MARKET PROSPECTS FOR FUEL CELL/ABSORPTION CHILLERS TO DISPLACE ELECTRIC CHILLING IN HOSPITALS IN CALFORNIA

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1. Executive Summary

The Advanced Power and Energy Program (APEP) collaborated with Empowered Energy to perform a System Market Analysis and Economic Analysis for the Development and Demonstration of a Novel High-Temperature Fuel Cell Absorption Chiller System (System). The purpose of the analyses is to determine the economic feasibility of deploying the High-Temperature Fuel Cell Absorption Chiller (HTFC/AC) System to meet the cooling, heating, and electrical load of one major target market (as defined by commercial building type) in the State of California.

Hospitals are identified as the primary target market in the System Market Analysis based primarily on their cooling intensity and on their 24/7 requirements for cooling, heating, and electricity. The technically feasible size of the 2024 market for Systems in California is 1,476 MW of fuel cell capacity, based primarily on System performance. The economic potential will be smaller than the technical potential and will depend on each hospital's specific location, its operating characteristics, and the underlying technology portfolio and input costs. The market potential will be smaller still and will be determined by policy, regulations, competing technologies, and market viability.

It is shown that HTFC/AC systems that are properly sized for the building they serve are economically preferable to traditional grid-based building utilities for each of the scenarios evaluated in southern California. Also, installing an HTFC/AC system in a building with low natural gas prices and high electricity prices yields the most significant savings.

2. System Market Analysis Purpose and Methodology

The purpose of the System Market Analysis is to determine the economic feasibility of deploying the System to meet the cooling, heating, and electrical load of the primary target market (as defined by commercial building type) in the State of California. To accomplish this purpose, the System Market Analysis proceeds through the following major steps:

- Identify the primary target market (commercial building type) for the System
- Identify the main competing technology now serving the target market
- Estimate the size of the target market in California

Each step of the System Market Analysis is described in detail in the sections that follow. Section 3 discusses how the commercial building type that should be the primary market for System deployment is identified. The main competing technology now serving the target market is identified in Section 4. Section 5 explains how the technically feasible size of the target market in California is calculated. Conclusions and recommendations are found in Section 6.

3. Identification of the Primary Target Market

The primary target market for the System is defined as the commercial building type that is most suitable for the System's operating characteristics. In this section, the characteristics of different commercial building types in California are examined, with an emphasis on cooling, given that commercial buildings in California have a much greater need for cooling than for heating. Various data sources are examined and compared, resulting in a comparison and ranking of the cooling and heating intensities (in kWh per square foot) of commercial building types.

Recent experience designing and installing a System at the University of California-Irvine Medical Complex has shown that the amount of heating that could be recovered was so small that it was not worth the cost of installing the heat exchangers required to capture the heat.

3.1 Sources of Data

3.1.1 Energy Efficiency Potential and Goals Study Analyses

Total commercial square footage by building type by utility has been updated regularly as part of the periodic Energy Efficiency Potential and Goals Study analyses undertaken on behalf of the California

Public Utility Commission (CPUC). These analyses were initiated in 2003, one year prior to the CPUC's adoption of ten-year energy savings goals established in conjunction with California's Energy Action Plan (EAP); the EAP placed energy efficiency as "the resource of first choice."[1] The energy efficiency goals serve several important policy roles, including:

- Providing guidance for the utilities' next energy efficiency portfolios
- Updating the forecast for energy procurement planning
- Informing strategic contributions to California's greenhouse gas reduction goals
- Setting benchmarks for utility shareholder incentives.

Although there is a wealth of information in the Energy Efficiency Potential and Goals Study analyses regarding specific types of appliances, there is little information on energy use at the commercial building level.

3.1.2 California Commercial End-Use Study

The most recent survey of electricity use by commercial building type for California was published in March 2006 in the *California Commercial End-Use Study* (CEUS). The CEUS surveyed electricity use in commercial buildings in California and includes data for the following utilities: Pacific Gas & Electric Company (PG&E), Southern California Edison Company (SCE), San Diego Gas & Electric Company (SDG&E), and the Sacramento Utility District (SMUD). Figure 1 provides a map showing the location of California's electrics utilities.

[1] For further information, see the Energy Efficiency Goals and Potential Studies home page at the following link: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/Energy+Efficiency+Goals+and+Potential+Studies.htm

