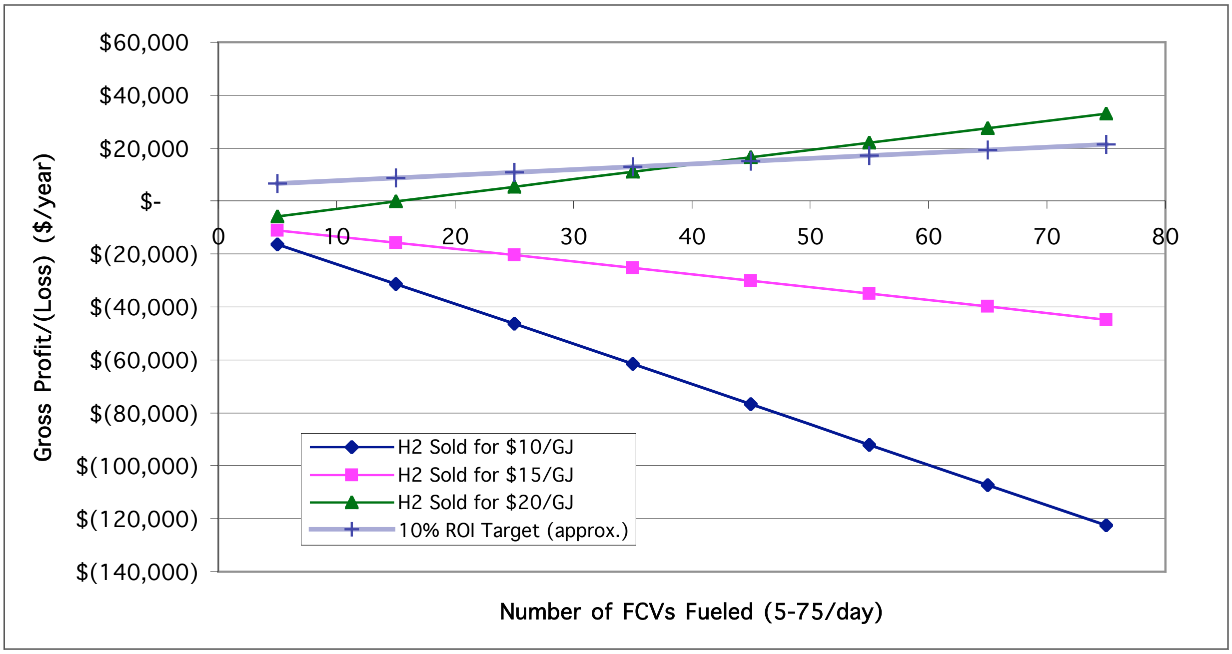
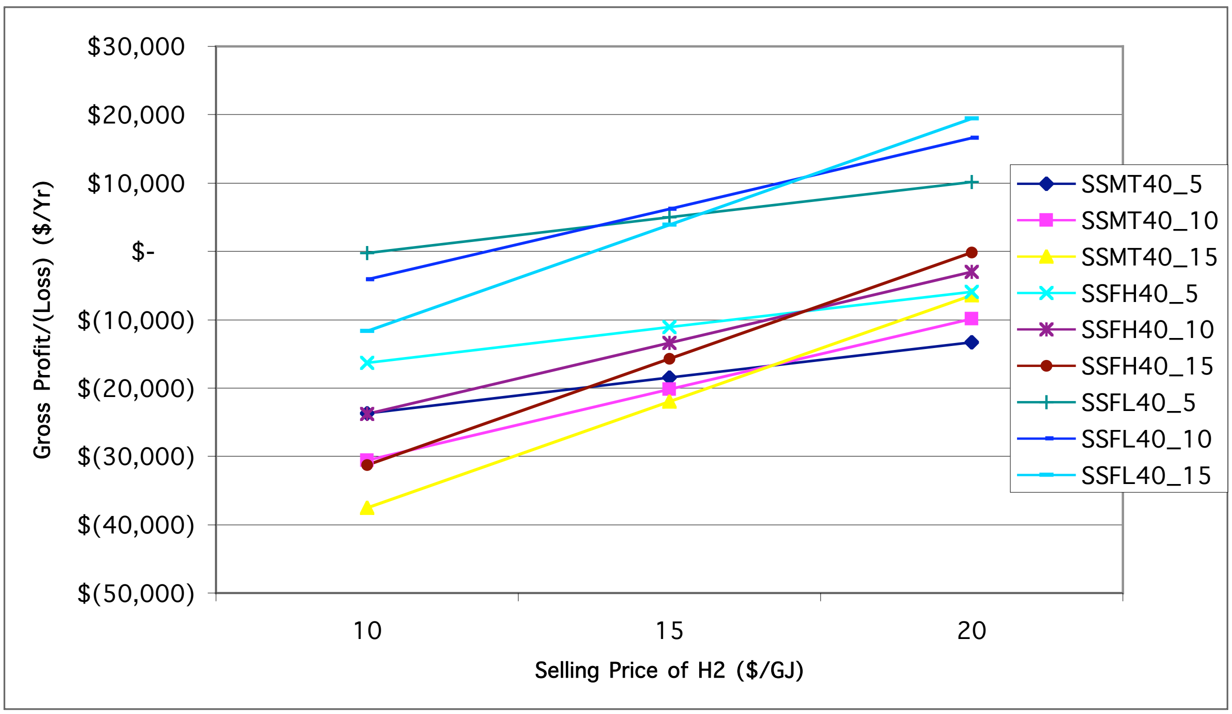


Figure ES3: Estimated Profit (or Loss) from H_2E-Service Station with 40 kW Fuel Cell and 5 to 15 FCVs Refueled per Day, with Medium Term, Future Low, and Future High Cost Assumptions

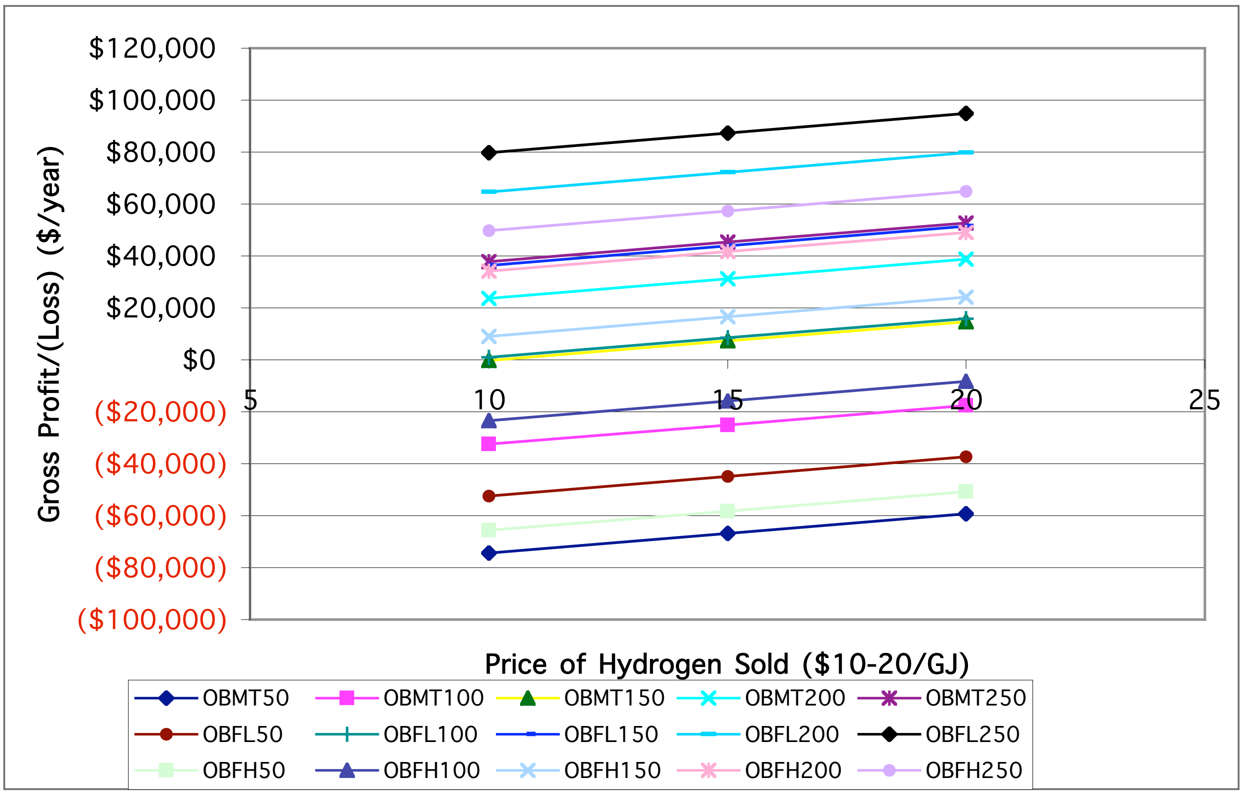


Note: FL = future low cost case; FH future high cost case; MT = medium term case; SS = service station; X_Y = Fuel Cell Size in kW_# of FCVs per Day refueled.

Figure ES3, above, shows that none of the "service station" H_2E-Stations that support only 5-15 vehicles per day are economically viable, with the exception of the "future low" cost cases with H_2 sales prices of over $15/GJ. In the "medium term" cases, the stations lose between $5,000 per year and $40,000 per year, and in the "future high" cost cases, the stations just break even with $20/GJ H_2 sales, but lose up to $30,000 per year at $10/GJ of H_2 sold.

Figures ES4 and ES5, below, show a set of results for office building H_2E-Stations with refueling for 10 FCVs per day and 50 to 250-kW fuel cells. Figure ES4 shows that the economics of these stations depend strongly on the size of the fuel cell incorporated into the office building, and also the capital costs of the technology. In these cases, with relatively optimistic capital cost assumptions, the size of the fuel cell system is actually the most dominant factor, with the 250 kW fuel cell being well-suited to this building load (peaking at about 300 kW) and offering favorable economics in all three of the cost assumption cases.

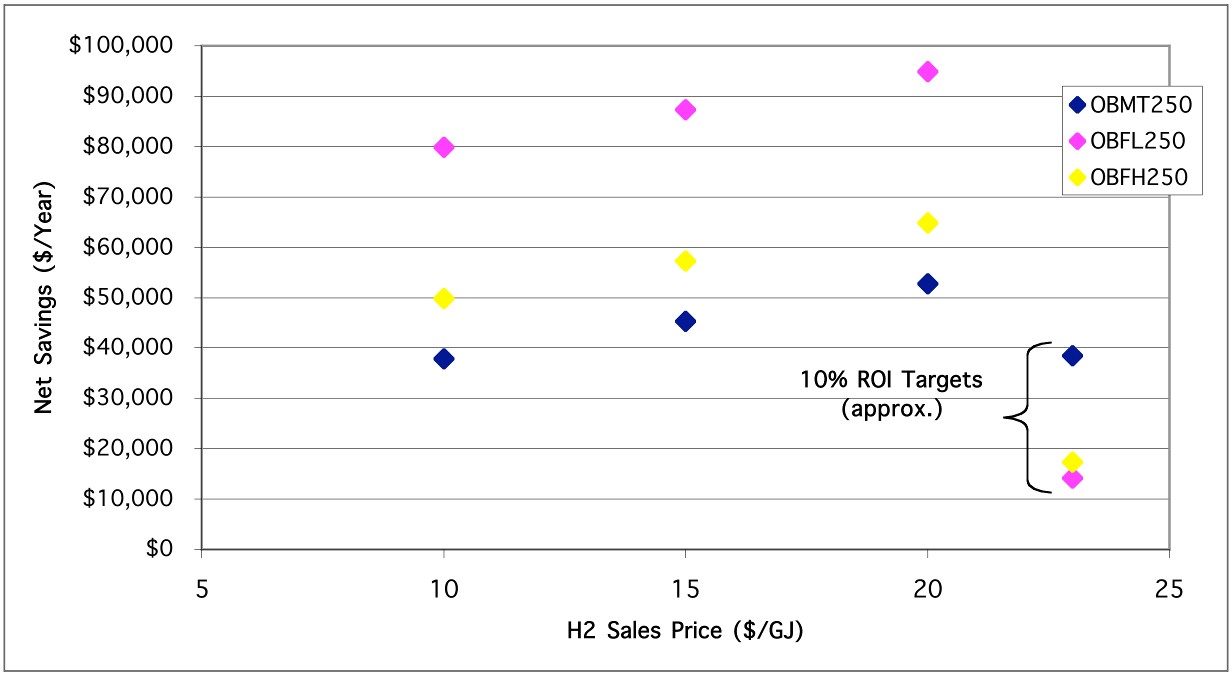
Figure ES4: Estimated Profit/(Loss) from Office Building H_2E-Stations with 50 to 250-kW Fuel Cell and 10 FCVs/Day Refueled, with Medium Term, Future Low, and Future High Cost Cases



Note: FH = future high cost case; FL = future low cost case; OB = office building; 50-250 = fuel cell peak kW.

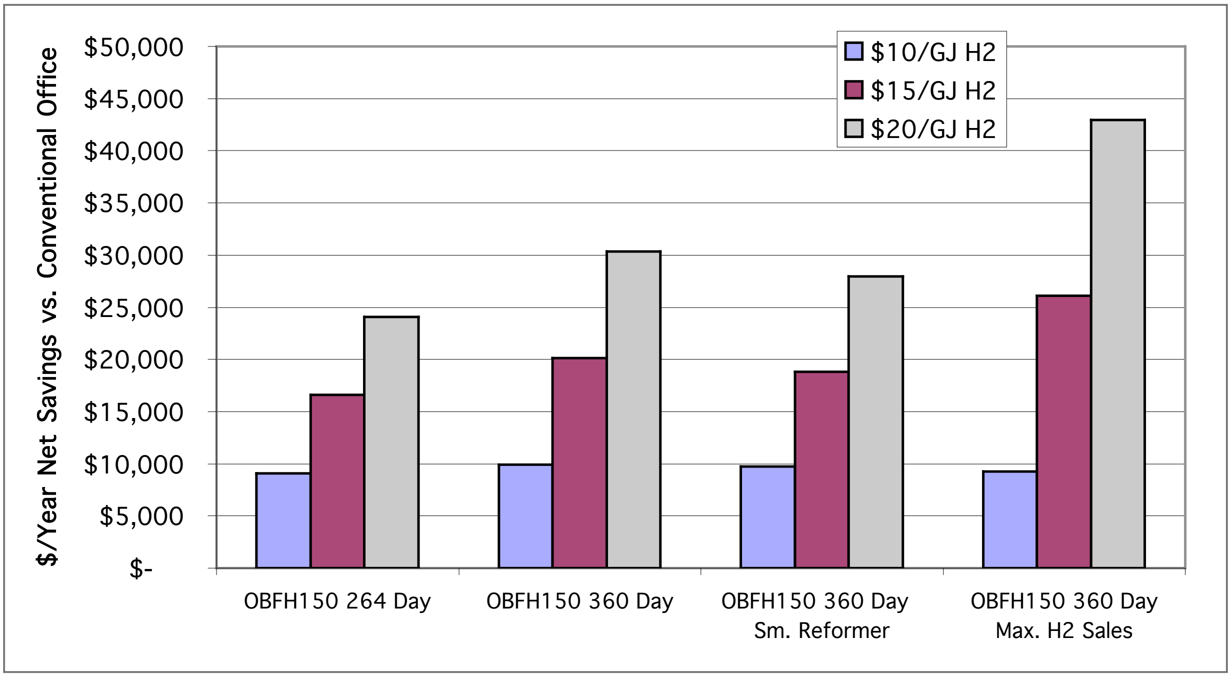
Figure ES5 makes this point more clear by showing the results for the 250-kW fuel cell office building H_2E-Station cases, along with approximate 10% ROI targets for each case (based on the installed capital costs of each fuel cell/reformer/H_2 storage and dispensing system). It would seem that in the energy market conditions that prevail in certain parts of California such as the South Coast, fuel cells with these capital and operating costs could be cost-effective, and H_2E-Stations based on these relatively large fuel cells at office buildings could prove to be attractive.

Figure ES5: Estimated Savings from Office Building H_2E-Stations with 250-kW Fuel Cell and 10 FCVs/Day Refueled for 264 Days/Year, with Medium Term, Future Low, and Future High Cost Cases, and Approximate 10% ROI Targets



As shown in Figure ES6, below, in the case in which H_2 sales are maximized (e.g. the case where the amount of hydrogen sold is nearly optimized on “day type-by-day type” basis) and an average of about 16 vehicles per day are refueled, the net savings/profit from the H_2E-Station are enhanced by up to about $12,000 per year in the case where H_2 is sold for $20/GJ (relative to the case in which only 10 FCVs per day are refueled).

Figure ES6: Estimated Annual Savings of Office-Building Energy Station Design, Relative to Conventional Office Building (150-kW FC, 10 FCVs/Day Refueled, Future High Costs)



Notes:
$/GJ figures are retail hydrogen sales prices.
"Sm. Reformer" case refers to a case where the fuel reformer is slightly undersized, thus saving a small amount of capital cost but somewhat restricting the amount of H_2 that can be sold (and FCVs refueled) on peak electricity demand days.
"Max. H_2 Sales" case refers to a case where the amount of hydrogen sold is nearly optimized on "day type-by-day type" basis, such that the average number of FCVs refueled per day is approximately 16 rather than 10.

Conclusions

This analysis, as any prospective and forward-looking investigation, entails considerable uncertainty. This uncertainty has been roughly examined in the present analysis by examining two somewhat different future cost cases; a "future low" cost case based on relatively optimistic fuel cell and H_2 hardware manufacturing cost estimates made by DTI (Thomas et al., 2000) and a "future high" cost case that is more conservative, with higher fuel cell cost estimates and a 25% multiplier to DTI's equipment cost estimates for H_2 reformation, purification, compression, storage, and dispensing.

However, despite the considerable uncertainty in this analysis, with regard to these forward-looking capital cost estimates as well as natural gas fuel costs and other variables, a few broad conclusions are possible:

1) The economics of supporting small numbers of FCVs, on the order of 5-15 per day, are difficult. Only under the most favorable circumstances can these break even or turn a small profit (e.g., H_2E-Station configurations where some

electricity cost savings are realized, future low capital cost assumptions, and H_2 prices on the order of \$20/GJ of H_2 sold);

2) However, the losses associated with supporting early FCVs with hydrogen fueling can potentially be reduced by employing H_2E-Station designs, when combined with future, lower-cost fuel cell and H_2 compression and storage hardware, and in areas with relatively high electricity prices (of ~\$0.12 per kWh or more);

3) The economics of "office building" H_2E-Stations appear favorable relative to "service station" H_2E-Stations, once fuel cell and H_2 equipment becomes mass produced and less expensive, and where the economics of producing electricity and displacing grid purchases are favorable (e.g. prevailing commercial prices of \$0.12/kWh plus demand charges of \$5-12 per kW-peak/month);

4) In cases where 50 to 75 FCVs per day are supported in service station H_2E-Station designs with a 40 kW fuel cell and "future high" cost estimates, a 10% ROI target can be achieved but only with hydrogen sold at or near \$20 per GJ. With natural gas prices lower than \$6/GJ, the prospects for economic sales of hydrogen at closer to \$15/GJ would brighten;

5) If H_2 sales could be maximized at office buildings, based on the peak amount of H_2 that can be sold each day given the varying building electrical load, the economics of the H_2E-Stations can be improved, particularly with high H_2 sales prices; and

6) Office building H_2E-Station cases with downsized reformers save on capital costs, but lose some H_2 sales on summer peak days, and for this reason do not appear to be economically advantageous (but perhaps would be with higher near-term reformer costs).