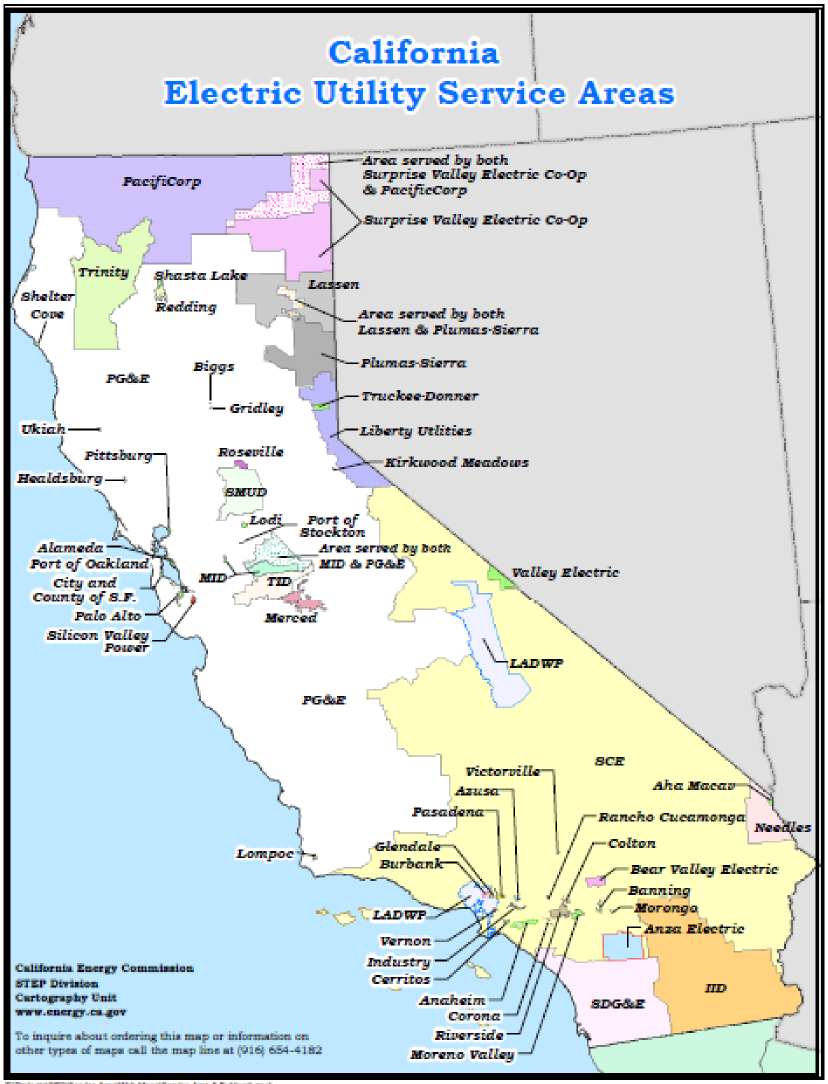

Figure 1: California Electric Utility Service Areas

The CEUS is based on electricity usage by building type by end use for calendar year 2002 and includes estimated total commercial square footage by building type by utility. Because the CEUS data are already quite dated, they are used in this analysis solely as a point of comparison with California Energy Commission (CEC) data for the same year, as explained in greater detail below.

3.1.3 CEC Electricity Supply Analysis Division, Demand Analysis Office Forecasts

The CEC's Electricity Supply Analysis Division, Demand Analysis Office, forecasts commercial floor space (square footage) and commercial electricity use by planning area (utility), climate zone, building type, and end use. The CEC's floor space forecast is generated using an econometric model developed by the CEC. The CEC's electricity end-use forecast is generated by running an end-use forecasting model. Empowered Energy received the CEC's forecast data directly from the CEC's Demand Analysis Office in

March, 2014, and the following analysis relies on this forecast data.[2] Estimated and forecast commercial floor space and electricity use data from the CEC cover the time period from 1990-2024, with forecast data used in the CEC's ten-year statewide electricity demand forecast.

3.2 Comparison of Data Sources

3.2.1 CEUS Data with 2002 CEC Data

The Cooling Electricity Usage Intensity (EUI) metric measures the average kWh/sq.ft. used for cooling. Tables 1 and 2 compare the CEC and CEUS 2002 Cooling EUI rankings by building type and utility for PG&E, SCE, SDG&E, and SMUD, the four utilities included in the CEUS. The tabular rankings shown in Tables 1 and 2 are identical, but the direction of the arrows associated with those rankings differs. The arrows in Table 1 indicate movement of the CEC's 2002 building type-utility combinations from one quartile to another when compared to the CEUS rankings. The arrows in Table 2 indicate movement of the CEUS building type-utility combinations from one quartile to another when compared to the CEC rankings. Movements within any given quartile are not indicated in Tables 1 and 2.

In both Table 1 and Table 2, only four building type-utility combinations change quartiles when comparing the 2002 CEC and CEUS Cooling EUI rankings. The only changes in the Cooling EUI rankings going from the CEC to the CEUS data (Table 1) are from the top quartile to the second quartile, with the food service (FOOD) category dropping from 5th in the CEC data to 20th in the CEUS data. The changes in the Cooling EUI ranking going from the CEUS to the CEC data (Table 2) are much more dramatic, with the 10th ranked refrigerated warehouse (RWHSE) category in the CEUS data falling to 37th in the CEC data. There are significant differences in the nature of the survey data in the CEUS data set and the econometrically-derived data in the CEC data set, so the similarities in the Cooling EUI rankings between the two are perhaps more significant than are the differences.

[2] Empowered Energy would like to thank Mr. Mohsen Abrishimi of the Demand Analysis for providing both the CEC forecast data and explanations of how and why the CEC data differed from the CEUS forecast data.

Table 1: 2002 CEC Movement Compared to CEUS Data

Comparison of CEC and CEUS 2002 Cooling EUI Rankings by Building Type and Utility

(PG&E, SCE, SDG&E, SMUD Only)

ARROWS SHOWING TOP QUARTILE RANKING MOVEMENT BETWEEN CEC AND CEUS RESULTS:

2002	BLDG TYP	Utility	Cooling EUI	2002	BLDG TYP	Utility	Cooling EUI
1	***HOSP***	***SMUD***	***9.81***	1	***REST***	***SCE***	***10.22***
2	HOSP	PG&E	8.34	2	REST	SDG&E	9.53
3	***HOSP***	***SCE***	***8.10***	3	***REST***	***SMUD***	***8.97***
4	***HOSP***	***SDG&E***	***6.53***	4	***REST***	***PG&E***	***6.80***
5	FOOD	PG&E	5.03	5	***FOOD***	***SMUD***	***6.15***
6	***REST***	***SMUD***	***4.89***	6	FOOD	SCE	6.09
7	***REST***	***PG&E***	***4.69***	7	***HOSP***	***SMUD***	***5.34***
8	OFF-LRG	SMUD	4.65	8	OFF-LRG	SDG&E	4.86
9	***OFF-LRG***	***SCE***	***4.39***	9	***HOSP***	***SCE***	***4.70***
10	***FOOD***	***SMUD***	***4.17***	10	RWHSE	SDG&E	4.70
11	***REST***	***SCE***	***4.09***	11	***HOSP***	***SDG&E***	***4.64***
12	OFF-LRG	PG&E	4.02	12	***OFF-LRG***	***SCE***	***4.30***
13	***HOTEL***	***SCE***	***3.78***	13	HOSP	PG&E	4.27
14	REST	SDG&E	3.63	14	FOOD	SDG&E	4.02
15	OFF-SMALL	SMUD	3.61	15	RETAIL	SCE	4.01
16	MISC	SCE	3.28	16	OFF-LRG	PG&E	4.01
17	***HOTEL***	***SDG&E***	***3.19***	17	OFF-LRG	SMUD	3.98
18	OFF-LRG	SDG&E	2.88	18	RETAIL	SDG&E	3.96
19	MISC	SDG&E	2.87	19	***HOTEL***	***SDG&E***	***3.82***
20	OFF-SMALL	SDG&E	2.51	20	FOOD	PG&E	3.74
21	***OFF-SMALL***	***PG&E***	***2.27***	21	***HOTEL***	***SCE***	***3.48***
22	COLLEGE	SCE	2.18	22	***OFF-SMALL***	***PG&E***	***3.42***
23	***OFF-SMALL***	***SCE***	***2.11***	23	***OFF-SMALL***	***SCE***	***3.16***
24	COLLEGE	SDG&E	1.86	24	MISC	SMUD	3.11
25	RETAIL	SCE	1.67	25	COLLEGE	SDG&E	3.02
26	***RETAIL***	***SMUD***	***1.65***	26	RWHSE	SCE	2.98
27	MISC	PG&E	1.56	27	RWHSE	PG&E	2.83
28	***COLLEGE***	***SMUD***	***1.56***	28	OFF-SMALL	SMUD	2.82
29	RETAIL	SDG&E	1.36	29	HOTEL	SMUD	2.81
30	SCHOOL	SDG&E	1.26	30	RWHSE	SMUD	2.64
31	COLLEGE	PG&E	1.24	31	NWHSE	SDG&E	2.63
32	MISC	SMUD	1.12	32	***COLLEGE***	***SMUD***	***2.57***
33	SCHOOL	SCE	0.98	33	***RETAIL***	***SMUD***	***2.56***
34	***RETAIL***	***PG&E***	***0.90***	34	OFF-SMALL	SDG&E	2.49
35	NWHSE	SMUD	0.75	35	***RETAIL***	***PG&E***	***2.42***
36	FOOD	SDG&E	0.71	36	COLLEGE	SCE	2.40
37	FOOD	SCE	0.69	37	MISC	SCE	2.29
38	***NWHSE***	***PG&E***	***0.58***	38	COLLEGE	PG&E	2.28
39	HOTEL	SMUD	0.57	39	***HOTEL***	***PG&E***	***2.24***
40	***HOTEL***	***PG&E***	***0.53***	40	***NWHSE***	***SCE***	***2.00***
41	***SCHOOL***	***SMUD***	***0.24***	41	SCHOOL	SCE	1.99
42	***SCHOOL***	***PG&E***	***0.17***	42	MISC	SDG&E	1.88
43	NWHSE	SDG&E	0.16	43	NWHSE	SMUD	1.72
44	***NWHSE***	***SCE***	***0.16***	44	MISC	PG&E	1.64
45	RWHSE	SMUD	0.14	45	***SCHOOL***	***SMUD***	***1.52***
46	RWHSE	SCE	0.11	46	***SCHOOL***	***PG&E***	***1.37***
47	RWHSE	SDG&E	0.07	47	SCHOOL	SDG&E	1.19
48	RWHSE	PG&E	0.06	48	***NWHSE***	***PG&E***	***0.89***