Finally, we note that the analysis results described above have considered many key economic variables, but have left out many minor but potentially significant costs associated with fuel cell and H_2 equipment siting, permitting, grid interconnection, and utility interface. These costs are uncertain at this time due to site-specific variables and pending regulations regarding distributed power generating equipment interconnection, and these will also vary regionally and internationally. See Table 1 for a summary of the economic costs included and excluded from the modeling effort and analysis described herein.

Introduction

Fuel cell vehicles (FCVs) powered with onboard hydrogen will need access to hydrogen refueling infrastructure. For this reason, most direct-hydrogen FCVs introduced prior to 2008-2010 are likely to be placed in fleets where they can be centrally refueled. However, access to additional refueling sites would increase the usefulness of these early FCVs, and once FCV commercialization spreads to the general public, consumers will require at least a minimal or "skeletal" hydrogen refueling infrastructure in order to make FCV use feasible. Ideally a robust hydrogen infrastructure would rapidly evolve with the successful introduction of the vehicles, but a key question is:

> "Will the market provide this infrastructure alone, or will public-private partnerships be needed, especially initially, in order to deploy early systems and gain design and operational experience?"

In other words, creating a serviceable hydrogen infrastructure that is extensive enough to provide convenient refueling to early FCV purchasers, but probably not economic in the near term due to low numbers of vehicles supported, is a key challenge to commercializing FCVs that operate on hydrogen.

One option for expanding the infrastructure for FCVs beyond fleet refueling applications, or potentially even for forming the basis of central refueling stations, is the concept of the "hydrogen energy station" (or H_2E-Station). These H_2E-Stations would be either dedicated refueling facilities or a key component of the energy production, use, and management portion of a commercial or industrial facility. The energy station component would consist of a natural gas reformer or other hydrogen generation appliance, a stationary fuel cell integrated into the building with the potential capability for combined heat and power (CHP) production, and a hydrogen compression, storage, and dispensing facility.

In essence, the H_2E-Station seeks to capture synergies between producing hydrogen for a stationary fuel cell electricity generator that provides part or all of the power for the local building load (as well as the capability to supply excess electricity to the grid), and refueling FCVs with additional high-purity hydrogen that is produced through the same hydrogen generation system. In principle, many different hydrogen energy station concepts and designs are possible, including:

- "service station" type designs that are primarily intended to produce hydrogen;
- "office building" based designs that primarily provide electricity and waste heat to the building but also include a small off-shoot for FCV refueling; and
- "distributed generation" facilities that are primarily intended to supply excess electricity to the power grid, but that also include some provision for FCV refueling.

In addition, FCVs parked near the H_2E-Station for any sizable length of time could in principle supply electricity to the building or grid, since they would have access to a fuel supply.

Project Goals

This project expands on a previously conducted, preliminary H_2E-Station analysis in a number of important directions. This additional analysis, based on an integrated Excel/MATLAB/Simulink fuel cell system cost and performance model called CETEEM[1], includes the following:

- Inclusion of several energy station designs based on different sizes of fuel cell systems and hydrogen storage and delivery systems for service station and office building settings.
- Characterization of a typical year of operation based on seasonally varying electrical load profiles for office building cases, rather than a single daily load profile.
- More careful specification of input variables, and inclusion of future "high" and "low" cost cases for each set of model runs.
- Sensitivity analysis of key variables including natural gas prices, fuel cell costs, reformer system costs, and other capital and operating costs.

This expanded analysis allows for a more complete feasibility analysis of the energy station concept. There are, however, many more energy station design concepts that are possible, and additional facets of this concept that will be explored in future analysis. These include H_2E-Station designs that are primarily established to supply electricity to utility grids as well as meeting local needs, and office building energy stations where FCVs parked in the building parking lot produce power during the day to complement the power produced by the stationary fuel cell system.[2]

Cases Analyzed and Key Assumptions

In this analysis, we focus on two basic energy station settings: a gasoline service station setting, and a medium-sized office building setting. The gasoline service station has a basic electricity load profile that varies hourly and ranges from 40 kW to 64 kW, with the highest electricity use occurring during the night time hours when the station's lights are on. For purposes of this analysis, the service station electrical load profile is assumed to be constant throughout the year, but is adjusted to account for the additional electricity required for hydrogen compression (details are given below). The office building has an electrical load that varies hourly and ranges from 30 kW to 170 kW. This electrical load profile is assumed to vary throughout the year, and is also adjusted to account for the additional electricity needed for hydrogen compression for FCV refueling. As explained below, we use 12 sample load profiles to approximate the daily and seasonal variation in electrical load profile for this office building, to model the response of the fuel cell system to the variation in electrical load, and to allow for a yearly summation of total electricity requirements and other model results. Figure 1, below, shows a diagram of the general design of the office building H_2E-Station, and Figure 9 (at the beginning of the results section) shows designs for H_2E service stations and alternative H_2 service stations.

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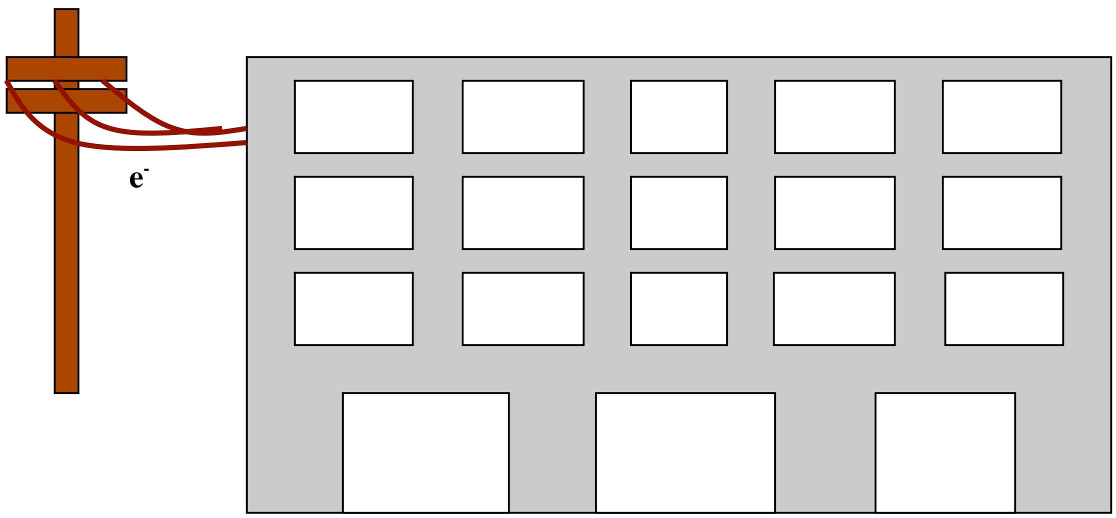
[1] The Clean Energy Technology Economic and Emissions Model

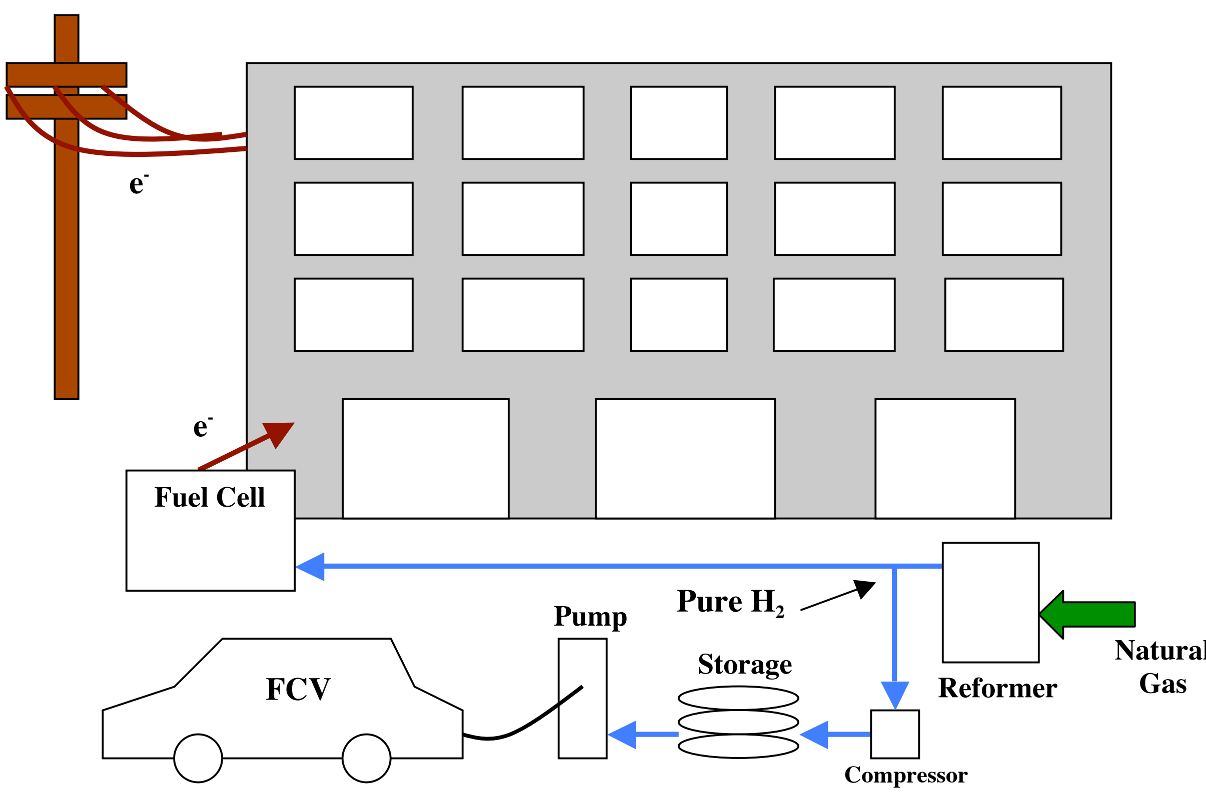
[2] We have previously used CETEEM to analyze cases in which FCVs produce power at both office building and residential locations, and a report released under the University of California Energy Institute's POWER paper series, Lipman et al., 2002, is available for download on the RAEL website: http://socrates.berkeley.edu/~rael

Figure 1: Conventional Office Building vs. Office Building H_2E-Station

Conventional Office Building



Office Building H_2E-Station



In this analysis, we include economic analysis of the key costs associated with constructing and operating the H_2E-Stations. We focus on a southern California location for the energy station concepts, and we include electricity and natural gas costs that are appropriate for this region. However, there are some costs that we do not include, but that could and perhaps should be included in a more complete analysis. Table 1 below lists the costs and revenues that are and are not included in this analysis.

Table 1: Costs and Revenues Included and Not Included in the Analysis

Costs and Revenues Included in the Analysis	**Costs and Revenues Not Included in the Analysis**
• Fuel cell system capital costs • Natural gas reformer capital costs • Capital costs for FCV refueling equipment, including H_2 compressor, H_2 storage, and H_2 dispensing pump • Natural gas fuel costs for electricity and hydrogen production • Fuel cell system annual maintenance and periodic stack refurbishment • Reformer maintenance • Purchased electricity, including fixed monthly charges, energy charges, and demand charges • Revenues from hydrogen sales to FCVs • Avoided electricity costs due to self-generation • Avoided natural gas costs due to co-generation of hot water with fuel cell system waste heat	• Equipment installation costs • Safety equipment costs • Costs of any required construction permits or regulatory permits • Costs associated with any property that is devoted to FCV refueling • Utility “standby charges” for providing backup for electricity self-generation • Costs of any labor associated with energy station operation or administration • Federal, state, and local taxes on corporate income, including tax credits for equipment depreciation, etc. • Revenues from government incentives for fuel cell installation/operation or hydrogen dispensing

We also make the following general assumptions throughout the analysis:

- Reformers in conjunction with membrane purification systems produce high-purity hydrogen for both stationary fuel cell system and vehicle refueling (i.e., fuel cell stack performance is assessed based on neat hydrogen fuel input rather than reformate input);

- Hydrogen is dispensed to FCVs through a cascade storage system that can dispense up to half of the amount of stored hydrogen each day, and is sold to consumers at prices of $10-20 per GJ;

- For the service station cases, we vary the number of FCVs refueled per day, with 5, 10, and 15 vehicles refueled per day for each of two fuel cell system sizes (25 kW and

40 kW) and for each of three sets of economic assumptions, and we assume that FCVs are refueled 360 days per year;

• For the office building cases, we fix the number of FCVs refueled per day at 10, we assume that FCVs are refueled only on weekdays, or 264 days per year (in the base case), and we vary the size of the stationary fuel cell from 50 kW to 250 kW in 50 kW increments;

• For the fuel cell and reformer systems, we assume that the fuel cell system efficiency varies with load, but that the reformer system has a fixed efficiency of 70% (energy value of hydrogen out over the energy value of the natural gas plus electricity in, on an HHV basis);

• We assume an inverter efficiency of 92%, and a hydrogen utilization efficiency for the fuel cell of 98% (based on the use of neat hydrogen rather than reformate);

• We assume that capital equipment has a useful life of 15 years, and we use a real interest rate of 8% to produce a capital recovery factor of 0.117, that we then apply to annualize all capital costs (assuming "straight line" depreciation);

• We assume that the fuel cell stacks are designed to operate for 5 years, and that each 5 years they are refurbished at a cost of 50-75% of a new fuel cell stack.

In addition to these general assumptions, there are also several more specific assumptions that must be made for each case, regarding specific equipment capital and maintenance costs, natural gas and electricity costs, and so on. These detailed assumptions are shown in Tables 2 through 5. In general, most of the fuel cell system, reformer, and hydrogen storage and dispensing system costs have been derived from published analysis by Directed Technologies, Inc. (Thomas et al., 2000). These are the only publicly available estimates of these costs that are sufficiently detailed to allow for analysis of the cost vs. size scaling effects that are important to this study. However, we note that these costs are considered by many analysts to be relatively optimistic, and we consider them to be appropriate only for the future and perhaps even the distant future.

For the "future low cost" cases, we use the DTI estimates that assume high-volume production of 60,000 fuel cell systems and other components per year. For the "future high cost" cases, we base our estimates on the DTI analysis that assumes production of 10,000 units per year, but we mark up the costs by 25% to account for the potential that costs as low as DTI forecasts will not be realized. For the "medium term" case, considered to be 5-7 years from now, we assume that fuel cell systems are produced in units of 100 per year, and again use the DTI estimates for this production volume, but we assume more conservative reformer costs under the assumption that reformer manufacture will be less amenable to mass production than will be fuel cell system manufacture, and that reformer costs may remain relatively high in the medium-term.

Electricity costs, shown in Table 5 as \$0.12 per kWh, also include two other components: a fixed monthly charge and a "demand charge" based on the peak kW consumption of the building in a given month. We derive these charges from Southern California Edison's electricity tariff schedule GS-2, which became effective on September 20, 2001. This rate schedule applies to commercial customers using either single-phase or three-phase power, who have peak demands between 20 kW and 500 kW. Schedule GS-2 shows a fixed monthly charge of $60.30 per month, an electricity energy charge of approximately $0.12 per month, and demand charges of approximately $5 per peak-kW per month during the 8 non-peak months (first Sunday in October until the first Sunday in June) and approximately $12 per peak-kW per month during the four peak-demand months (first Sunday in June until the first Sunday in October).

Table 2: Input Assumptions for Service Station (SS) and Office Building (OB) Cases

Case	Fuel Cell Size (kW)	Reformer Size (GJ of H_2/day)	H_2 Compressor (kg H_2/hr)	FCVs Refueled per Day	Days per Year FCVs Refueled
SSMT25_5	25	9.07	2.661	5	360
SSMT25_10	25	11.91	3.495	10	360
SSMT25_15	25	14.77	4.334	15	360
SSFL25_5	25	9.07	2.661	5	360
SSFL25_10	25	11.91	3.495	10	360
SSFL25_15	25	14.77	4.334	15	360
SSFH25_5	25	9.07	2.661	5	360
SSFH25_10	25	11.91	3.495	10	360
SSFH25_15	25	14.77	4.334	15	360
SSMT40_5	40	12.8	3.756	5	360
SSMT40_10	40	15.64	4.589	10	360
SSMT40_15	40	18.58	5.452	15	360
SSFL40_5	40	12.8	3.756	5	360
SSFL40_10	40	15.64	4.589	10	360
SSFL40_15	40	18.58	5.452	15	360
SSFH40_5	40	12.8	3.756	5	360
SSFH40_10	40	15.64	4.589	10	360
SSFH40_15	40	18.58	5.452	15	360
OBMT50	50	18.2	5.340	10	264
OBMT100	100	24	7.042	10	264
OBMT150	150	30.4	8.920	10	264
OBMT200	200	34.9	10.241	10	264
OBMT250	250	39.7	11.649	10	264
OBFL50	50	18.2	5.340	10	264
OBFL100	100	24	7.042	10	264
OBFL150	150	30.4	8.920	10	264
OBFL200	200	34.9	10.241	10	264
OBFL250	250	39.7	11.649	10	264
OBFH50	50	18.2	5.340	10	264
OBFH100	100	24	7.042	10	264
OBFH150	150	30.4	8.920	10	264
OBFH200	200	34.9	10.241	10	264
OBFH250	250	39.7	11.649	10	264

Table 3: Input Assumptions for Service Station (SS) and Office Building (OB) Cases (cont'd)

Case	**Days Per Year Electricity Produced**	**Percent of Ref. Cost for FCVs**	**Fuel Cell Cost ($kW) (stack + aux + inverter)**	**Fuel Cell Stack Only Cost ($/kW)**	**Reformer Cost ($)**
SSMT25_5	360	31%	685	311	83,267
SSMT25_10	360	48%	685	311	93,684
SSMT25_15	360	58%	685	311	104,174
SSFL25_5	360	31%	460	106	12,345
SSFL25_10	360	48%	460	106	14,645
SSFL25_15	360	58%	460	106	16,962
SSFH25_5	360	31%	516	162	13,879
SSFH25_10	360	48%	516	162	16,459
SSFH25_15	360	58%	516	162	19,057
SSMT40_5	360	22%	606	291	96,948
SSMT40_10	360	36%	606	291	107,365
SSMT40_15	360	46%	606	291	118,148
SSFL40_5	360	22%	404	291	15,366
SSFL40_10	360	36%	404	291	17,666
SSFL40_15	360	46%	404	291	20,047
SSFH40_5	360	22%	456	155	17,267
SSFH40_10	360	36%	456	155	19,847
SSFH40_15	360	46%	456	155	22,518
OBMT50	360	35%	580	285	116,755
OBMT100	360	24%	524	272	138,028
OBMT150	360	19%	503	267	161,502
OBMT200	360	16%	490	265	178,008
OBMT250	360	15%	481	264	195,613
OBFL50	360	35%	385	79	19,739
OBFL100	360	24%	344	78	24,437
OBFL150	360	19%	329	77	296,20
OBFL200	360	16%	319	77	33,264
OBFL250	360	15%	312	77	37,151
OBFH50	360	35%	436	118	22,173
OBFH100	360	24%	392	115	27,442
OBFH150	360	19%	376	114	33,256
OBFH200	360	16%	366	113	37,344
OBFH250	360	15%	358	113	41,704