Data Source: CEC

Data Source: CEUS

Notes: ***Bold & italicized if Cooling EUI is in the same quartile for both CEC and CEUS results.***

Table 2: CEUS Movement Compared to 2002 CEC Data

Comparison of CEC and CEUS 2002 Cooling EUI Rankings by Building Type and Utility

(PG&E, SCE, SDG&E, SMUD Only)

ARROWS SHOWING TOP QUARTILE RANKING MOVEMENT BETWEEN CEUS AND CEC RESULTS:

2002	BLDG TYP	Utility	Cooling EUI		2002	BLDG TYP	Utility	Cooling EUI
1	***HOSP***	***SMUD***	***9.81***		1	***REST***	***SCE***	***10.22***
2	HOSP	PG&E	8.34		2	REST	SDG&E	9.53
3	***HOSP***	***SCE***	***8.10***		3	***REST***	***SMUD***	***8.97***
4	***HOSP***	***SDG&E***	***6.53***		4	***REST***	***PG&E***	***6.80***
5	FOOD	PG&E	5.03		5	***FOOD***	***SMUD***	***6.15***
6	***REST***	***SMUD***	***4.89***		6	FOOD	SCE	6.09
7	***REST***	***PG&E***	***4.69***		7	***HOSP***	***SMUD***	***5.34***
8	OFF-LRG	SMUD	4.65		8	OFF-LRG	SDG&E	4.86
9	***OFF-LRG***	***SCE***	***4.39***		9	***HOSP***	***SCE***	***4.70***
10	***FOOD***	***SMUD***	***4.17***		10	RWHSE	SDG&E	4.70
11	***REST***	***SCE***	***4.09***		11	***HOSP***	***SDG&E***	***4.64***
12	OFF-LRG	PG&E	4.02		12	***OFF-LRG***	***SCE***	***4.30***
13	***HOTEL***	***SCE***	***3.78***		13	HOSP	PG&E	4.27
14	REST	SDG&E	3.63		14	FOOD	SDG&E	4.02
15	OFF-SMALL	SMUD	3.61		15	RETAIL	SCE	4.01
16	MISC	SCE	3.28		16	OFF-LRG	PG&E	4.01
17	***HOTEL***	***SDG&E***	***3.19***		17	OFF-LRG	SMUD	3.98
18	OFF-LRG	SDG&E	2.88		18	RETAIL	SDG&E	3.96
19	MISC	SDG&E	2.87		19	***HOTEL***	***SDG&E***	***3.82***
20	OFF-SMALL	SDG&E	2.51		20	FOOD	PG&E	3.74
21	***OFF-SMALL***	***PG&E***	***2.27***		21	***HOTEL***	***SCE***	***3.48***
22	COLLEGE	SCE	2.18		22	***OFF-SMALL***	***PG&E***	***3.42***
23	***OFF-SMALL***	***SCE***	***2.11***		23	***OFF-SMALL***	***SCE***	***3.16***
24	COLLEGE	SDG&E	1.86		24	MISC	SMUD	3.11
25	RETAIL	SCE	1.67		25	COLLEGE	SDG&E	3.02
26	***RETAIL***	***SMUD***	***1.65***		26	RWHSE	SCE	2.98
27	MISC	PG&E	1.56		27	RWHSE	PG&E	2.83
28	***COLLEGE***	***SMUD***	***1.56***		28	OFF-SMALL	SMUD	2.82
29	RETAIL	SDG&E	1.36		29	HOTEL	SMUD	2.81
30	SCHOOL	SDG&E	1.26		30	RWHSE	SMUD	2.64
31	COLLEGE	PG&E	1.24		31	NWHSE	SDG&E	2.63
32	MISC	SMUD	1.12		32	***COLLEGE***	***SMUD***	***2.57***
33	SCHOOL	SCE	0.98		33	***RETAIL***	***SMUD***	***2.56***
34	***RETAIL***	***PG&E***	***0.90***		34	OFF-SMALL	SDG&E	2.49
35	NWHSE	SMUD	0.75		35	***RETAIL***	***PG&E***	***2.42***
36	FOOD	SDG&E	0.71		36	COLLEGE	SCE	2.40
37	FOOD	SCE	0.69		37	MISC	SCE	2.29
38	***NWHSE***	***PG&E***	***0.58***		38	COLLEGE	PG&E	2.28
39	HOTEL	SMUD	0.57		39	***HOTEL***	***PG&E***	***2.24***
40	***HOTEL***	***PG&E***	***0.53***		40	***NWHSE***	***SCE***	***2.00***
41	***SCHOOL***	***SMUD***	***0.24***		41	SCHOOL	SCE	1.99
42	***SCHOOL***	***PG&E***	***0.17***		42	MISC	SDG&E	1.88
43	NWHSE	SDG&E	0.16		43	NWHSE	SMUD	1.72
44	***NWHSE***	***SCE***	***0.16***		44	MISC	PG&E	1.64
45	RWHSE	SMUD	0.14		45	***SCHOOL***	***SMUD***	***1.52***
46	RWHSE	SCE	0.11		46	***SCHOOL***	***PG&E***	***1.37***
47	RWHSE	SDG&E	0.07		47	SCHOOL	SDG&E	1.19
48	RWHSE	PG&E	0.06		48	***NWHSE***	***PG&E***	***0.89***

Data Source: CEC | Data Source: CEUS

Notes: ***Bold & italicized if Cooling EUI is in the same quartile for both CEC and CEUS results.***

3.2.2 Comparison of 2002 versus 2012 CEC Data

The previous section illustrated the similarities between the 2002 CEC data and the CEUS data, the latter of which was based on surveys related to calendar year 2002. This section takes the 2002 CEC data from the previous section and compares it with the same CEC data from 2012 to see how the data differ over a period of time.