Table 4: Input Assumptions for Service Station (SS) and Office Building (OB) Cases (cont'd)

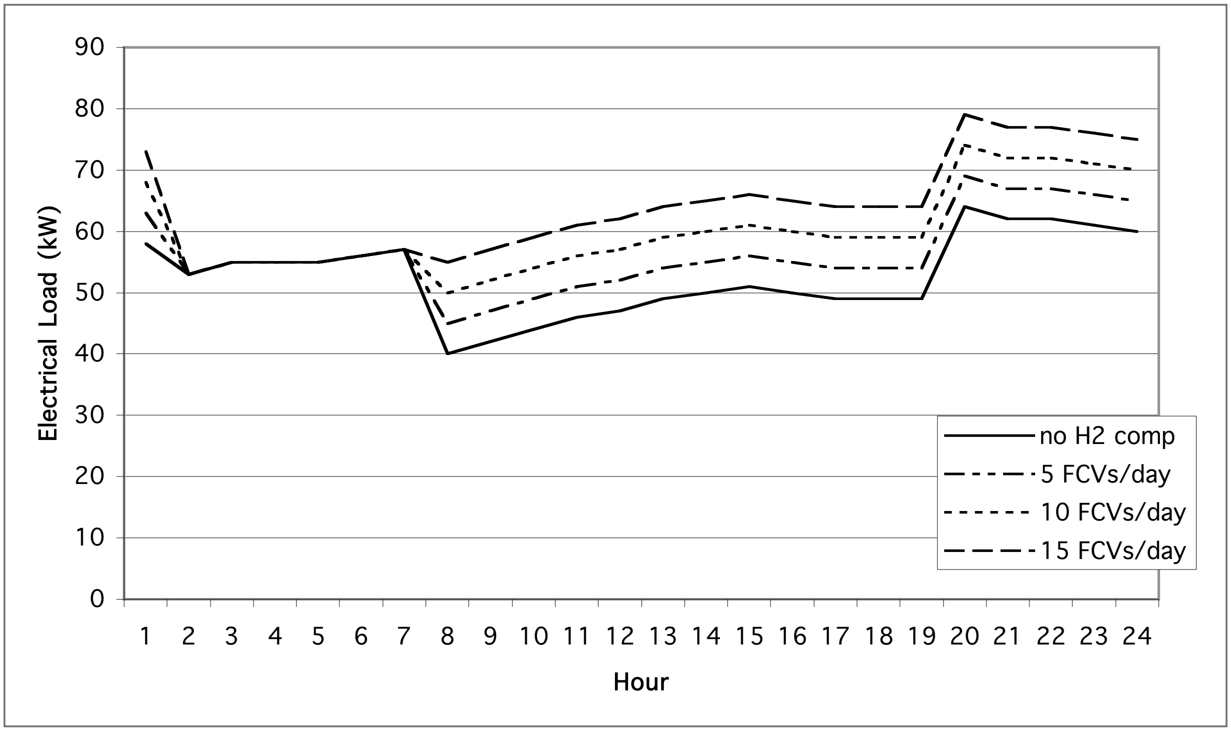
Case	H2 Compressor Cost ($)	H2 Storage System Cost ($)	H2 Pump Cost ($)	Total H2 Dispensing Infr. Cost ($)	FC Waste Heat Used for Hot Water?
SSMT25_5	6,609	9,810	42,000	58,419	No
SSMT25_10	6,907	17,490	42,000	66,397	No
SSMT25_15	7,207	25,170	42,000	74,377	No
SSFL25_5	5,287	7,848	4,800	17,935	No
SSFL25_10	5,525	13,992	4,800	24,317	No
SSFL25_15	5,766	20,136	4,800	30,702	No
SSFH25_5	6,609	9,810	14,300	30,719	No
SSFH25_10	6,907	17,490	14,300	38,697	No
SSFH25_15	7,207	25,170	14,300	46,677	No
SSMT40_5	7,000	9,810	42,000	58,810	No
SSMT40_10	7,298	17,490	42,000	66,788	No
SSMT40_15	7,607	25,170	42,000	74,777	No
SSFL40_5	5,600	7,848	4,800	18,248	No
SSFL40_10	5,839	13,992	4,800	24,631	No
SSFL40_15	6,085	20,136	4,800	31,021	No
SSFH40_5	7,000	9,810	14,300	31,110	No
SSFH40_10	7,298	17,490	14,300	39,088	No
SSFH40_15	7,607	25,170	14,300	47,077	No
OBMT50	7,567	17,490	42,000	67,057	Yes
OBMT100	8,175	17,490	42,000	67,665	Yes
OBMT150	8,846	17,490	42,000	68,336	Yes
OBMT200	9,319	17,490	42,000	68,809	Yes
OBMT250	9,822	17,490	42,000	69,312	Yes
OBFL50	6,053	13,992	4,800	24,845	Yes
OBFL100	6,540	13,992	4,800	25,332	Yes
OBFL150	7,077	13,992	4,800	25,869	Yes
OBFL200	7,455	13,992	4,800	26,247	Yes
OBFL250	7,858	13,992	4,800	26,650	Yes
OBFH50	7,567	17,490	14,300	39,357	Yes
OBFH100	8,175	17,490	14,300	39,965	Yes
OBFH150	8,846	17,490	14,300	40,636	Yes
OBFH200	9,319	17,490	14,300	41,109	Yes
OBFH250	9,822	17,490	14,300	41,612	Yes

Table 5: Input Assumptions for Service Station (SS) and Office Building (OB) Cases (cont'd)

Case	FC Fixed Maint. + 5-Year Stack Replacement ($/kW-yr)	% of New FC Stack Cost for Replacement Stack	Reformer Maintenance ($/kW-yr)	Natural Gas Cost ($/GJ)	Electricity Energy Charge ($/kWh) SCE Territory
SSMT25_5	66.66	75%	30	5	0.12
SSMT25_10	66.66	75%	30	5	0.12
SSMT25_15	66.66	75%	30	5	0.12
SSFL25_5	22.59	50%	15	4	0.12
SSFL25_10	22.59	50%	15	4	0.12
SSFL25_15	22.59	50%	15	4	0.12
SSFH25_5	44.29	75%	30	6	0.12
SSFH25_10	44.29	75%	30	6	0.12
SSFH25_15	44.29	75%	30	6	0.12
SSMT40_5	58.71	75%	30	5	0.12
SSMT40_10	58.71	75%	30	5	0.12
SSMT40_15	58.71	75%	30	5	0.12
SSFL40_5	20.35	50%	15	4	0.12
SSFL40_10	20.35	50%	15	4	0.12
SSFL40_15	20.35	50%	15	4	0.12
SSFH40_5	38.32	75%	30	6	0.12
SSFH40_10	38.32	75%	30	6	0.12
SSFH40_15	38.32	75%	30	6	0.12
OBMT50	62.73	75%	30	5	0.12
OBMT100	58.26	75%	30	5	0.12
OBMT150	56.77	75%	30	5	0.12
OBMT200	56.03	75%	30	5	0.12
OBMT250	55.58	75%	30	5	0.12
OBFL50	17.91	50%	15	4	0.12
OBFL100	16.65	50%	15	4	0.12
OBFL150	16.08	50%	15	4	0.12
OBFL200	15.85	50%	15	4	0.12
OBFL250	15.71	50%	15	4	0.12
OBFH50	37.71	75%	30	6	0.12
OBFH100	34.72	75%	30	6	0.12
OBFH150	33.72	75%	30	6	0.12
OBFH200	33.22	75%	30	6	0.12
OBFH250	32.92	75%	30	6	0.12

With regard to the building electrical load profiles, as noted above we assume a single daily load profile for the service station, but we modify it to account for the additional need for electricity to compress hydrogen for dispensing to FCVs. The following figure shows the initial service station load profile, that we use for comparison purposes, and the three modified profiles that reflect hydrogen dispensed to 5, 10, and 15 FCVs per day. We assume that FCVs are refueled sporadically from 7:00 AM until 1:00 AM, and that the compressor runs slowly and continuously during this period to refill the hydrogen storage system.

Figure 2: Service Station Electrical Load Profiles



For the office building case, we adopt a convention used in some commercial building load profile databases whereby a month of the year is characterized with three "day types": a "peak day" that represents the average of the three peak days of the month; a "week day" that represents the average of the remaining 19 week days in a typical month, and a "weekend day" that represents the average of the 8 weekend days in a typical month. In order to reduce the number of runs necessary for each case, we characterize the twelve months of the year with four representative months: January, to represent the Winter months of December, January, and February; April to represent the Spring months of March, April, and May; July to represent the Summer months of June, July, and August; and October to represent the Fall months of September, October, and November. These simplification means that a typical year can be modeled with twelve runs of CETEEM; three day types to characterize each month, and then four representative months to characterize the twelve months of the year.

Figure 3, below, depicts the load shapes used to characterize the office building electricity demand. In the figure, "Ja" stands for January, "Ap" stands for April, "Jl" stands for July, "Oc" stands for October, "WD" stands for weekday, "PD" stands for peak day, and "WE" stands for weekend day.

Figure 3: California Medium Office Building Load Shape Patterns

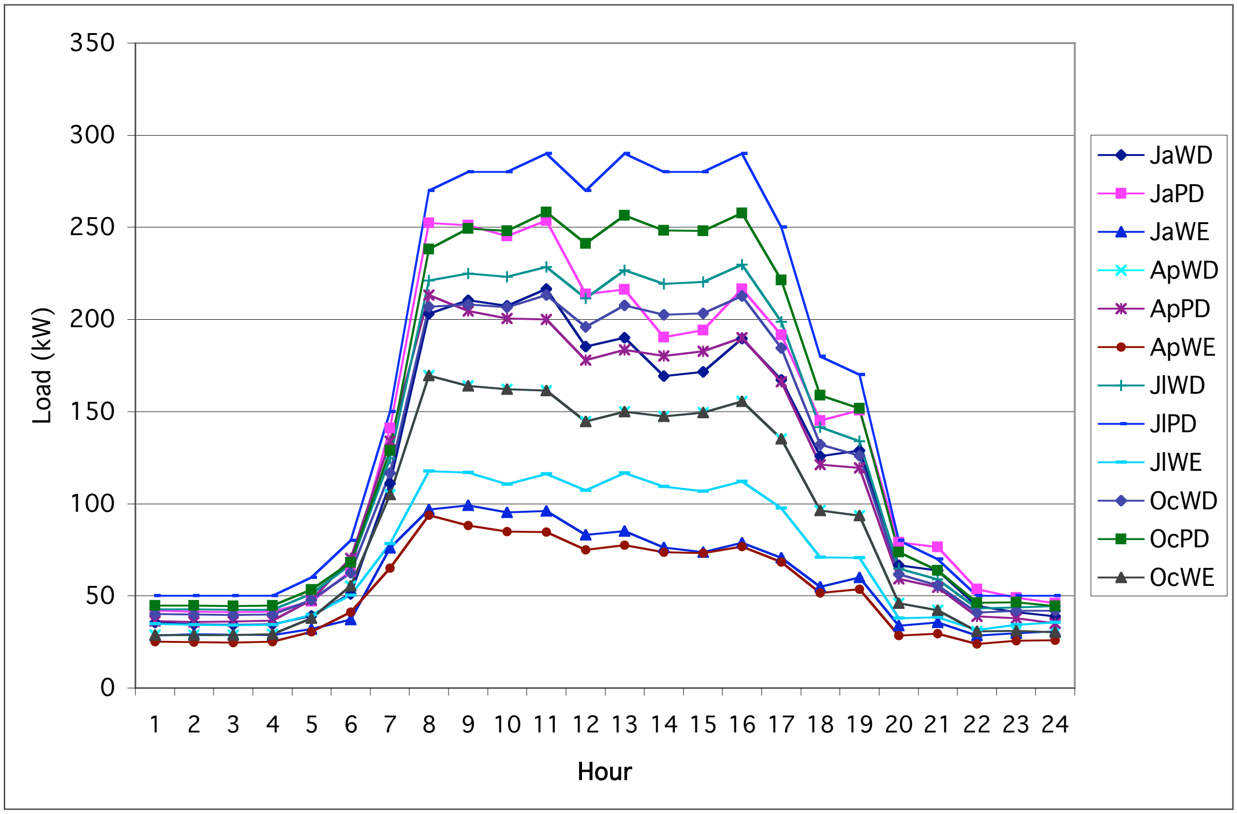
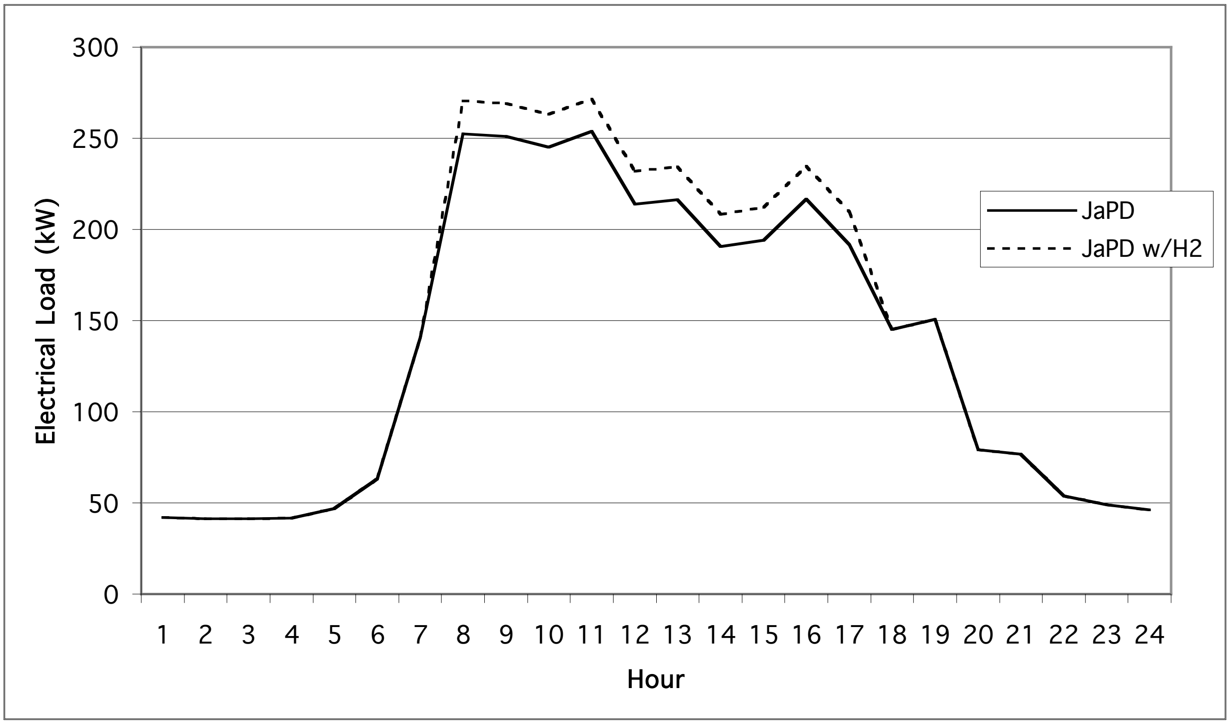


Figure 4 shows a single day type that is modified to account for the additional electricity needed to run the hydrogen compressor to refuel 10 FCVs per day at the office building energy station. As noted above, for the office building cases, we assume that vehicles are refueled 5 days per week, so we do not modify the "weekend day" electrical load profiles since the energy station is assumed to be producing electricity during weekend days but not extra hydrogen for FCV refueling. We further assume that the 10 FCVs are refueled sporadically from 8:00 AM until 6:00 PM, and that is the period during which the compressor needs to be running to maintain the level and pressure of the hydrogen storage system.

Figure 4: Office Building January "Peak Day" Load Profile and Modified Load Profile to Account for Electricity for Hydrogen Compression



CETEEM Model Description

In order to analyze the economics of operating stationary and/or motor vehicle PEM fuel cell systems to provide power to buildings and/or the electrical grid, we have constructed an integrated MATLAB/Simulink/Excel model. This model, which we have named the Clean Energy Technology Economic and Emissions Model (or CETEEM, pronounced "see team"), has been designed in order to assess the economics and emissions of criteria pollutants and greenhouse gases (GHGs) associated with the use of CETs for distributed power generation. CETEEM has been developed to characterize the use of PEM fuel cell systems powered by hydrogen produced with natural gas reformers, but it can be readily modified to characterize other CETs and fueling arrangements. These might include solar PV systems, wind power generating systems, other fuel cell technologies such as solid-oxide fuel cells, fuel cell systems operating in conjunction with electrolyzers to produce hydrogen (and hybrid renewable/fuel cell systems), natural gas powered microturbines, and other DG technologies.

CETEEM makes use of the Excel Link package of MATLAB to read input variables into the model from Excel spreadsheets, and to output results into spreadsheets so that they can be catalogued and further analyzed. First, constant and time-varying input values are read into the MATLAB workspace from two Excel input files, and these are then made available to the Simulink portion of the model through the use of "matrix input" blocks in Simulink. Once all of the input values have been entered into MATLAB/Simulink, using Excel macros to automate the process, the Simulink model is run. The Simulink model run time is approximately 10 seconds, depending somewhat on the speed of the personal computer used. Then, output values are automatically read from Simulink into the MATLAB workspace using "matrix output" Simulink blocks. Finally, a macro in the Excel output file reads the results from MATLAB into the Excel spreadsheet again using the Excel Link package.

CETEEM has the following principal features:

- Ability to simulate the partial load efficiency of distributed electricity generating systems (stationary and vehicular PEM fuel cells in the present analysis) in meeting hour-by-hour variations in building electrical loads;
- Inclusion of a cogeneration sub-model that estimates the economic implications of combined heat and power (CHP) generation to displace hot water heater natural gas consumption, given an hour-by-hour building hot water load;
- Ability to separately characterize up to 10 individual CET systems at a given location, or 10 "proxy groups" of any number of CET systems with each group assumed to operate similarly (e.g., 10 FCVs parked in an office building parking lot, combinations of a stationary fuel cell system plus one or more FCVs at a hydrogen "energy station," etc.);
- Calculation of costs of electricity, fuel costs, and operating efficiencies for individual CET subsystems and for the overall electricity generating system;
- Ability to model varying operational strategies, including load-following operation, where the entire local building load is met with local generation, partial load-following operation, where some portion of the local load is met with onsite generation and the rest is made up with purchased power, and excess "grid supply" operation where onsite generation provides power for the electrical grid (directly or in addition to meeting the local load) during one or more hours of the day;
- Ability to analyze system economics in response to hour-by-hour variations in electricity purchase prices and sales prices (or net-metering "credit" rates), thus allowing analysis of time-of-use (TOU) or real-time pricing tariff structures, and also including both electricity energy charges (in terms of $/kWh) and demand charges (in terms of $/peak-kW) for commercial customers;
- Characterization of fuel cell (or other CET) system operating efficiencies under varying system operating conditions (e.g., high or low fuel cell air side pressure, operation on pure hydrogen or natural gas reformate, etc.);
- Allowance for specification and sensitivity analysis of a number of key economic input variables such as natural gas purchase prices, system capital costs, system installation costs, system operation and maintenance costs, hours of operation per year, capital cost recovery factors (based on a specified system lifetime and interest rate), and system capital cost financing arrangements (versus upfront system purchase);
- Calculation of fuel upstream and system operating emissions, divided into approximate "in-basin" and "out-of-basin" components, including criteria pollutants (oxides of nitrogen, carbon monoxide, reactive hydrocarbons, fine particulates, and sulfur dioxide) and greenhouse gases (carbon dioxide, methane,

and nitrous oxide), and based on three different fuel cycle emissions analyses (the GREET model analysis, the Delucchi model analysis, and the Acurex analysis);

- Ability to analyze the case of a hydrogen "energy station" where excess hydrogen is produced, compressed, stored, and then sold to fuel FCVs (in addition producing hydrogen to power a building-integrated stationary fuel cell system).