3.2.2.1 Cooling EUI Rankings

Table 3 compares the 2002 CEC Cooling EUI rankings with the 2012 CEC Cooling EUI rankings. The Cooling EUI rankings on the right-hand side of Table 3 are the same 2002 CEC rankings shown in Tables 1 and 2 (above). The 2012 CEC Cooling EUI rankings are shown on the left-hand side of Table 3. There are no inter-quartile movements between the 2002 and 2012 CEC data, *i.e.*, no building type-utility combination moved from one quartile to another from 2002 to 2012. However, there are some building type-utility combinations that move *within* a quartile from 2002 to 2012 based on their Cooling EUI rankings.

The CEC building type-utility combinations showing intra-quartile movements from 2002 to 2012 are shaded in various colors in Table 3, with the same building type-utility combinations having the same color for both the 2002 and 2012 CEC data. Most notable is the movement within the top quartile, which shows a relative increase in the Cooling EUI of large office buildings (OFF-LRG) and a relative decrease in the Cooling EUI of restaurant (REST) and wholesale food (FOOD) commercial buildings served by PG&E and SMUD from 2002 to 2012.

Table 3 clearly shows that hospital (HOSP) buildings in all four utility franchise areas top the list of Cooling EUI rankings in both 2002 and 2012. Large office buildings (OFF-LRG) and restaurants (REST) dominate the remainder of the top quartile of Cooling EUI rankings. Small office buildings (OFF-SMALL) make up a large share of the second quartile of Cooling EUI rankings, accompanied by hotels (HOTEL), colleges (COLLEGE), and restaurants (REST). The miscellaneous (MISC) building category for several utilities shows up in the second quartile, but the non-specific nature of this catch-all category makes its continued inclusion in the analysis of little use.

Table 3: Intra-Quartile Movement between 2002 and 2012 CEC Data

CEC 2012 and 2002 Cooling EUI Rankings by Building Type and Utility

(PG&E, SCE, SDG&E, SMUD Only)

SHADING SHOWS RANKING MOVEMENT, WHICH OCCURS ONLY WITHIN QUARTILES:

2012 Ranking	BLDG TYP	Utility	Cooling EUI	2002 Ranking	BLDG TYP	Utility	Cooling EUI
1	HOSP	SMUD	9.85	1	HOSP	SMUD	9.81
2	HOSP	SCE	8.38	2	HOSP	PG&E	8.34
3	HOSP	PG&E	8.13	3	HOSP	SCE	8.10
4	HOSP	SDG&E	6.61	4	HOSP	SDG&E	6.53
5	FOOD	PG&E	4.78	5	FOOD	PG&E	5.03
6	OFF-LRG	SMUD	4.77	6	REST	SMUD	4.89
7	OFF-LRG	SCE	4.53	7	REST	PG&E	4.69
8	REST	PG&E	4.44	8	OFF-LRG	SMUD	4.65
9	REST	SMUD	4.25	9	OFF-LRG	SCE	4.39
10	OFF-LRG	PG&E	3.94	10	FOOD	SMUD	4.17
11	REST	SCE	3.79	11	REST	SCE	4.09
12	FOOD	SMUD	3.78	12	OFF-LRG	PG&E	4.02
13	HOTEL	SCE	3.46	13	HOTEL	SCE	3.78
14	REST	SDG&E	3.46	14	REST	SDG&E	3.63
15	OFF-SMALL	SMUD	3.18	15	OFF-SMALL	SMUD	3.61
16	MISC	SCE	3.10	16	MISC	SCE	3.28
17	HOTEL	SDG&E	2.98	17	HOTEL	SDG&E	3.19
18	OFF-LRG	SDG&E	2.86	18	OFF-LRG	SDG&E	2.88
19	MISC	SDG&E	2.74	19	MISC	SDG&E	2.87
20	OFF-SMALL	SDG&E	2.34	20	OFF-SMALL	SDG&E	2.51
21	OFF-SMALL	PG&E	2.13	21	OFF-SMALL	PG&E	2.27
22	COLLEGE	SCE	2.06	22	COLLEGE	SCE	2.18
23	OFF-SMALL	SCE	2.01	23	OFF-SMALL	SCE	2.11
24	COLLEGE	SDG&E	1.70	24	COLLEGE	SDG&E	1.86
25	RETAIL	SCE	1.56	25	RETAIL	SCE	1.67
26	MISC	PG&E	1.52	26	RETAIL	SMUD	1.65
27	RETAIL	SMUD	1.43	27	MISC	PG&E	1.56
28	RETAIL	SDG&E	1.31	28	COLLEGE	SMUD	1.56
29	COLLEGE	SMUD	1.25	29	RETAIL	SDG&E	1.36
30	SCHOOL	SDG&E	1.16	30	SCHOOL	SDG&E	1.26
31	COLLEGE	PG&E	1.15	31	COLLEGE	PG&E	1.24
32	MISC	SMUD	1.01	32	MISC	SMUD	1.12
33	SCHOOL	SCE	1.01	33	SCHOOL	SCE	0.98
34	RETAIL	PG&E	0.87	34	RETAIL	PG&E	0.90
35	NWHSE	SMUD	0.72	35	NWHSE	SMUD	0.75
36	FOOD	SDG&E	0.68	36	FOOD	SDG&E	0.71
37	FOOD	SCE	0.66	37	FOOD	SCE	0.69
38	NWHSE	PG&E	0.56	38	NWHSE	PG&E	0.58
39	HOTEL	SMUD	0.53	39	HOTEL	SMUD	0.57
40	HOTEL	PG&E	0.49	40	HOTEL	PG&E	0.53
41	SCHOOL	SMUD	0.22	41	SCHOOL	SMUD	0.24
42	NWHSE	SDG&E	0.16	42	SCHOOL	PG&E	0.17
43	SCHOOL	PG&E	0.16	43	NWHSE	SDG&E	0.16
44	NWHSE	SCE	0.15	44	NWHSE	SCE	0.16
45	RWHSE	SMUD	0.14	45	RWHSE	SMUD	0.14
46	RWHSE	SCE	0.10	46	RWHSE	SCE	0.11
47	RWHSE	SDG&E	0.07	47	RWHSE	SDG&E	0.07
48	RWHSE	PG&E	0.06	48	RWHSE	PG&E	0.06