Figure 5 depicts the "top level" of the CETEEM model, and provides some sense of the model structure. However, the Simulink environment allows for a hierarchical structure of model design, and there are several layers of nested complexity in the CETEEM model. Figures 6, 7, and 8 depict other parts of the model: an economic analysis sub-model, the cost-of-electricity calculation with the economic analysis sub-model, and a hot water heating cogeneration sub-model.

In order to provide an accurate analysis of the hydrogen energy stations analyzed in this project, CETEEM was modified in a few important ways. First, provision was made for the capital and maintenance costs of the natural gas reformer to be split between its uses in generating hydrogen for the stationary fuel cell for electricity production, and for producing hydrogen for FCV refueling. This means that the reformer can be sized properly for the combination of both uses without spuriously increasing the cost of electricity and affecting the electricity production calculations. Second, a number of additional model outputs were developed, including outputs related to the use of natural gas for hydrogen production for FCVs, the fraction of hydrogen used for FCVs (to allow the reformer costs to be divided), the maximum number of FCVs that could in principle be refueled per day, and the costs associated with producing extra hydrogen for FCVs. Finally, provision was added to allow the actual number of FCVs refueled per day to be different than the maximum number of FCVs that could be refueled, so that consistent numbers of vehicles could be assumed to be refueled each day even when the building electrical loads vary daily and seasonally (as in the office building cases).

Figure 5: CETEEM Top Level System Diagram

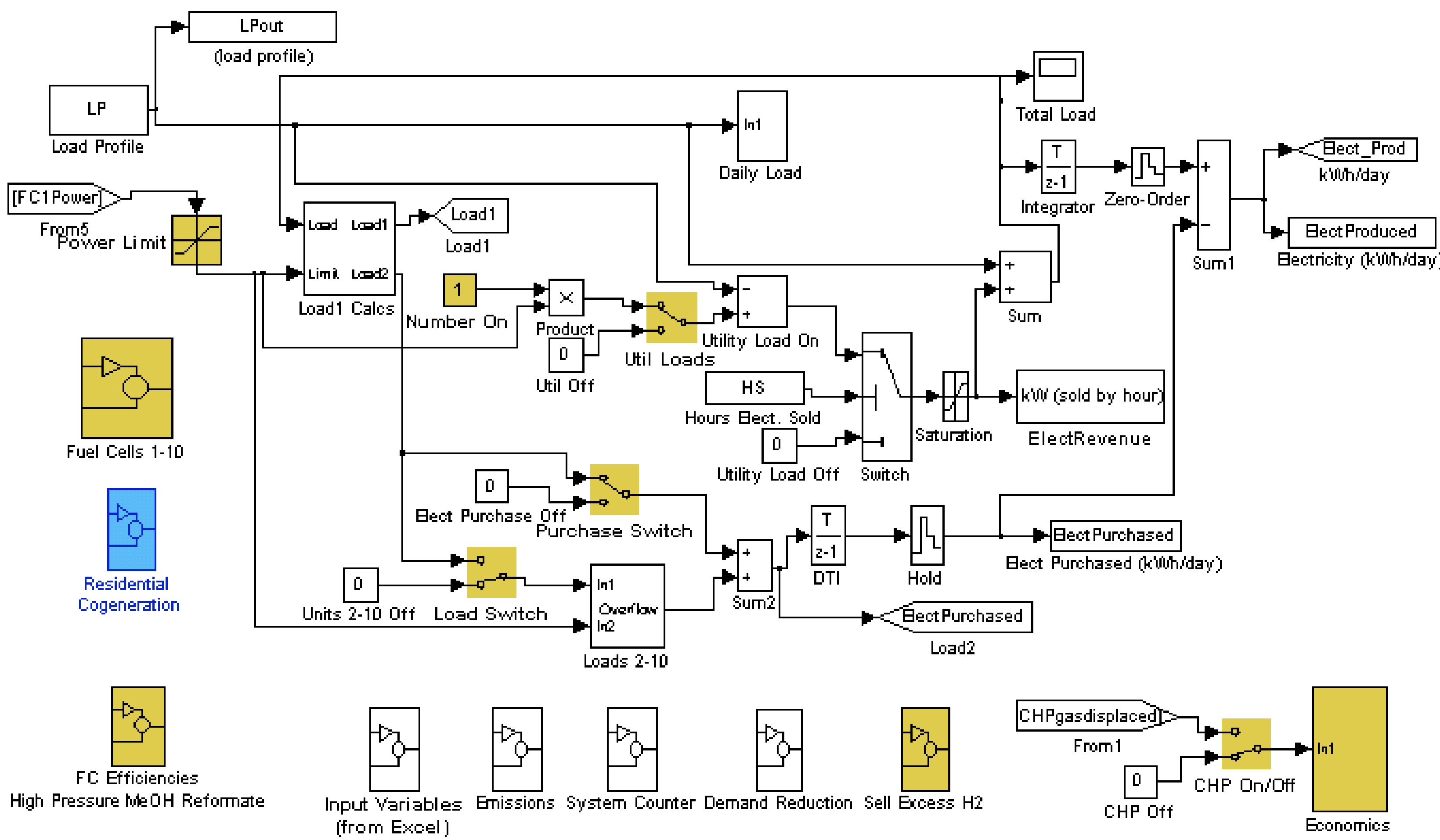


Figure 6: CETEEM Economic Analysis Sub-model Top Level

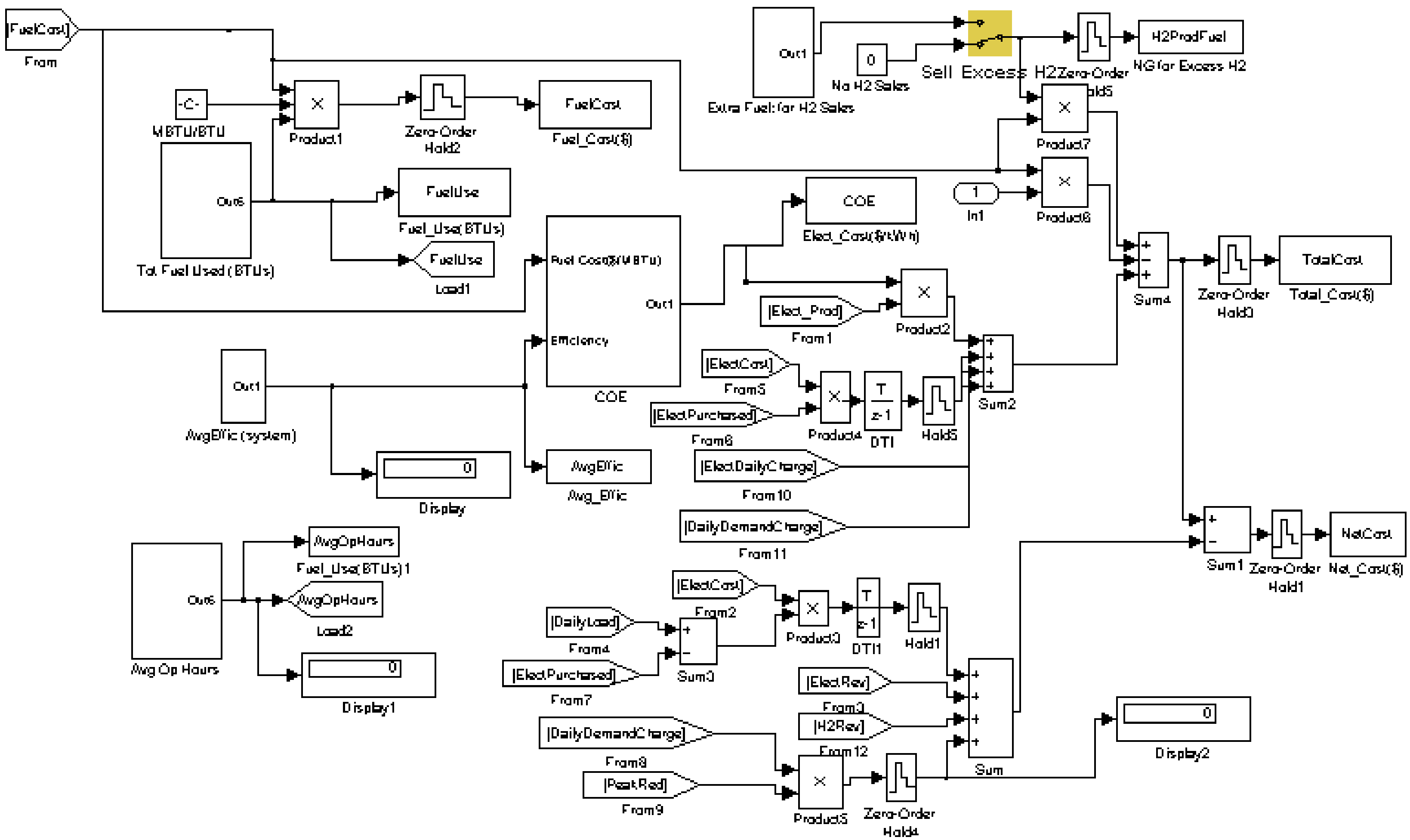


Figure 7: CETEEM Economic Analysis "Cost of Electricity" Sub-model

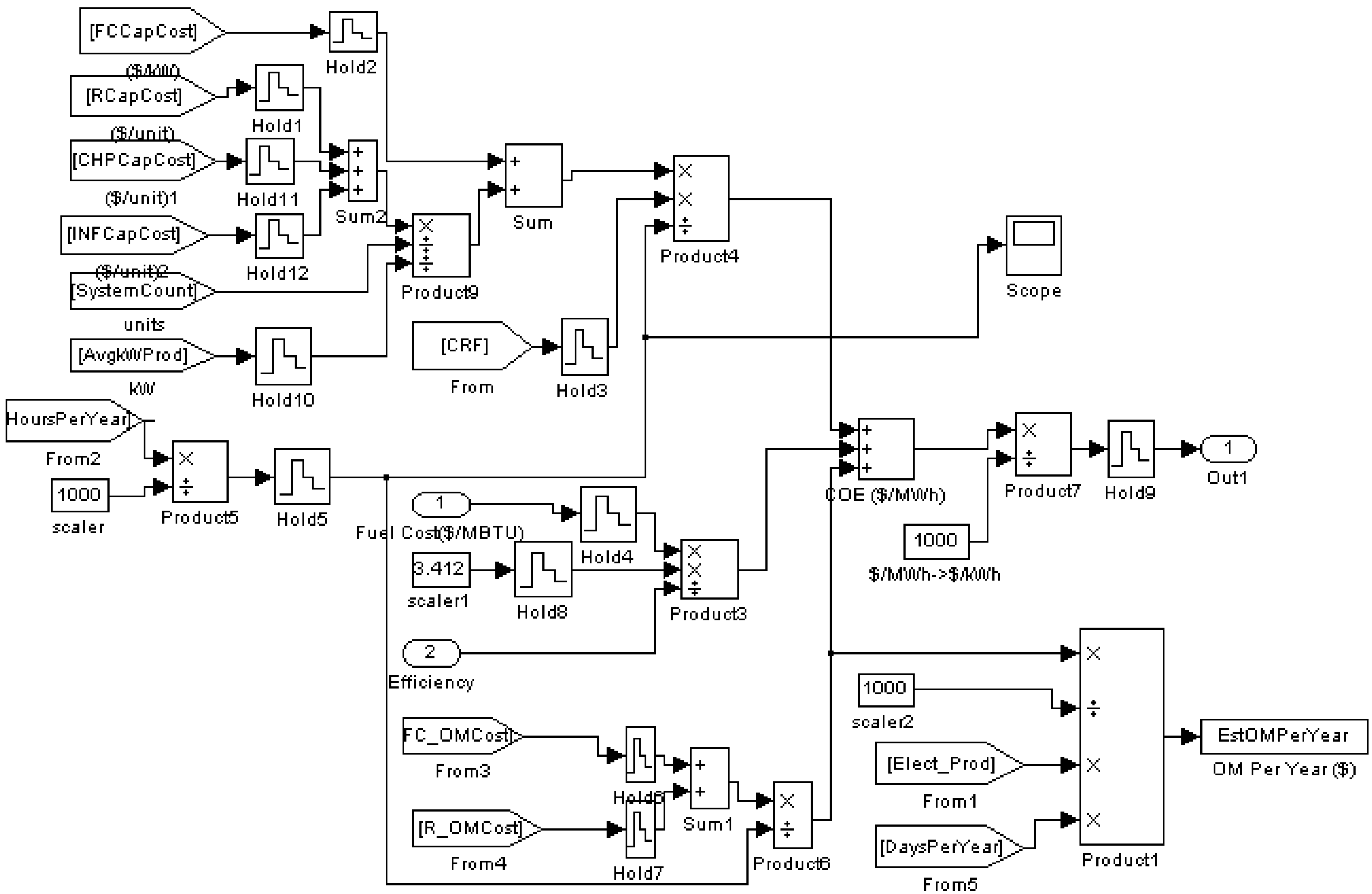
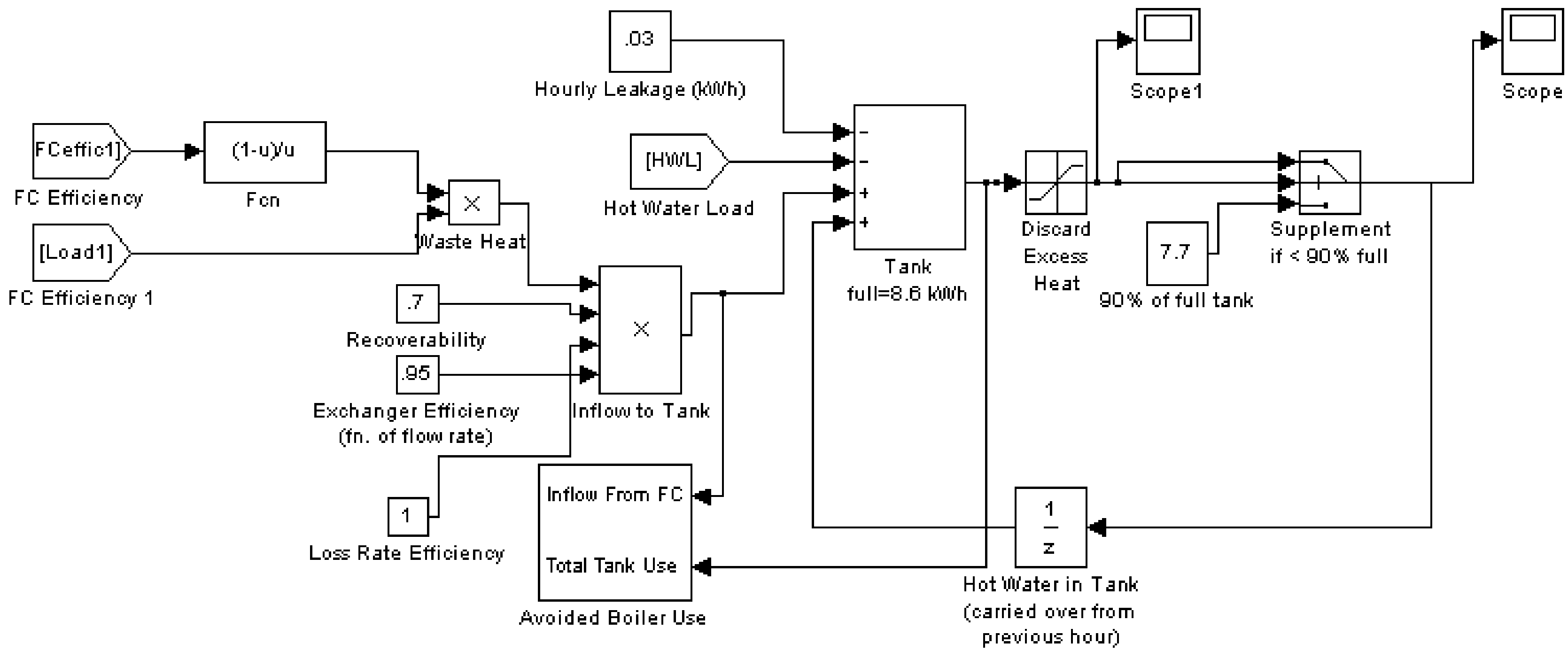


Figure 8: CETEEM Hot Water Cogeneration Sub-model



With regard to the economic calculations in CETEEM, the following formula is used to calculate the cost of electricity (COE) for both individual subsystems (e.g., individual fuel cells) and for the overall system. The overall system can include up to 10 generating units, additional system-level components such as a central reformer, installation costs, and other cost variables:

$$COE = \frac{CRF \bullet CC}{H} + \frac{3.412 \bullet FC}{\eta} + \frac{O\&M}{H}$$

Where:
CC = system capital cost or capital plus installation cost ($/kW)
COE = cost of electricity ($/MWh)
CRF = capital cost recovery factor
η (eta) = average system efficiency (0-1.0)
FC = fuel cost ($/MMBTU)
H = hours of operation per year, divided by 1000
O&M = operation and maintenance costs ($/kW-year)

This COE formula is a common one that is widely used, for example in U.S. DOE (2000). It is important to note that by using a capital cost recovery factor to account for system depreciation, this formula assumes a constant or "straight-line" depreciation schedule. Analysis of system economics with more complicated depreciation schedules would require the use of a different formula, and then the system economics would depend to some extent on the year of analysis relative to the system lifetime. In the CETEEM model, we modify this formula slightly by using a factor of 1/1000 in order to produce COE estimates in terms of $/kWh rather than $/MWh.