Data Source: CEC

Data Source: CEC

Tables 1 through 3 included only the four utilities that were included in the original CEUS survey data. However, the complete CEC database includes data for four additional utilities, namely Burbank, the Imperial Irrigation District (IID), the Los Angeles Department of Water and Power (LADWP), and Pasadena. To extend the breadth of the analysis, Table 4 includes the 2012 CEC Cooling EUI rankings for all eight reported utilities. Because the number of reported utilities has doubled, each quartile now includes 24 building type-utility combinations.

The IID service area borders Baja California and southwestern Arizona, as seen in Figure 1. The significant cooling requirement in the geographic area served by the IID is readily apparent in the Cooling EUI rankings in Table 4. Commercial buildings served by the IID make up fully one-third of the expanded top quartile of Cooling EUI rankings. There are several building type-utility combinations for the other three added utilities (*i.e.*, Burbank, LADWP, and Pasadena) whose Cooling EUIs also show up in the top quartile of rankings in Table 4. Most notable of these are the hospitals (HOSP) for all three added utilities, restaurants (REST) for Burbank and Pasadena, and large and small office buildings (OFF-LRG and OFF-SMALL) for Pasadena.

Up to this point, all of the building type-utility combination rankings have been based solely on the intensity of the cooling demand, as measured by the Cooling EUI. It is possible for a building type-utility combination to have a high Cooling EUI but to be part of a relatively small market for electricity consumption for cooling in terms of total Giga-Watt hours (GWh). Table 5 shows the rankings for building type-utility combinations for all eight reported utilities based on the 2012 CEC Cooling GWh value, which reflects the forecast total amount of electricity consumed for cooling each building type-utility combination.

Based solely on the Cooling GWh values, large office buildings (OFF-LRG) tend to dominate the top quartile rankings, with this category included for five of the eight reported utilities (i.e., SCE, PG&E, LADWP, SDG&E, and SMUD). These five utilities are the largest of the eight reported utilities so it is no surprise that the total Cooling GWh for large office buildings (OFF-LRG) ranks high. Hospitals (HOSP) for SCE, PG&E, LADWP, and SDG&E are also included in the top quartile rankings for total Cooling GWh, and hospitals (HOSP) in SMUD's franchise territory rank 4th in the second quartile rankings. Retail (RETAIL) buildings, restaurants (REST), and small office buildings (OFF-SMALL) in SCE's and PG&E's franchise territories are also included in the top quartile rankings for total Cooling GWh, but no other building type has more than one entry in the top quartile rankings for total Cooling GWh.

Table 4: 2012 CEC Data Cooling EUI Rankings for All Reported Utilities

CEC 2012 Cooling EUI Rankings, by Building Type and Utility

(All Reported Utilities)

2012 Ranking	BLDG TYP	Utility	Cooling EUI	2012 Ranking	BLDG TYP	Utility	Cooling EUI
1	HOSP	IID	14.63	49	OFF-SMALL	SDG&E	2.34
2	MISC	IID	14.11	50	RETAIL	Pasadena	2.32
3	REST	IID	11.49	51	FOOD	IID	2.31
4	OFF-LRG	IID	11.43	52	OFF-SMALL	PG&E	2.13
5	HOSP	SMUD	9.85	53	COLLEGE	SCE	2.06
6	HOSP	LADWP	9.63	54	OFF-SMALL	SCE	2.01
7	SCHOOL	IID	9.26	55	OFF-SMALL	LADWP	1.94
8	HOSP	Pasadena	8.40	56	HOTEL	Pasadena	1.87
9	HOSP	SCE	8.38	57	RETAIL	Burbank	1.79
10	HOSP	PG&E	8.13	58	COLLEGE	SDG&E	1.70
11	OFF-SMALL	IID	8.05	59	RETAIL	SCE	1.56
12	HOSP	Burbank	7.66	60	MISC	PG&E	1.52
13	COLLEGE	IID	7.23	61	NWHSE	IID	1.50
14	HOSP	SDG&E	6.61	62	HOTEL	Burbank	1.50
15	RETAIL	IID	5.87	63	RETAIL	LADWP	1.48
16	REST	Pasadena	5.38	64	RETAIL	SMUD	1.43
17	FOOD	PG&E	4.78	65	RETAIL	SDG&E	1.31
18	OFF-LRG	SMUD	4.77	66	FOOD	Pasadena	1.30
19	OFF-LRG	SCE	4.53	67	COLLEGE	SMUD	1.25
20	REST	PG&E	4.44	68	SCHOOL	SDG&E	1.16
21	REST	Burbank	4.35	69	COLLEGE	PG&E	1.15
22	OFF-LRG	Pasadena	4.33	70	FOOD	Burbank	1.07
23	REST	SMUD	4.25	71	SCHOOL	LADWP	1.05
24	OFF-SMALL	Pasadena	4.16	72	MISC	SMUD	1.01
25	OFF-LRG	PG&E	3.94	73	SCHOOL	SCE	1.01
26	MISC	Pasadena	3.94	74	NWHSE	Pasadena	0.95
27	REST	LADWP	3.90	75	RETAIL	PG&E	0.87
28	REST	SCE	3.79	76	NWHSE	Burbank	0.74
29	FOOD	SMUD	3.78	77	NWHSE	SMUD	0.72
30	COLLEGE	LADWP	3.70	78	FOOD	SDG&E	0.68
31	HOTEL	IID	3.49	79	FOOD	SCE	0.66
32	HOTEL	SCE	3.46	80	NWHSE	PG&E	0.56
33	COLLEGE	Pasadena	3.46	81	HOTEL	SMUD	0.53
34	REST	SDG&E	3.46	82	FOOD	LADWP	0.53
35	OFF-LRG	LADWP	3.45	83	HOTEL	PG&E	0.49
36	OFF-LRG	Burbank	3.36	84	SCHOOL	SMUD	0.22
37	OFF-SMALL	Burbank	3.33	85	NWHSE	SDG&E	0.16
38	OFF-SMALL	SMUD	3.18	86	SCHOOL	PG&E	0.16
39	COLLEGE	Burbank	3.14	87	NWHSE	SCE	0.15
40	MISC	SCE	3.10	88	NWHSE	LADWP	0.14
41	MISC	Burbank	3.09	89	RWHSE	SMUD	0.14
42	HOTEL	SDG&E	2.98	90	RWHSE	Pasadena	0.13
43	OFF-LRG	SDG&E	2.86	91	RWHSE	IID	0.11
44	SCHOOL	Pasadena	2.83	92	RWHSE	SCE	0.10
45	MISC	LADWP	2.82	93	RWHSE	Burbank	0.10
46	MISC	SDG&E	2.74	94	RWHSE	LADWP	0.09
47	HOTEL	LADWP	2.65	95	RWHSE	SDG&E	0.07
48	SCHOOL	Burbank	2.58	96	RWHSE	PG&E	0.06

Data Source: CEC

Table 5: 2012 CEC Data Cooling GWh Rankings for All Reported Utilities

CEC 2012 Cooling GWh Rankings, by Building Type and Utility

(All Reported Utilities)