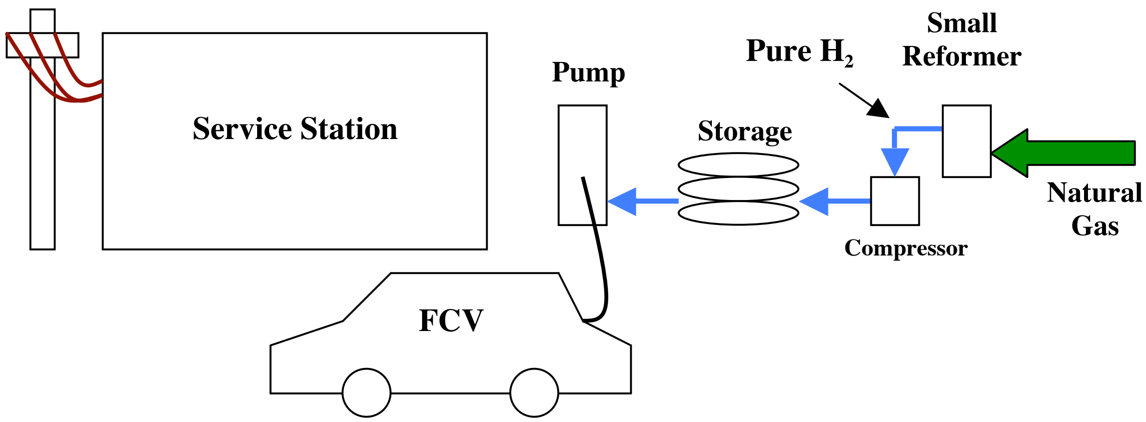
Analysis Results

The detailed results for each analysis case are shown in the tables in Appendix A at the end of the report. Appendix B provides a detailed description of the table headings in the Appendix A tables that are not self-explanatory. The following tables (Table 6 through Table 8), figures (Figure 10 through Figure 15), and text summarize the key analysis findings.

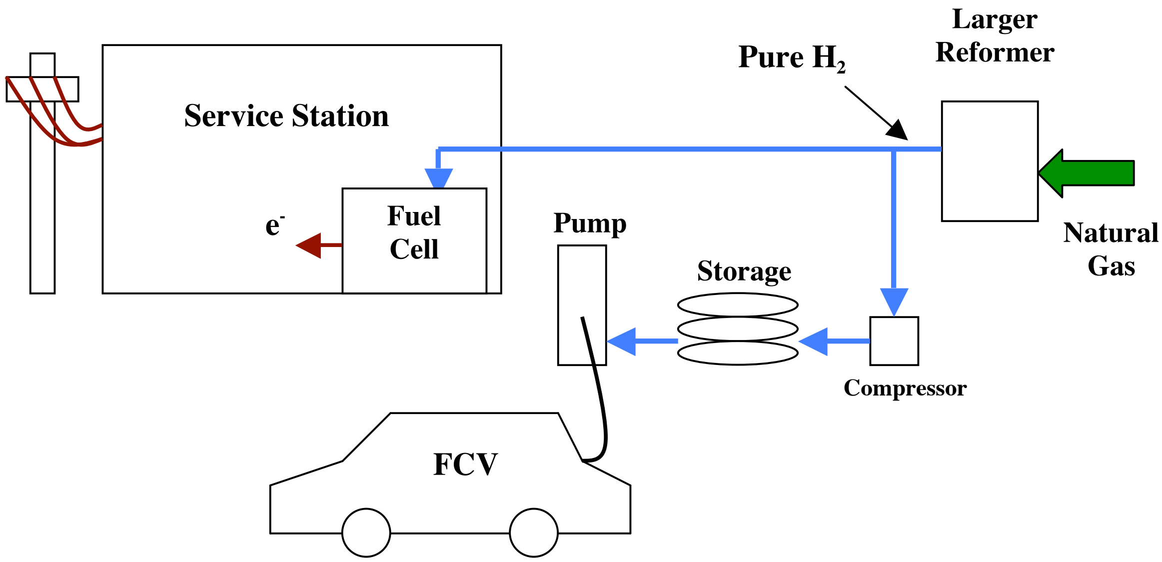
As an introduction to the analysis results, note that for the service station cases, the "net costs" calculated include the total costs of electricity and H_2 production on an annualized basis, minus the electricity energy and demand charges that are avoided through electricity self-generation, minus H_2 sales revenues. In essence, these net costs are thus the incremental costs of operating the H_2 energy stations, relative to the costs of operating a regular gasoline station that does not produce electricity or H_2. However, a more interesting comparison is to compare the costs of the energy stations with gasoline service stations that are retrofitted to produce H_2 for refueling similar numbers of FCVs, as shown in Figure 9 below.

Figure 9: Service Station Designs for Dispensing H_2 to FCVs

Service Station Scenario 1: H_2 Station



Service Station Scenario 2: H_2E-Station



The question then becomes:

> "Given that a certain number of FCVs per day need to be refueled, is the H_2E-Station a more economical way of providing this refueling than a station that employs a similar H_2 production and refueling system that is dedicated to the FCVs, but that does not co-produce electricity with a fuel cell?"

To shed light on this question, Table 6, below, shows the results of the energy station analysis for the service stations, compared with the calculated costs of providing the same level of FCV refueling with dedicated systems, and assuming for the moment an H_2 sales price of $10 per GJ.

Table 6: Comparison of Energy (H_2E) Station versus Dedicated (H_2) Station Costs for Service Station Setting

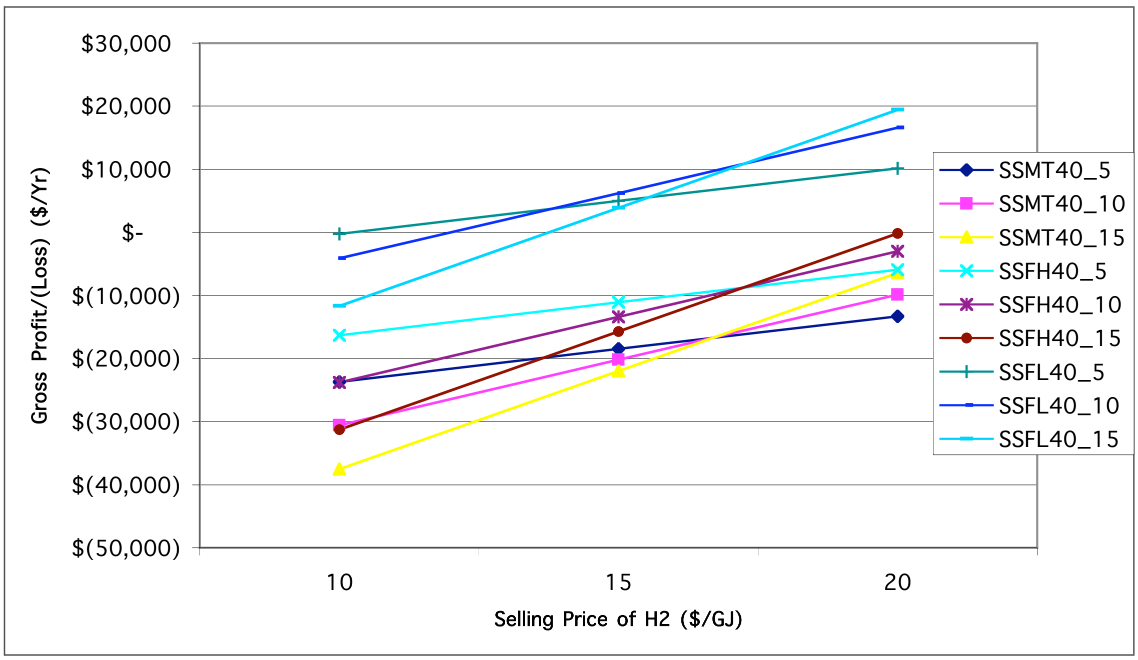
Service Station Case -- 25/40 kW fuel cell -- 5-15 FCVs/day	**Calculated Net Cost of Energy Station Operation ($/year)**	**Incremental Cost of Operating Dedicated H2 Station ($/year)**	**Savings from Energy Station Design ($/year)**
SSMT25_5	$43,216	$70,810	$27,594
SSMT25_10	$50,159	$74,022	$23,863
SSMT25_15	$57,163	$77,161	$19,998
SSFL25_5	$23,457	$58,473	$35,016
SSFL25_10	$27,847	$58,984	$31,137
SSFL25_15	$32,266	$59,495	$27,229
SSFH25_5	$36,040	$63,036	$26,996
SSFH25_10	$43,459	$66,722	$23,263
SSFH25_15	$51,112	$70,409	$19,297
SSMT40_5	$23,670	$70,810	$47,140
SSMT40_10	$30,572	$74,022	$43,450
SSMT40_15	$37,566	$77,161	$39,595
SSFL40_5	($220)	$58,473	$58,693
SSFL40_10	$4,151	$58,984	$54,833
SSFL40_15	$11,682	$59,495	$47,813
SSFH40_5	$16,281	$63,036	$46,755
SSFH40_10	$23,749	$66,722	$42,973
SSFH40_15	$31,277	$70,409	$39,132

Note: FH = future high; FL = future low (DTI); MT = medium term; SS = service station. "Incremental Cost of Operating Dedicated H2 Station" is the estimated additional cost of adding a hydrogen dispensing facility to an existing service station.

As shown above, in only one case, the service station with a 40 kW fuel cell, refueling for 5 FCVs per day, and "future low cost" economic assumptions, does any station actually cover its basic amortized capital and operational costs. In every other case, there is a net loss associated with operating the energy station. Furthermore, the losses tend to increase as the number of supported FCVs increases, in this case where hydrogen is being sold at a low price of $10 per GJ. Also, note that the energy stations that use the 40-kW fuel cell have better economics than the stations that use the 25-kW fuel cell, with net costs on the order of $20,000 per year less than the stations with the 25-kW fuel cell. This is because the additional electricity produced "adds value" that helps to make up for the low-cost hydrogen sales (see detailed results tables and various figures below for results with higher H_2 sales prices).

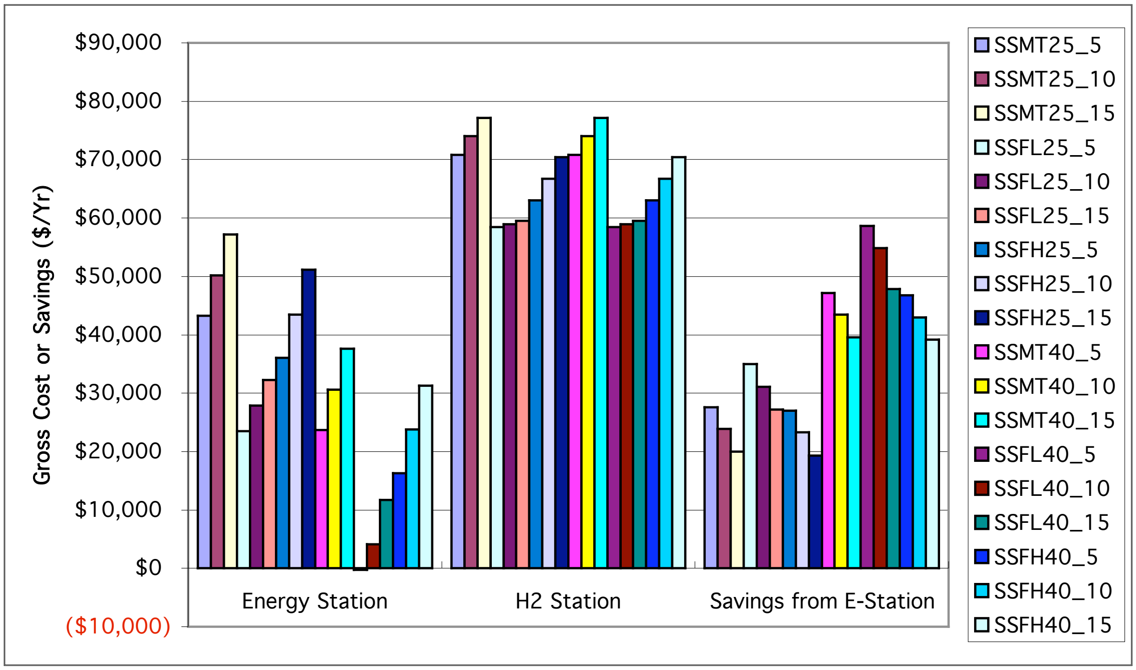
Figure 10, below, further shows that none of the 40-kW fuel cell "service station" H_2E-Stations that support only 5-15 vehicles per day are economically viable, with the exception of the "future low" cost cases with H_2 sales prices of over $15/GJ. In the "medium term" cases, the stations lose between $5,000 per year and $40,000 per year, and in the "future high" cost cases, the stations just break even with $20/GJ H_2 sales, but lose up to $30,000 per year at $10/GJ of H_2 sold.

Figure 10: Estimated Profit/Loss from H_2E-Service Station with 40 kW Fuel Cell and 5 to 15 FCVs Refueled per Day, with Medium Term, Future Low, and Future High Cost Assumptions



However, as expected, the costs of providing the same amount of hydrogen for FCVs through dedicated hydrogen refueling systems are invariably higher than the H_2E-Station designs. The H_2E-Station designs save $20,000 to almost $60,000 per year, as a way of supporting refueling for these small numbers of FCVs (See Figure 11, below).

Figure 11: Estimated Costs of H_2E-Stations with 25 and 40 kW Fuel Cell and 5-15 FCVs Refueled per Day, Compared with Costs of Dedicated H_2 Stations (H_2 price of $10/GJ)



With regard to the office building cases, Table 7 below shows the total costs per year of station operation, the net costs of station operation (again compared with an office building that produced no electricity or hydrogen), and the total initial capital investment required, for stations with H_2 sales prices of $10/GJ. Figures 12 and 13 show results for a variety of cases, and for H_2 sales prices of $10/GJ, $15/GJ, and $20/GJ.

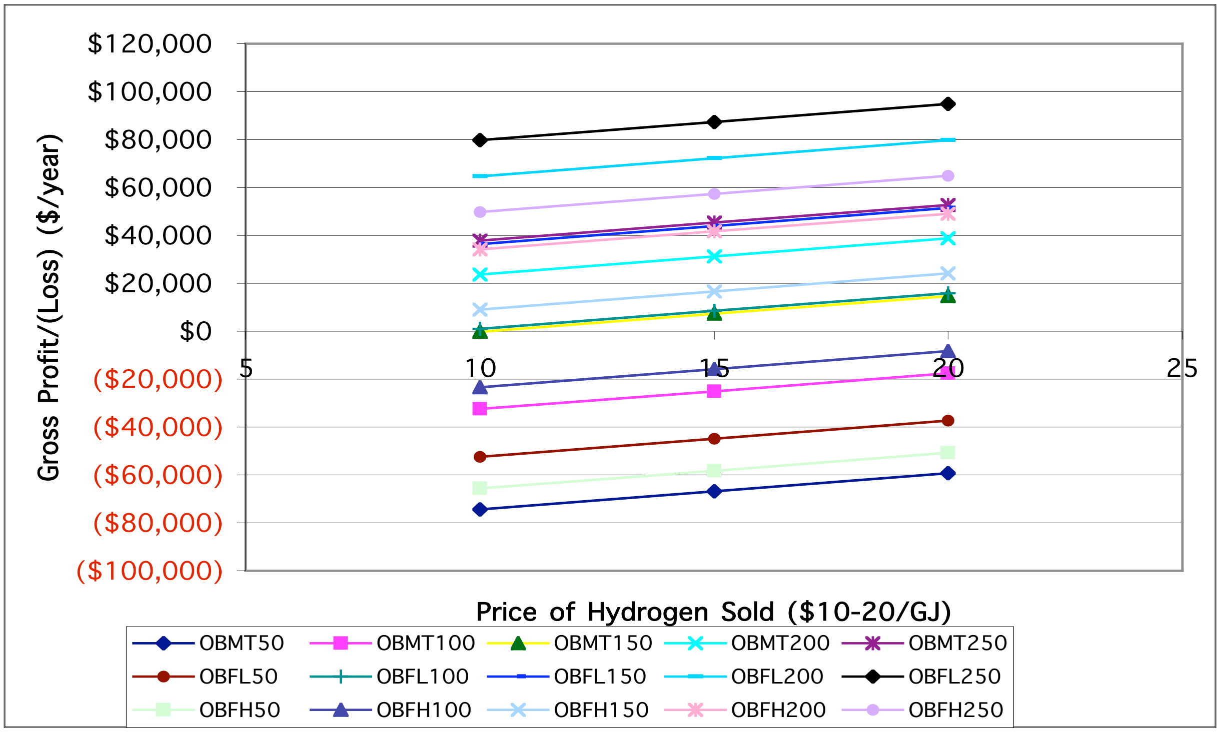
Table 7: Office Building Energy Station Results

Office Building Case	**Calculated Total Cost of Energy Station Operation ($/year)**	**Calculated Net Cost of Energy Station Operation ($/year)**	**Initial Capital Investment ($)**
OBMT50	$133,309	$74,339	$212,812
OBMT100	$122,967	$32,505	$258,093
OBMT150	$114,917	$292	$305,288
OBMT200	$109,139	($23,772)	$344,817
OBMT250	$105,723	($37,795)	$385,175
OBFL50	$105,698	$52,430	$63,834
OBFL100	$89,503	($959)	$84,169
OBFL150	$78,263	($36,362)	$104,839
OBFL200	$69,179	($64,731)	$123,311
OBFL250	$63,697	($79,821)	$141,801
OBFH50	$124,682	$65,712	$83,330
OBFH100	$113,781	$23,319	$106,607
OBFH150	$105,540	($9,086)	$130,292
OBFH200	$98,779	($34,132)	$151,653
OBFH250	$93,697	($49,821)	$172,816

As shown in the table above, in several cases the office building H_2E-Stations generate enough savings from electricity self-generation, coupled with the hydrogen sales revenue, that net savings can be realized even with H_2 sold at $10 per GJ. This savings increases with larger fuel cell systems and greater levels of electricity self-generation, and is of course greatest in the "future low cost" cases. The calculated savings ranges from about $1,000 per year up to about $80,000 per year, while in other cases with relatively small fuel cells the net cost is positive and ranges from a few hundred dollars per year to almost $75,000 per year.

Figures 10 and 11, below, show a set of results for office building H_2E-Stations with refueling for 10 FCVs per day and 50 to 250-kW fuel cells. Figure ES4 shows that the economics of these stations depend strongly on the size of the fuel cell incorporated into the office building, and also the capital costs of the technology. In these cases, with relatively optimistic capital cost assumptions, the size of the fuel cell system is actually the most dominant factor, with the 250 kW fuel cell being well-suited to this building load (peaking at about 300 kW) and offering favorable economics in all three of the cost assumption cases.

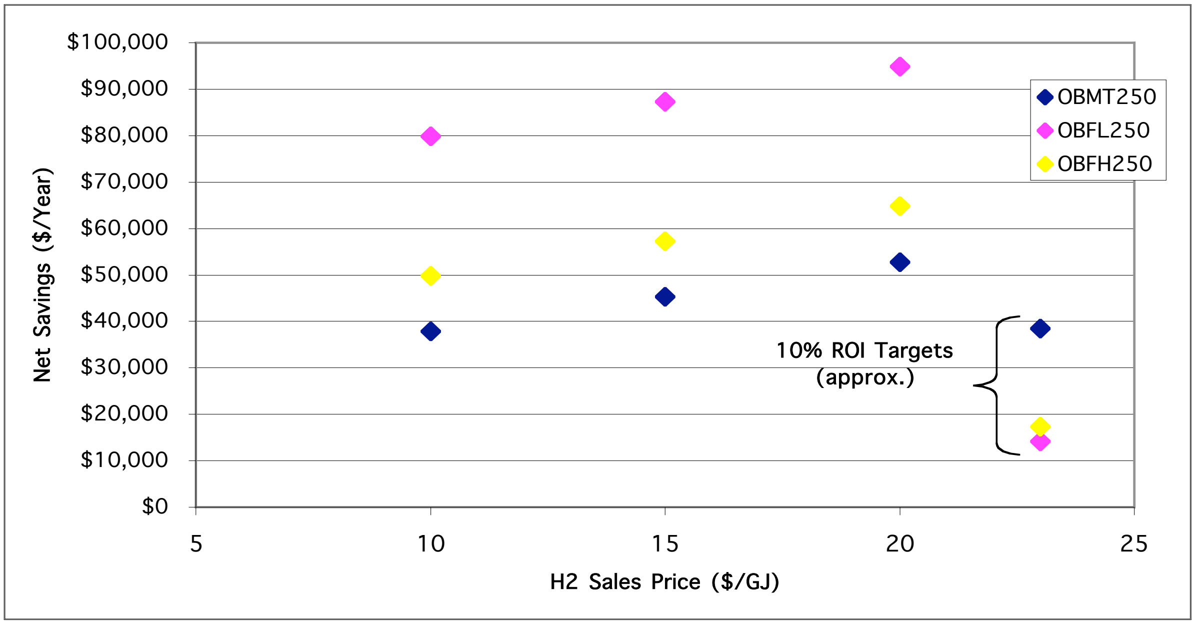
Figure 12: Estimated Profit/(Loss) from Office Building H_2E-Stations with 50 to 250-kW Fuel Cell and 10 FCVs/Day Refueled, with Medium Term, Future Low, and Future High Cost Cases



Notes: FH = future high costs; FL = future low costs; OB = office building; 50-250 = fuel cell peak kW.

Figure 13 makes this point more clear by showing the results for the 250-kW fuel cell office building H_2E-Station cases, along with approximate 10% ROI targets for each case (based on the installed capital costs of each fuel cell/reformer/H_2 storage and dispensing system). Note that even with the medium-term case it appears that the ROI target could be met or exceeded, with a range of H_2 sales prices. It would seem that in the energy market conditions that prevail in certain parts of California such as the South Coast, fuel cells with these capital and operating costs could be cost-effective, and H_2E-Stations based on these relatively large fuel cells at office buildings could prove to be attractive.

Figure 13: Estimated Savings from Office Building H_2E-Stations with 250-kW Fuel Cell and 10 FCVs/Days Refueled for 264 Days/Year, with Medium Term, Future Low, and Future High Cost Cases, and Approximate 10% ROI Targets



Additional Sensitivity Analysis

Due to the many different design possibilities and input variables involved in the analysis of hydrogen energy stations, additional sensitivity analysis is warranted with regard to component sizing, the economics of supporting greater numbers of FCVs with refueling systems of greater capacity, and various hydrogen sales prices. Analysis of these additional cases is discussed below:

- higher efficiency fuel cell operation at service station sites (50 kW fuel cell limited to 25 kW);
- greater numbers of FCVs supported at service station sites;
- hydrogen sales prices of \$10/GJ, \$15/GJ and \$20/GJ; and
- cases in which there is no specific upper limit on the number of FCVs refueled per day and hydrogen sales are maximized, and cases in which the fuel reformer is downsized slightly such that costs are reduced but fewer vehicles are fueled on peak days.

<u>Higher Efficiency Fuel Cell Operation</u>

Since cases in which the stationary fuel cells are operated at near peak power for much of the time (such as with a 25-kW fuel cell at the service station and a 50-kW fuel cell at an office building) result in relatively low overall efficiencies, of in some cases under 30%, an interesting question is how the costs of one of these cases compares with those where a larger fuel cell has its output restricted to improve efficiency. In the following case, we compare an H_2E service station with a 25-kW fuel cell that operates at peak power all the time with a similar station that incorporates a 50-kW fuel cell that is power limited (or "de-rated") to 25 kW.

Table 8: Comparison of H_2E Service Stations with 25-kW and 50-kW "Power-Limited to 25 kW" Fuel Cells

	SSFH25_5	**SSFH50HE_5**
Fuel Cell Size	25 kW	50 kW (25 kW max power)
FCVs Fueled per Day	5	5
Average Overall FC/Reformer Efficiency	24.3%	35.1%
Cost of Electricity	$0.111/kWh	$0.077/kWh
Total Initial Capital	$61,723	$87,534
Net Cost (w/Demand Charge Savings)	$36,060	$31,427

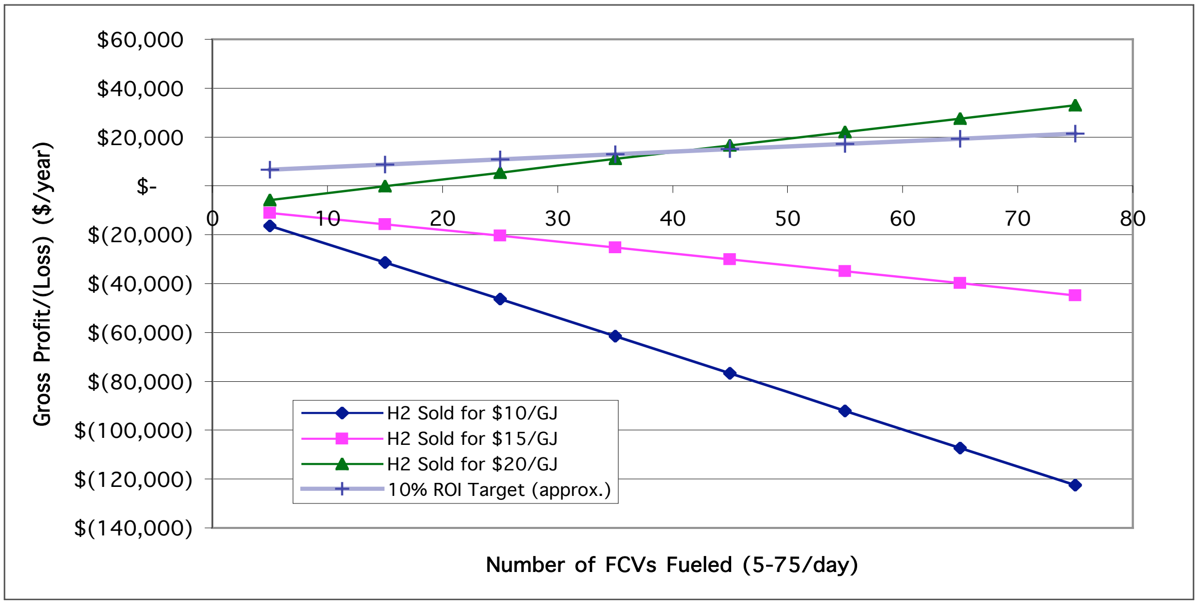
As shown in the table, the oversized fuel cell operates with an overall efficiency that is more than 10 percentage points greater, and this reduces the cost of electricity considerably even given the greater fuel cell capital cost. On an annual basis the H_2E service station with the 50 kW fuel cell that is power limited to 25 kW operates at about $3,500 per year less cost than the 25-kW fuel cell design, but neither one comes close to turning a profit with only 5 FCVs per day supported (and with hydrogen sales at $10 per GJ).

<u>Greater Numbers of FCVs Supported at Service Station Sites</u>

Clearly, the economics of supporting small number of hydrogen FCVs, even with creative H_2E Station designs, are marginal at best. Supporting larger numbers of vehicles should prove more economically feasible due to economies of scale, but how do the economics of future, larger H_2E Stations look?

We examine that question with the case of an H_2E service station with a 40-kW fuel cell and various numbers of vehicles refueled per day. Figure 14, below, shows that a 10% simple ROI target can be met with this type of H_2E-Station, that supports larger numbers of FCVs, but only with relatively high H_2 sales prices of about $20 per GJ and only with about 50 or more vehicles per day refueled. At lower H_2 sales prices of $10-15/GJ, the economics of this type of station do not look attractive, even with significant numbers of vehicles refueled. However, with lower natural gas prices this picture would change somewhat (note that this "future high" cost case assumes $6/GJ natural gas – about the present retail level in California).

Figure 14: Estimated Profit/Loss from H_2E-Service Station with 40 kW Fuel Cell, 5 to 75 FCVs Refueled per Day, and Future High Costs (w/approx. 10% ROI target)



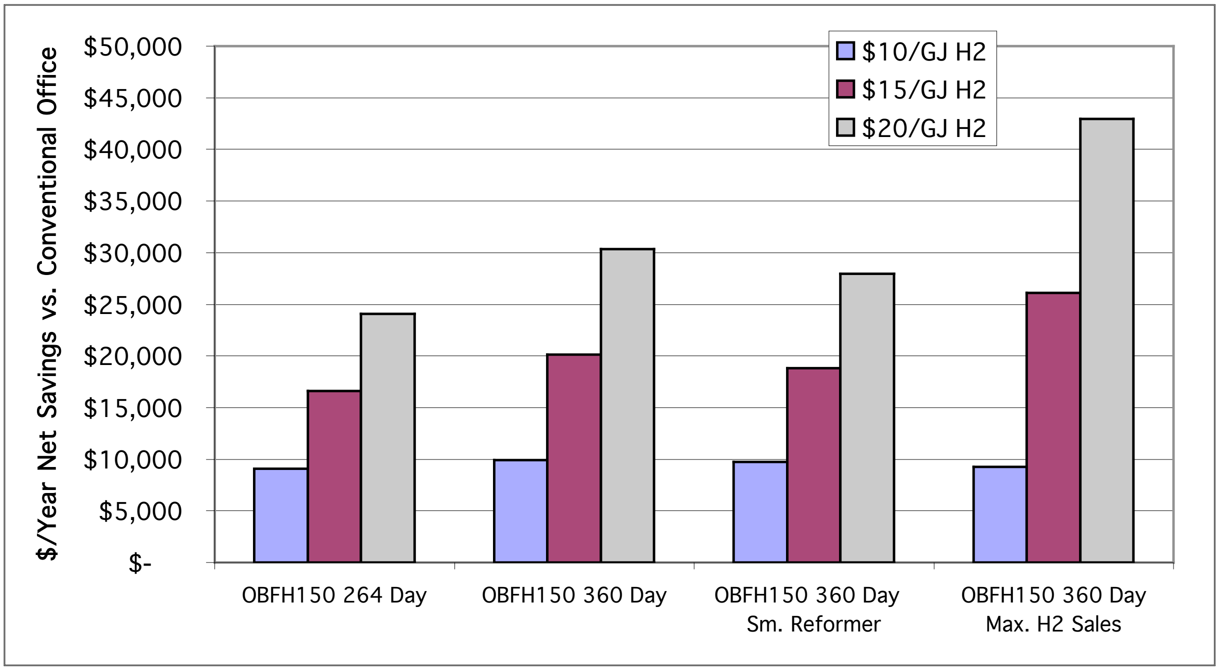
Variations in H_2E-Station Design

Finally, we analyze a few additional cases related to the design and operation of H_2E-Stations at office building locations. First, we examine a case in which the hydrogen sales from the H_2E-Station are maximized (e.g. nearly all of the available hydrogen is sold each day, rather than simply having a fixed number of vehicles per day refueled). Second, we analyze a case in which fewer vehicles are refueled at the office-building H_2E-Station on summer peak days, so that the reformer can be sized slightly smaller (e.g. the reformer is sized a bit less stringently, but some H_2 revenues are lost).

As shown in Figure 15, below, in the case in which H_2 sales are maximized and an average of about 18 vehicles per day are refueled, the net savings/profit from the H_2E-Station are enhanced by up to about $12,000 per year in the case where H_2 is sold for $20/GJ (relative to the case in which only 10 FCVs per day are refueled).

An interesting finding with regard to the case in which the reformer is downsized in order to reduce capital costs is that this strategy does not seem to pay off. This is because the revenues that are lost from the hydrogen that is not sold are greater than the savings in amortized capital cost from downsizing the reformer. In other words, given the costs of the other system components that do not scale with size when the reformer is downsized, reducing the size of the reformer alone does not seem to be a cost-effective way to improve the economics of the station.

Figure 15: Estimated Annual Savings of Office-Building Energy Station Design, Relative to Conventional Office Building (150-kW FC, 10 FCVs/Day Refueled, Future High Costs)



Notes: $/GJ figures are retail hydrogen sales prices.
"Sm. Reformer" case refers to a case where the fuel reformer is slightly undersized, thus saving a small amount of capital cost but somewhat restricting the amount of H_2 that can be sold (and FCVs refueled) on peak electricity demand days.
"Max. H_2 Sales" case refers to a case where the amount of hydrogen sold is nearly optimized on "day type-by-day type" basis, such that the average number of FCVs refueled per day is approximately 16 rather than 10.

Conclusions

In general, and particularly in the low-cost future cases, the H_2E-Stations designs that appear to be the most economically attractive are the office building setting where relatively large fuel cells in the 100-250 kW size displace significant electricity purchases in the form of electricity energy and demand charges. These avoided electricity costs help to cover the costs of producing hydrogen for FCVs, and the economics of these stations tend to look better than those of H_2E-Stations based at gasoline service stations.

However, even these H_2E-Stations at gasoline stations are more attractive than simply adding hydrogen-dispensing infrastructure to a gasoline station without co-producing electricity, and this generally reinforces the potential attractiveness of the hydrogen energy station scheme in both office building and service station locations.

Prior to presenting some initial conclusions below, we note that this analysis, as any prospective analysis, entails considerable uncertainty. This future uncertainty has been addressed here, at least to some extent, by examining two somewhat different future cost cases:

- a "future low" cost case based on relatively optimistic fuel cell and H_2 hardware manufacturing cost estimates made by DTI (Thomas et al., 2000); and
- a "future high" cost case that is simply a somewhat more conservative case with higher fuel cell cost estimates and a 25% multiplier to DTI's estimates for equipment for H_2 reformation, purification, compression, storage, and dispensing.

However, despite the considerable uncertainty in this analysis, with regard to these forward-looking capital cost estimates as well as natural gas fuel costs and other variables, a few broad conclusions are possible:

1) The economics of supporting small numbers of FCVs, on the order of 5-15 per day, are difficult and only under the most favorable circumstances can these break even or turn a small profit (e.g., H_2E-Station configurations where some electricity cost savings are realized, future low capital cost assumptions, and H_2 prices on the order of \$20/GJ of H_2 sold);

2) However, the losses associated with supporting early FCVs with hydrogen fueling can potentially be reduced by employing H_2E-Station designs, when combined with future, lower-cost fuel cell and H_2 compression and storage hardware, and in areas with relatively high electricity prices (of ~\$0.12 per kWh or more);

3) The economics of "office building" H_2E-Stations appear favorable relative to "service station" H_2E-Stations, once fuel cell and H_2 equipment becomes mass produced and less expensive, and where the economics of producing electricity and displacing grid purchases are favorable (e.g. prevailing commercial prices of \$0.12/kWh plus demand charges of \$5-12 per kW-peak/month);

4) In cases where 50 to 75 FCVs per day are supported in service station H_2E-Station designs with a 40 kW fuel cell and "future high" cost estimates, a 10% ROI target can be achieved but only with hydrogen sold at or near \$20 per GJ. With lower natural gas prices than \$6/GJ, the prospects for economic sales of hydrogen at closer to \$15/GJ would brighten;

5) If H_2 sales could be maximized at office buildings, based on the peak amount of H_2 that can be sold each day given the varying building electrical load, the economics of the H_2E-Stations can be improved, particularly with high H_2 sales prices; and

6) Office building H_2E-Station cases with slightly downsized reformers to save capital cost, but where some H_2 sales on summer peak days are lost, do not appear to be economically advantageous (but perhaps would be to some extent with higher near-term reformer costs).

Finally, we note that the analysis results described above have considered many key economic variables, but have left out many minor but potentially significant costs associated with fuel cell and H_2 equipment siting, permitting, grid interconnection, and utility interface. These costs are uncertain at this time due to site-specific variables and pending regulations regarding distributed power generating equipment interconnection, and these will also vary regionally and internationally. Again, please see Table 1 for a summary of the economic costs included and excluded from the modeling effort and analysis described herein.

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Thomas, C. E., J. P. Barbour, B. D. James, and F. D. Lomax (2000). "Analysis of Utility Hydrogen Systems and Hydrogen Airport Ground Support Equipment," Proceedings of the 1999 U.S. DOE Hydrogen Program Review, NREL/CP-570-26938.

U.S. DOE (2000). Fuel Cell Handbook: Fifth Edition. Morgantown, National Energy Technology Laboratory, DOE/NETL-2000/1110

Appendix A:

Detailed Tables of Results

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 5 FCVs per Day for 360 Days per Year, and Medium-Term Economic Assumptions (SSMT25_5)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$78,123
Avoided Electricity Energy Charges ($/year)	$22,338
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	25.00
Avoided Electricity Demand Charges ($/year)	$2,200
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$10,369
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $43,216** **H2 sales @ $15/GJ: $38,032** **H2 sales @ $20/GJ: $32,847**
Initial Capital Investment ($)	**$158,811**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1238	Potential Excess H2 (GJ/year)	1,039
Fuel ($/kWh)	$0.0741	Actual Excess H2 Produced (GJ/year)	1,037
Amortized Capital Cost ($/kWh)	$0.0398	NG for Actual Excess H2 (GJ/year)	1,481
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0100	Capital and Maintenance Cost for Excess H2 ($/year)	$9,841
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$17,247
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	5.01
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	5
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.31
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	32,850
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	275,210		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	494,210		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, and Medium-Term Economic Assumptions (SSMT25_10)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$91,493
Avoided Electricity Energy Charges ($/year)	$18,396
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	25.00
Avoided Electricity Demand Charges ($/year)	$2,200
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$20,739
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $50,159** **H2 sales @ $15/GJ: $39,790** **H2 sales @ $20/GJ: $29,420**
Initial Capital Investment ($)	**$177,206**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1186	Potential Excess H2 (GJ/year)	2,075
Fuel ($/kWh)	$0.0741	Actual Excess H2 Produced (GJ/year)	2,074
Amortized Capital Cost ($/kWh)	$0.0351	NG for Actual Excess H2 (GJ/year)	2,963
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0094	Capital and Maintenance Cost for Excess H2 ($/year)	$13,011
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$27,824
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	10.01
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.48
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	65,700
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	308,060		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	527,060		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 15 FCVs per Day for 360 Days per Year, and Medium-Term Economic Assumptions (SSMT25_15)

Summary of Total and Net Costs:			
Total Cost of Electricity and Hydrogen Production ($/year)			$104,925
Avoided Electricity Energy Charges ($/year)			$14,454
Demand Charge ($//kW-month)			$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)			25.00
Avoided Electricity Demand Charges ($/year)			$2,200
Electricity Sales Revenue ($/year)			$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:			$31,108
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)			**H2 sales @ $10/GJ: $57,163** **H2 sales @ $15/GJ: $41,609** **H2 sales @ $20/GJ: $26,055**
Initial Capital Investment ($)			**$195,676**
Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1156	Potential Excess H2 (GJ/year)	3,120
Fuel ($/kWh)	$0.0741	Actual Excess H2 Produced (GJ/year)	3,111
Amortized Capital Cost ($/kWh)	$0.0325	NG for Actual Excess H2 (GJ/year)	4,444
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0090	Capital and Maintenance Cost for Excess H2 ($/year)	$15,748
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$37,968
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	15.04
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	15
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.58
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	98,550
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	340,910		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	559,910		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 5 FCVs per Day for 360 Days per Year, and Future Low Cost Economic Assumptions (SSFL25_5)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$58,364
Avoided Electricity Energy Charges ($/year)	$22,338
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	25.00
Avoided Electricity Demand Charges ($/year)	$2,200
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$10,369
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $23,457** **H2 sales @ $15/GJ: $18,273** **H2 sales @ $20/GJ: $13,088**
Initial Capital Investment ($)	**$41,780**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0737	Potential Excess H2 (GJ/year)	1,039
Fuel ($/kWh)	$0.0593	Actual Excess H2 Produced (GJ/year)	1,037
Amortized Capital Cost ($/kWh)	$0.0107	NG for Actual Excess H2 (GJ/year)	1,481
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0038	Capital and Maintenance Cost for Excess H2 ($/year)	$2,542
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$8,468
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	5.01
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	5
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.31
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	32,850
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	275,210		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	494,210		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, and Future Low Cost Economic Assumptions (SSFL25_10)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$69,182
Avoided Electricity Energy Charges ($/year)	$18,396
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	25.00
Avoided Electricity Demand Charges ($/year)	$2,200
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$20,739
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $27,847** **H2 sales @ $15/GJ: $17,478** **H2 sales @ $20/GJ: $7,108**
Initial Capital Investment ($)	**$50,462**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0729	Potential Excess H2 (GJ/year)	2,075
Fuel ($/kWh)	$0.0593	Actual Excess H2 Produced (GJ/year)	2,074
Amortized Capital Cost ($/kWh)	$0.0102	NG for Actual Excess H2 (GJ/year)	2,963
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0035	Capital and Maintenance Cost for Excess H2 ($/year)	$3,662
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$15,513
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	10.01
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.48
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	65,700
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	308,060		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	527,060		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 15 FCVs per Day for 360 Days per Year, and Future Low Cost Economic Assumptions (SSFL25_15)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$80,028
Avoided Electricity Energy Charges ($/year)	$14,454
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	25.00
Avoided Electricity Demand Charges ($/year)	$2,200
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$31,108
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $32,266** **H2 sales @ $15/GJ: $16,712** **H2 sales @ $20/GJ: $1,158**
Initial Capital Investment ($)	**$59,164**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0725	Potential Excess H2 (GJ/year)	3,120
Fuel ($/kWh)	$0.0593	Actual Excess H2 Produced (GJ/year)	3,111
Amortized Capital Cost ($/kWh)	$0.0099	NG for Actual Excess H2 (GJ/year)	4,444
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0033	Capital and Maintenance Cost for Excess H2 ($/year)	$4,736
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$22,512
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	15.04
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	15
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.58
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	98,550
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	340,910		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	559,910		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 5 FCVs per Day for 360 Days per Year, and Future High Cost Economic Assumptions (SSFH25_5)

Summary of Total and Net Costs:			
Total Cost of Electricity and Hydrogen Production ($/year)		$70,947	
Avoided Electricity Energy Charges ($/year)		$22,338	
Demand Charge ($//kW-month)		$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)	
Avg. Peak Demand Reduction (kW)		25.00	
Avoided Electricity Demand Charges ($/year)		$2,200	
Electricity Sales Revenue ($/year)		$0	
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:		$10,369	
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)		**H2 sales @ $10/GJ: $36,040** **H2 sales @ $15/GJ: $30,856** **H2 sales @ $20/GJ: $25,671**	
Initial Capital Investment ($)		**$61,723**	
Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1106	Potential Excess H2 (GJ/year)	1,039
Fuel ($/kWh)	$0.0889	Actual Excess H2 Produced (GJ/year)	1,037
Amortized Capital Cost ($/kWh)	$0.0142	NG for Actual Excess H2 (GJ/year)	1,481
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0074	Capital and Maintenance Cost for Excess H2 ($/year)	$4,092
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$12,980
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	5.01
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	5
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.31
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	32,850
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	275,210		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	494,210		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, and Future High Cost Economic Assumptions (SSFH25_10)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$84,883
Avoided Electricity Energy Charges ($/year)	$18,396
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	25.00
Avoided Electricity Demand Charges ($/year)	$2,200
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$20,739
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $43,549** **H2 sales @ $15/GJ: $33,180** **H2 sales @ $20/GJ: $22,810**
Initial Capital Investment ($)	**$72,281**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1094	Potential Excess H2 (GJ/year)	2,075
Fuel ($/kWh)	$0.0889	Actual Excess H2 Produced (GJ/year)	2,074
Amortized Capital Cost ($/kWh)	$0.0137	NG for Actual Excess H2 (GJ/year)	2,963
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0068	Capital and Maintenance Cost for Excess H2 ($/year)	$5,444
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$23,220
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	10.01
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.48
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	65,700
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	308,060		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	527,060		

Service Station Case with 25 kW Stationary Fuel Cell, Refueling for 15 FCVs per Day for 360 Days per Year, and Future Low Cost Economic Assumptions (SSFL25_15)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$98,874
Avoided Electricity Energy Charges ($/year)	$14,454
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	25.00
Avoided Electricity Demand Charges ($/year)	$2,200
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$31,108
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $51,112** **H2 sales @ $15/GJ: $35,558** **H2 sales @ $20/GJ: $20,004**
Initial Capital Investment ($)	**$82,859**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1088	Potential Excess H2 (GJ/year)	3,120
Fuel ($/kWh)	$0.0889	Actual Excess H2 Produced (GJ/year)	3,111
Amortized Capital Cost ($/kWh)	$0.0134	NG for Actual Excess H2 (GJ/year)	4,444
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0065	Capital and Maintenance Cost for Excess H2 ($/year)	$6,745
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$33,409
NG for Electricity Production (GJ/yr)	3,245	Maximum Number of FCVs Refueled Per Day	15.04
H2 for Electricity Production (GJ/yr)	2,271	Actual FCVs Refueled Per Day	15
Electricity Produced (kWh/yr)	219,000	Fraction of Reformer Cost for FCV Fuel Production	0.58
Avg. Power Produced (kW)	25.00	Additional Electricity for H2 Compression (kWh/year)	98,550
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	340,910		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	559,910		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 5 FCVs per Day for 360 Days per Year, and Medium-Term Economic Assumptions (SSMT40_5)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$75,665
Avoided Electricity Energy Charges ($/year)	$38,106
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$10,369
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $23,670** **H2 sales @ $15/GJ: $18,486** **H2 sales @ $20/GJ: $13,301**
Initial Capital Investment ($)	**$179,998**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1167	Potential Excess H2 (GJ/year)	1,038
Fuel ($/kWh)	$0.0741	Actual Excess H2 Produced (GJ/year)	1,037
Amortized Capital Cost ($/kWh)	$0.0333	NG for Actual Excess H2 (GJ/year)	1,481
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0094	Capital and Maintenance Cost for Excess H2 ($/year)	$9,363
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$16,769
NG for Electricity Production (GJ/yr)	5,192	Maximum Number of FCVs Refueled Per Day	5.01
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	5
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.22
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	32,850
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	143,810		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	494,210		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, and Medium-Term Economic Assumptions (SSMT40_10)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$88,995
Avoided Electricity Energy Charges ($/year)	$34,164
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$20,739
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $30,572** **H2 sales @ $15/GJ: $20,203** **H2 sales @ $20/GJ: $9,833**
Initial Capital Investment ($)	**$198,393**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1140	Potential Excess H2 (GJ/year)	2,075
Fuel ($/kWh)	$0.0741	Actual Excess H2 Produced (GJ/year)	2,074
Amortized Capital Cost ($/kWh)	$0.0310	NG for Actual Excess H2 (GJ/year)	2,963
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0089	Capital and Maintenance Cost for Excess H2 ($/year)	$12,318
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$27,132
NG for Electricity Production (GJ/yr)	5,915	Maximum Number of FCVs Refueled Per Day	10.01
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.36
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	65,700
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	176,660		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	527,060		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 15 FCVs per Day for 360 Days per Year, and Medium-Term Economic Assumptions (SSMT40_15)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$102,416
Avoided Electricity Energy Charges ($/year)	$30,222
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$31,108
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $37,566** **H2 sales @ $15/GJ: $22,012** **H2 sales @ $20/GJ: $6,458**
Initial Capital Investment ($)	**$217,165**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1120	Potential Excess H2 (GJ/year)	3,120
Fuel ($/kWh)	$0.0741	Actual Excess H2 Produced (GJ/year)	3,111
Amortized Capital Cost ($/kWh)	$0.0294	NG for Actual Excess H2 (GJ/year)	4,444
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0086	Capital and Maintenance Cost for Excess H2 ($/year)	$15,086
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$37,306
NG for Electricity Production (GJ/yr)	5,195	Maximum Number of FCVs Refueled Per Day	15.04
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	15
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.46
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	98,550
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	209,510		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	559,910		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 5 FCVs per Day for 360 Days per Year, and Future Low Cost Economic Assumptions (SSFL40_5)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$51,776
Avoided Electricity Energy Charges ($/year)	$38,106
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$10,369
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $220** **H2 sales @ $15/GJ: ($4,965)** **H2 sales @ $20/GJ: ($10,149)**
Initial Capital Investment ($)	**$49,774**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0723	Potential Excess H2 (GJ/year)	1,038
Fuel ($/kWh)	$0.0593	Actual Excess H2 Produced (GJ/year)	1,037
Amortized Capital Cost ($/kWh)	$0.0094	NG for Actual Excess H2 (GJ/year)	1,481
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0037	Capital and Maintenance Cost for Excess H2 ($/year)	$2,527
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$8,452
NG for Electricity Production (GJ/yr)	5,192	Maximum Number of FCVs Refueled Per Day	5.01
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	5
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.22
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	32,850
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	143,810		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	494,210		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, and Future Low Cost Economic Assumptions (SSFL40_10)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$62,573
Avoided Electricity Energy Charges ($/year)	$34,164
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$20,739
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $4,151** **H2 sales @ $15/GJ: ($6,219)** **H2 sales @ $20/GJ: ($16,588)**
Initial Capital Investment ($)	**$58,457**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0718	Potential Excess H2 (GJ/year)	2,075
Fuel ($/kWh)	$0.0593	Actual Excess H2 Produced (GJ/year)	2,074
Amortized Capital Cost ($/kWh)	$0.0092	NG for Actual Excess H2 (GJ/year)	2,963
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0034	Capital and Maintenance Cost for Excess H2 ($/year)	$3,620
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$15,471
NG for Electricity Production (GJ/yr)	5,915	Maximum Number of FCVs Refueled Per Day	10.01
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.36
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	65,700
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	176,660		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	527,060		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 15 FCVs per Day for 360 Days per Year, and Future Low Cost Economic Assumptions (SSFL40_15)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$76,532
Avoided Electricity Energy Charges ($/year)	$30,222
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$31,108
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $11,682** **H2 sales @ $15/GJ: ($3,872)** **H2 sales @ $20/GJ: ($19,426)**
Initial Capital Investment ($)	**$87,835**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0747	Potential Excess H2 (GJ/year)	3,148
Fuel ($/kWh)	$0.0593	Actual Excess H2 Produced (GJ/year)	3,111
Amortized Capital Cost ($/kWh)	$0.0101	NG for Actual Excess H2 (GJ/year)	4,444
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0053	Capital and Maintenance Cost for Excess H2 ($/year)	$6,710
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$24,486
NG for Electricity Production (GJ/yr)	5,915	Maximum Number of FCVs Refueled Per Day	15.2
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	15
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.46
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	98,550
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	209,510		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	559,910		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 5 FCVs per Day for 360 Days per Year, and Future High Cost Economic Assumptions (SSFH40_5)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$68,276
Avoided Electricity Energy Charges ($/year)	$38,106
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$10,369
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $16,281** **H2 sales @ $15/GJ: $11,097** **H2 sales @ $20/GJ: $5,912**
Initial Capital Investment ($)	**$66,617**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1065	Potential Excess H2 (GJ/year)	1,038
Fuel ($/kWh)	$0.0889	Actual Excess H2 Produced (GJ/year)	1,037
Amortized Capital Cost ($/kWh)	$0.0106	NG for Actual Excess H2 (GJ/year)	1,481
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0070	Capital and Maintenance Cost for Excess H2 ($/year)	$4,078
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$12,966
NG for Electricity Production (GJ/yr)	5,192	Maximum Number of FCVs Refueled Per Day	5.01
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	5
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.22
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	32,850
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	143,810		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	494,210		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, and Future High Cost Economic Assumptions (SSFH40_10)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$82,171
Avoided Electricity Energy Charges ($/year)	$34,164
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$20,739
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $23,749** **H2 sales @ $15/GJ: $13,380** **H2 sales @ $20/GJ: $3,010**
Initial Capital Investment ($)	**$77,175**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1058	Potential Excess H2 (GJ/year)	2,075
Fuel ($/kWh)	$0.0889	Actual Excess H2 Produced (GJ/year)	2,074
Amortized Capital Cost ($/kWh)	$0.0103	NG for Actual Excess H2 (GJ/year)	2,963
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0066	Capital and Maintenance Cost for Excess H2 ($/year)	$5,401
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$23,177
NG for Electricity Production (GJ/yr)	5,915	Maximum Number of FCVs Refueled Per Day	10.01
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.36
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	65,700
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	176,660		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	527,060		

Service Station Case with 40 kW Stationary Fuel Cell, Refueling for 15 FCVs per Day for 360 Days per Year, and Future High Cost Economic Assumptions (SSFH40_15)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$96,127
Avoided Electricity Energy Charges ($/year)	$30,222
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	40.00
Avoided Electricity Demand Charges ($/year)	$3,520
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$31,108
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $31,277** **H2 sales @ $15/GJ: $15,723** **H2 sales @ $20/GJ: $169**
Initial Capital Investment ($)	**$87,835**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1053	Potential Excess H2 (GJ/year)	3,120
Fuel ($/kWh)	$0.0889	Actual Excess H2 Produced (GJ/year)	3,111
Amortized Capital Cost ($/kWh)	$0.0101	NG for Actual Excess H2 (GJ/year)	4,444
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0062	Capital and Maintenance Cost for Excess H2 ($/year)	$6,710
Avg. Fuel Cell + Reformer System Efficiency (%)	24.3	Total Cost for Excess H2 ($/year)	$33,374
NG for Electricity Production (GJ/yr)	5,195	Maximum Number of FCVs Refueled Per Day	15.04
H2 for Electricity Production (GJ/yr)	3,634	Actual FCVs Refueled Per Day	15
Electricity Produced (kWh/yr)	350,400	Fraction of Reformer Cost for FCV Fuel Production	0.46
Avg. Power Produced (kW)	40.00	Additional Electricity for H2 Compression (kWh/year)	98,550
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	209,510		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	559,910		

Office Building Case with 50 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Medium-Term Economic Assumptions (OBMT50)

Summary of Total and Net Costs:			
Total Cost of Electricity and Hydrogen Production ($/year)			$133,309
Avoided Electricity Energy Charges ($/year)			$41,153
Demand Charge ($//kW-month)			$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)			32.00
Avoided Electricity Demand Charges ($/year)			$2,817
Electricity Sales Revenue ($/year)			$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:			$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)			**H2 sales @ $10/GJ: $74,339** **H2 sales @ $15/GJ: $66,839** **H2 sales @ $20/GJ: $59,339**
Initial Capital Investment ($)			**$212,812**
Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.1070	Potential Excess H2 (GJ/year)	2,784
Fuel ($/kWh)	$0.0663	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0312	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0095	Capital and Maintenance Cost for Excess H2 ($/year)	$12,032
Avg. Fuel Cell + Reformer System Efficiency (%)	27.2	Total Cost for Excess H2 ($/year)	$22,746
NG for Electricity Production (GJ/yr)	5,382	Average Maximum Number of FCVs Refueled Per Day	13.61
H2 for Electricity Production (GJ/yr)	3,768	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	390,461	Fraction of Reformer Cost for FCV Fuel Production	0.32
Avg. Power Produced (kW)	45.19	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	566,992		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 100 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Medium-Term Economic Assumptions (OBMT100)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$122,967
Avoided Electricity Energy Charges ($/year)	$68,244
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	82.00
Avoided Electricity Demand Charges ($/year)	$7,218
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $32,505** **H2 sales @ $15/GJ: $25,005** **H2 sales @ $20/GJ: $17,505**
Initial Capital Investment ($)	**$258,093**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0956	Potential Excess H2 (GJ/year)	2,935
Fuel ($/kWh)	$0.0596	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0268	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0093	Capital and Maintenance Cost for Excess H2 ($/year)	$11,614
Avg. Fuel Cell + Reformer System Efficiency (%)	30.3	Total Cost for Excess H2 ($/year)	$22,328
NG for Electricity Production (GJ/yr)	8,150	Average Maximum Number of FCVs Refueled Per Day	14.35
H2 for Electricity Production (GJ/yr)	5,705	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	616,221	Fraction of Reformer Cost for FCV Fuel Production	0.24
Avg. Power Produced (kW)	71.32	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	341,232		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 150 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Medium-Term Economic Assumptions (OBMT150)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$114,917
Avoided Electricity Energy Charges ($/year)	$88,007
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	132.00
Avoided Electricity Demand Charges ($/year)	$11,618
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $292** **H2 sales @ $15/GJ: ($7,208)** **H2 sales @ $20/GJ: ($14,708)**
Initial Capital Investment ($)	**$305,288**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0923	Potential Excess H2 (GJ/year)	3,914
Fuel ($/kWh)	$0.0562	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0268	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0093	Capital and Maintenance Cost for Excess H2 ($/year)	$11,410
Avg. Fuel Cell + Reformer System Efficiency (%)	32.2	Total Cost for Excess H2 ($/year)	$22,124
NG for Electricity Production (GJ/yr)	10,043	Average Maximum Number of FCVs Refueled Per Day	19.13
H2 for Electricity Production (GJ/yr)	7,030	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	780,911	Fraction of Reformer Cost for FCV Fuel Production	0.19
Avg. Power Produced (kW)	90.38	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	176,541		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 200 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Medium-Term Economic Assumptions (OBMT200)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$109,139
Avoided Electricity Energy Charges ($/year)	$101,891
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	182.00
Avoided Electricity Demand Charges ($/year)	$16,020
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($23,772)** **H2 sales @ $15/GJ: ($31,272)** **H2 sales @ $20/GJ: ($38,772)**
Initial Capital Investment ($)	**$344,817**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0902	Potential Excess H2 (GJ/year)	4,806
Fuel ($/kWh)	$0.0536	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0273	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0093	Capital and Maintenance Cost for Excess H2 ($/year)	$11,211
Avg. Fuel Cell + Reformer System Efficiency (%)	33.7	Total Cost for Excess H2 ($/year)	$21,925
NG for Electricity Production (GJ/yr)	11,082	Average Maximum Number of FCVs Refueled Per Day	23.5
H2 for Electricity Production (GJ/yr)	7,758	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	896,609	Fraction of Reformer Cost for FCV Fuel Production	0.16
Avg. Power Produced (kW)	103.77	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	60,843		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 250 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Medium-Term Economic Assumptions (OBMT250)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$105,723
Avoided Electricity Energy Charges ($/year)	$108,444
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	227.32
Avoided Electricity Demand Charges ($/year)	$20,074
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($37,795)** **H2 sales @ $15/GJ: ($45,295)** **H2 sales @ $20/GJ: ($52,795)**
Initial Capital Investment ($)	**$385,175**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0888	Potential Excess H2 (GJ/year)	6,776
Fuel ($/kWh)	$0.0510	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0286	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0093	Capital and Maintenance Cost for Excess H2 ($/year)	$11,368
Avg. Fuel Cell + Reformer System Efficiency (%)	35.4	Total Cost for Excess H2 ($/year)	$22,082
NG for Electricity Production (GJ/yr)	10,737	Average Maximum Number of FCVs Refueled Per Day	33.2
H2 for Electricity Production (GJ/yr)	7,516	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	951,221	Fraction of Reformer Cost for FCV Fuel Production	0.15
Avg. Power Produced (kW)	110.10	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	6,231		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 50 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future Low Cost Economic Assumptions (OBFL50)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$105,698
Avoided Electricity Energy Charges ($/year)	$41,153
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	32.00
Avoided Electricity Demand Charges ($/year)	$2,817
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $52,430** **H2 sales @ $15/GJ: $44,930** **H2 sales @ $20/GJ: $37,430**
Initial Capital Investment ($)	**$63,834**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0653	Potential Excess H2 (GJ/year)	2,784
Fuel ($/kWh)	$0.0530	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0091	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0032	Capital and Maintenance Cost for Excess H2 ($/year)	$3,591
Avg. Fuel Cell + Reformer System Efficiency (%)	27.2	Total Cost for Excess H2 ($/year)	$12,162
NG for Electricity Production (GJ/yr)	5,382	Average Maximum Number of FCVs Refueled Per Day	13.61
H2 for Electricity Production (GJ/yr)	3,768	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	390,461	Fraction of Reformer Cost for FCV Fuel Production	0.32
Avg. Power Produced (kW)	45.19	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	566,992		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 100 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future Low Cost Economic Assumptions (OBFL100)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$89,503
Avoided Electricity Energy Charges ($/year)	$68,244
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	82.00
Avoided Electricity Demand Charges ($/year)	$7,218
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($959)** **H2 sales @ $15/GJ: ($8,459)** **H2 sales @ $20/GJ: ($15,959)**
Initial Capital Investment ($)	**$84,169**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0589	Potential Excess H2 (GJ/year)	2,935
Fuel ($/kWh)	$0.0476	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0081	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0032	Capital and Maintenance Cost for Excess H2 ($/year)	$3,595
Avg. Fuel Cell + Reformer System Efficiency (%)	30.3	Total Cost for Excess H2 ($/year)	$12,166
NG for Electricity Production (GJ/yr)	8,150	Average Maximum Number of FCVs Refueled Per Day	14.35
H2 for Electricity Production (GJ/yr)	5,705	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	616,221	Fraction of Reformer Cost for FCV Fuel Production	0.24
Avg. Power Produced (kW)	71.32	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	341,232		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 150 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future Low Cost Economic Assumptions (OBFL150)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$78,263
Avoided Electricity Energy Charges ($/year)	$88,007
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	132.00
Avoided Electricity Demand Charges ($/year)	$11,618
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($36,362)** **H2 sales @ $15/GJ: ($43,862)** **H2 sales @ $20/GJ: ($51,362)**
Initial Capital Investment ($)	**$104,839**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0562	Potential Excess H2 (GJ/year)	3,914
Fuel ($/kWh)	$0.0449	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0081	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0032	Capital and Maintenance Cost for Excess H2 ($/year)	$3,629
Avg. Fuel Cell + Reformer System Efficiency (%)	32.2	Total Cost for Excess H2 ($/year)	$12,201
NG for Electricity Production (GJ/yr)	10,043	Average Maximum Number of FCVs Refueled Per Day	19.13
H2 for Electricity Production (GJ/yr)	7,030	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	780,911	Fraction of Reformer Cost for FCV Fuel Production	0.19
Avg. Power Produced (kW)	90.38	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	176,541		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 200 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future Low Cost Economic Assumptions (OBFL200)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$69,179
Avoided Electricity Energy Charges ($/year)	$101,891
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	182.00
Avoided Electricity Demand Charges ($/year)	$16,020
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($64,731)** **H2 sales @ $15/GJ: ($72,231)** **H2 sales @ $20/GJ: ($79,731)**
Initial Capital Investment ($)	**$123,311**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0543	Potential Excess H2 (GJ/year)	4,806
Fuel ($/kWh)	$0.0429	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0081	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0032	Capital and Maintenance Cost for Excess H2 ($/year)	$3,638
Avg. Fuel Cell + Reformer System Efficiency (%)	33.7	Total Cost for Excess H2 ($/year)	$12,209
NG for Electricity Production (GJ/yr)	11,082	Average Maximum Number of FCVs Refueled Per Day	23.5
H2 for Electricity Production (GJ/yr)	7,758	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	896,609	Fraction of Reformer Cost for FCV Fuel Production	0.16
Avg. Power Produced (kW)	103.77	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	60,843		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 250 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future Low Cost Economic Assumptions (OBFL250)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$63,697
Avoided Electricity Energy Charges ($/year)	$108,444
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	227.32
Avoided Electricity Demand Charges ($/year)	$20,074
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($79,821)** **H2 sales @ $15/GJ: ($87,321)** **H2 sales @ $20/GJ: ($94,821)**
Initial Capital Investment ($)	**$141,801**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0524	Potential Excess H2 (GJ/year)	6,776
Fuel ($/kWh)	$0.0408	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0084	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0032	Capital and Maintenance Cost for Excess H2 ($/year)	$3,713
Avg. Fuel Cell + Reformer System Efficiency (%)	35.4	Total Cost for Excess H2 ($/year)	$12,284
NG for Electricity Production (GJ/yr)	10,737	Average Maximum Number of FCVs Refueled Per Day	33.1
H2 for Electricity Production (GJ/yr)	7,516	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	951,221	Fraction of Reformer Cost for FCV Fuel Production	0.15
Avg. Power Produced (kW)	110.10	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	6,231		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 50 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future High Cost Economic Assumptions (OBFH50)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$124,682
Avoided Electricity Energy Charges ($/year)	$41,153
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	32.00
Avoided Electricity Demand Charges ($/year)	$2,817
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $65,712** **H2 sales @ $15/GJ: $58,212** **H2 sales @ $20/GJ: $50,712**
Initial Capital Investment ($)	**$83,330**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0964	Potential Excess H2 (GJ/year)	2,784
Fuel ($/kWh)	$0.0795	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0103	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0066	Capital and Maintenance Cost for Excess H2 ($/year)	$5,353
Avg. Fuel Cell + Reformer System Efficiency (%)	27.2	Total Cost for Excess H2 ($/year)	$18,210
NG for Electricity Production (GJ/yr)	5,382	Average Maximum Number of FCVs Refueled Per Day	13.61
H2 for Electricity Production (GJ/yr)	3,768	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	390,461	Fraction of Reformer Cost for FCV Fuel Production	0.32
Avg. Power Produced (kW)	45.19	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	566,992		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 100 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future High Cost Economic Assumptions (OBFH100)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$113,781
Avoided Electricity Energy Charges ($/year)	$68,244
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	82.00
Avoided Electricity Demand Charges ($/year)	$7,218
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: $23,319** **H2 sales @ $15/GJ: $15,819** **H2 sales @ $20/GJ: $8,319**
Initial Capital Investment ($)	**$106,607**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0872	Potential Excess H2 (GJ/year)	2,935
Fuel ($/kWh)	$0.0715	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0092	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0066	Capital and Maintenance Cost for Excess H2 ($/year)	$5,364
Avg. Fuel Cell + Reformer System Efficiency (%)	30.3	Total Cost for Excess H2 ($/year)	$18,221
NG for Electricity Production (GJ/yr)	8,150	Average Maximum Number of FCVs Refueled Per Day	14.35
H2 for Electricity Production (GJ/yr)	5,705	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	616,221	Fraction of Reformer Cost for FCV Fuel Production	0.24
Avg. Power Produced (kW)	71.32	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	341,232		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 150 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future High Cost Economic Assumptions (OBFH150)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$105,540
Avoided Electricity Energy Charges ($/year)	$88,007
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	132.00
Avoided Electricity Demand Charges ($/year)	$11,618
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($9,086)** **H2 sales @ $15/GJ: ($16,586)** **H2 sales @ $20/GJ: ($24,086)**
Initial Capital Investment ($)	**$130,292**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0832	Potential Excess H2 (GJ/year)	3,914
Fuel ($/kWh)	$0.0449	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0081	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0032	Capital and Maintenance Cost for Excess H2 ($/year)	$5,411
Avg. Fuel Cell + Reformer System Efficiency (%)	32.2	Total Cost for Excess H2 ($/year)	$18,268
NG for Electricity Production (GJ/yr)	10,043	Average Maximum Number of FCVs Refueled Per Day	19.13
H2 for Electricity Production (GJ/yr)	7,030	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	780,911	Fraction of Reformer Cost for FCV Fuel Production	0.19
Avg. Power Produced (kW)	90.38	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	176,541		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 200 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future High Cost Economic Assumptions (OBFH200)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$98,779
Avoided Electricity Energy Charges ($/year)	$101,891
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	182.00
Avoided Electricity Demand Charges ($/year)	$16,020
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($34,132)** **H2 sales @ $15/GJ: ($41,632)** **H2 sales @ $20/GJ: ($49,132)**
Initial Capital Investment ($)	**$151,653**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0802	Potential Excess H2 (GJ/year)	4,806
Fuel ($/kWh)	$0.0643	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0092	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0067	Capital and Maintenance Cost for Excess H2 ($/year)	$5,425
Avg. Fuel Cell + Reformer System Efficiency (%)	33.7	Total Cost for Excess H2 ($/year)	$18,238
NG for Electricity Production (GJ/yr)	11,082	Average Maximum Number of FCVs Refueled Per Day	23.5
H2 for Electricity Production (GJ/yr)	7,758	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	896,609	Fraction of Reformer Cost for FCV Fuel Production	0.16
Avg. Power Produced (kW)	103.77	Additional Electricity for H2 Compression (kWh/year)	47,520
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	60,843		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case with 250 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 264 Days per Year, and Future High Cost Economic Assumptions (OBFH250)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$93,697
Avoided Electricity Energy Charges ($/year)	$108,444
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	227.32
Avoided Electricity Demand Charges ($/year)	$20,074
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$15,000
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($49,821)** **H2 sales @ $15/GJ: ($57,321)** **H2 sales @ $20/GJ: ($64,821)**
Initial Capital Investment ($)	**$172,816**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0773	Potential Excess H2 (GJ/year)	6,776
Fuel ($/kWh)	$0.0611	Actual Excess H2 Produced (GJ/year)	1,500
Amortized Capital Cost ($/kWh)	$0.0095	NG for Actual Excess H2 (GJ/year)	2,143
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.00367	Capital and Maintenance Cost for Excess H2 ($/year)	$5,516
Avg. Fuel Cell + Reformer System Efficiency (%)	35.4	Total Cost for Excess H2 ($/year)	$18,373
NG for Electricity Production (GJ/yr)	10,737	Average Maximum Number of FCVs Refueled Per Day	33.1
H2 for Electricity Production (GJ/yr)	7,516	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	951,221	Fraction of Reformer Cost for FCV Fuel Production	0.15
Avg. Power Produced (kW)	110.10	Additional Electricity for H2 Compression (kWh/year)	64,800
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	6,231		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	957,452		

Office Building Case: 150 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, and Future High Cost Case (OBFH150_360)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$111,814
Avoided Electricity Energy Charges ($/year)	$89,629
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	132.00
Avoided Electricity Demand Charges ($/year)	$11,619
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$20,455
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($9,889)** **H2 sales @ $15/GJ: ($20,117)** **H2 sales @ $20/GJ: ($30,344)**
Initial Capital Investment ($)	**$130,292**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0833	Potential Excess H2 (GJ/year)	3,769
Fuel ($/kWh)	$0.0677	Actual Excess H2 Produced (GJ/year)	2,046
Amortized Capital Cost ($/kWh)	$0.0090	NG for Actual Excess H2 (GJ/year)	2,922
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0066	Capital and Maintenance Cost for Excess H2 ($/year)	$5,411
Avg. Fuel Cell + Reformer System Efficiency (%)	32.0	Total Cost for Excess H2 ($/year)	$22,943
NG for Electricity Production (GJ/yr)	10,251	Average Maximum Number of FCVs Refueled Per Day	18.42
H2 for Electricity Production (GJ/yr)	7,175	Actual FCVs Refueled Per Day	10
Electricity Produced (kWh/yr)	794,432	Fraction of Reformer Cost for FCV Fuel Production	0.24
Avg. Power Produced (kW)	91.95	Additional Electricity for H2 Compression (kWh/year)	64,800
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	180,300		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	974,732		

Office Building Case: 150 kW Stationary Fuel Cell, Refueling for 10 FCVs per Day for 360 Days per Year, Future High Cost Case, and Smaller Reformer (OBFH150_SM)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$109,724
Avoided Electricity Energy Charges ($/year)	$89,629
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	132.00
Avoided Electricity Demand Charges ($/year)	$11,619
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$18,205
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($9,729)** **H2 sales @ $15/GJ: ($18,832)** **H2 sales @ $20/GJ: ($27,934)**
Initial Capital Investment ($)	**$128,220**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0833	Potential Excess H2 (GJ/year)	3,032
Fuel ($/kWh)	$0.0677	Actual Excess H2 Produced (GJ/year)	1,821
Amortized Capital Cost ($/kWh)	$0.0089	NG for Actual Excess H2 (GJ/year)	2,601
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0067	Capital and Maintenance Cost for Excess H2 ($/year)	$5,249
Avg. Fuel Cell + Reformer System Efficiency (%)	32.0	Total Cost for Excess H2 ($/year)	$20,853
NG for Electricity Production (GJ/yr)	10,251	Average Maximum Number of FCVs Refueled Per Day	14.82
H2 for Electricity Production (GJ/yr)	7,175	Actual FCVs Refueled Per Day	~9.5
Electricity Produced (kWh/yr)	794,432	Fraction of Reformer Cost for FCV Fuel Production	0.29
Avg. Power Produced (kW)	91.95	Additional Electricity for H2 Compression (kWh/year)	64,800
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	180,300		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	974,732		

Office Building Case: 150 kW Stationary Fuel Cell, Refueling for 10 FCVs/day 360 days/yr, Future High Cost Case, and Maximum H2 Sales (OBFH150_MX)

Summary of Total and Net Costs:	
Total Cost of Electricity and Hydrogen Production ($/year)	$127,750
Avoided Electricity Energy Charges ($/year)	$91,825
Demand Charge ($//kW-month)	$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)
Avg. Peak Demand Reduction (kW)	132.00
Avoided Electricity Demand Charges ($/year)	$11,425
Electricity Sales Revenue ($/year)	$0
Hydrogen Sales Revenue ($/year) - H2 sales @ $10/GJ:	$33,733
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)	**H2 sales @ $10/GJ: ($9,233)** **H2 sales @ $15/GJ: ($26,100)** **H2 sales @ $20/GJ: ($42,966)**
Initial Capital Investment ($)	**$130,292**

Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	$0.0833	Potential Excess H2 (GJ/year)	3,522
Fuel ($/kWh)	$0.0682	Actual Excess H2 Produced (GJ/year)	2,373
Amortized Capital Cost ($/kWh)	$0.0089	NG for Actual Excess H2 (GJ/year)	4,819
Maintenance and fuel cell stack refurbishment ($/kWh)	$0.0066	Capital and Maintenance Cost for Excess H2 ($/year)	$5,411
Avg. Fuel Cell + Reformer System Efficiency (%)	32.0	Total Cost for Excess H2 ($/year)	$34,325
NG for Electricity Production (GJ/yr)	10,251	Average Maximum Number of FCVs Refueled Per Day	17.22
H2 for Electricity Production (GJ/yr)	7,422	Actual FCVs Refueled Per Day	~16.5
Electricity Produced (kWh/yr)	812,729	Fraction of Reformer Cost for FCV Fuel Production	0.32
Avg. Power Produced (kW)	94.07	Additional Electricity for H2 Compression (kWh/year)	106,866
Electricity Sold to Grid (kWh/yr)	0		
Electricity Purchased (kWh/yr)	204,070		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	1,016,798		

Appendix B:

Explanation of Table Headings

Summary of Total and Net Costs:			
Total Cost of Electricity and Hydrogen Production ($/year)		Annualized cost of capital, plus fuel costs, plus maintenance and fuel cell stack refurbishment	
Avoided Electricity Energy Charges ($/year)		Avoided charge for electricity due to self generation, that would have been paid by a regular OB or SS with no self gen or H2 sales (and a lower electrical load w/no H2 compression)	
Demand Charge ($//kW-month)		$5/kW-month for 8 months (fall-spring) $12/kW-month for 4 months (summer)	
Avg. Peak Demand Reduction (kW)		Electricity demand reduction due to fuel cell self-generation	
Avoided Electricity Demand Charges ($/year)		Avoided electricity demand charge due to self generation	
Electricity Sales Revenue ($/year)		Revenue due to the sale of electricity to the grid	
Hydrogen Sales Revenue ($/year)		Revenue from the sale of H2 to FCVs @ $10/GJ	
Net Cost or (Savings) ($/year) (Total cost, minus avoided electricity energy and demand charges, minus H2 sales revenue)		Total cost above, minus avoided electricity energy and demand charges, minus H2 sales revenue, minus electricity sales revenue (if any)	
Initial Capital Investment ($)		Capital cost of fuel cell, reformer, and H2 compressor, storage, and pump	
Electricity Production:		**Hydrogen Production for FCVs:**	
Cost of Electricity ($/kWh)	COE	Potential Excess H2 (GJ/year)	H2 that could be produced with extra ref. cap.
Fuel ($/kWh)	Fuel component	Actual Excess H2 Produced (GJ/year)	Actual excess H2 produced for FCVs
Amortized Capital Cost ($/kWh)	Capital component	NG for Actual Excess H2 (GJ/year)	S.E.
Maintenance and fuel cell stack refurbishment ($/kWh)	Maint. component	Capital and Maintenance Cost for Excess H2 ($/year)	Annualized reformer capital and maint. for excess H2
Avg. Fuel Cell + Reformer System Efficiency (%)	System effic. (neat H2)	Total Cost for Excess H2 ($/year)	Above costs, plus fuel costs
NG for Electricity Production (GJ/yr)	NG used for elect.	Maximum Number of FCVs Refueled Per Day	S.E.
H2 for Electricity Production (GJ/yr)	H2 used for elect.	Actual FCVs Refueled Per Day	S.E.
Electricity Produced (kWh/yr)	S.E.	Fraction of Reformer Cost for FCV Fuel Production	S.E.
Avg. Power Produced (kW)	S.E.	Additional Electricity for H2 Compression (kWh/year)	S.E.
Electricity Sold to Grid (kWh/yr)	S.E.		
Electricity Purchased (kWh/yr)	S.E.		
Total Annual Electrical Load Including H2 Comp. (kWh/yr)	S.E.		

Note: S.E. = self-explanatory