2012 Ranking	BLDG TYP	Utility	Cooling GWh	2012 Ranking	BLDG TYP	Utility	Cooling GWh
1	OFF-LRG	SCE	1,894	49	SCHOOL	IID	45
2	OFF-LRG	PG&E	1,618	50	OFF-LRG	IID	45
3	MISC	SCE	1,566	51	MISC	Burbank	40
4	HOSP	PG&E	1,104	52	MISC	SMUD	38
5	HOSP	SCE	952	53	FOOD	SMUD	35
6	OFF-LRG	LADWP	703	54	SCHOOL	PG&E	34
7	RETAIL	SCE	697	55	HOSP	IID	28
8	MISC	PG&E	668	56	NWHSE	SMUD	27
9	FOOD	PG&E	504	57	HOSP	Burbank	26
10	HOSP	LADWP	401	58	MISC	Pasadena	26
11	HOTEL	SCE	369	59	REST	SMUD	24
12	RETAIL	PG&E	331	60	RETAIL	Burbank	20
13	OFF-LRG	SDG&E	315	61	FOOD	SDG&E	20
14	REST	SCE	313	62	NWHSE	IID	20
15	MISC	LADWP	298	63	NWHSE	LADWP	16
16	OFF-SMALL	PG&E	282	64	FOOD	LADWP	15
17	OFF-LRG	SMUD	281	65	HOSP	Pasadena	15
18	OFF-SMALL	SCE	248	66	COLLEGE	Burbank	15
19	COLLEGE	SCE	240	67	RETAIL	Pasadena	13
20	HOSP	SDG&E	229	68	HOTEL	IID	12
21	MISC	SDG&E	226	69	REST	IID	12
22	REST	PG&E	217	70	COLLEGE	SMUD	12
23	SCHOOL	SCE	216	71	COLLEGE	IID	11
24	NWHSE	PG&E	180	72	NWHSE	SDG&E	11
25	COLLEGE	LADWP	170	73	OFF-SMALL	Burbank	10
26	RETAIL	LADWP	169	74	FOOD	IID	9
27	COLLEGE	PG&E	150	75	COLLEGE	Pasadena	8
28	HOSP	SMUD	146	76	REST	Burbank	8
29	RETAIL	SDG&E	131	77	SCHOOL	Burbank	6
30	OFF-SMALL	SDG&E	125	78	OFF-SMALL	Pasadena	6
31	HOTEL	SDG&E	122	79	HOTEL	SMUD	6
32	MISC	IID	122	80	REST	Pasadena	5
33	HOTEL	LADWP	92	81	NWHSE	Burbank	4
34	REST	LADWP	88	82	SCHOOL	SMUD	4
35	OFF-SMALL	SMUD	79	83	SCHOOL	Pasadena	3
36	FOOD	SCE	76	84	HOTEL	Burbank	3
37	OFF-LRG	Burbank	74	85	FOOD	Burbank	3
38	RETAIL	SMUD	69	86	NWHSE	Pasadena	3
39	OFF-SMALL	LADWP	66	87	HOTEL	Pasadena	2
40	NWHSE	SCE	62	88	RWHSE	SCE	2
41	RETAIL	IID	60	89	FOOD	Pasadena	2
42	HOTEL	PG&E	59	90	RWHSE	PG&E	2
43	COLLEGE	SDG&E	55	91	RWHSE	LADWP	0
44	SCHOOL	SDG&E	54	92	RWHSE	SMUD	0
45	SCHOOL	LADWP	53	93	RWHSE	IID	0
46	REST	SDG&E	52	94	RWHSE	SDG&E	0
47	OFF-SMALL	IID	51	95	RWHSE	Burbank	0
48	OFF-LRG	Pasadena	50	96	RWHSE	Pasadena	0

Data Source: CEC

Table 6 combines the results for the top two quartiles of rankings from Tables 4 and 5, showing the top Cooling EUI rankings from Table 4 on the left-hand side and the top total Cooling GWh rankings from Table 5 on the right-hand side.[3]

As discussed previously and seen again on the left-hand side of Table 6, the Cooling EUI for hospitals (HOSP) is included in the top quartile of the CEC 2012 rankings for all eight reported utilities. This fact holds true only for hospitals, and the Cooling EUIs for each of the eight hospital building type-utility combinations is highlighted by a red oval in Table 6. Given that four of these hospital building type-utility combinations are also in the top quartile based on the total Cooling GWh rankings on the right-hand side of Table 6, hospitals are selected as the primary target market for the HTFC/AC technology. Hospitals for the eight reported utilities consumed 2,285 GWh for cooling based on the 2012 CEC data.

Hospitals have many characteristics that make them a good target market for combined heat and power applications. The U.S. Department of Energy touts hospitals as "ideal candidates for combined heat and power (CHP) systems. Because hospitals function 365 days a year, 24/7, they require round-the-clock energy. Combined systems enable hospitals to reduce energy costs, improve environmental performance, and increase energy reliability. Resources saved are often redirected to improve patient care."[4] Medrano, et al., conclude that hospitals are "perfectly suited for CCHP applications…"[5] Of the four commercial building types characterized by the California Stationary Fuel Cell Collaborative, Table 7 shows that hospitals had the lowest electric-to-thermal ratio by far, allowing hospitals to take maximum advantage of the thermal output from the HTFC.

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3 Results in Table 6 are limited to building type-utility combinations from the top two quartiles of rankings from Tables 4 and 5 to narrow the analysis. The combined results for the bottom two quartiles of rankings from Tables 4 and 5 can be found in Attachment A.

4 U.S. Department of Energy, EERE, p. 1.

5 Medrano, *et al*., 2004, p. 539.

Table 6: 2012 CEC Data Cooling EUI and Cooling GWh Rankings for All Reported Utilities

CEC 2012 Cooling EUI vs. Cooling GWh Rankings, by Building Type and Utility

(All Reported Utilities, Top Two Quartiles)

==> Also in Cooling EUI Top Quartile

2012 Ranking	BLDG TYP	Utility	Cooling EUI	Cooling GWh
1	**HOSP**	**IID**	**14.63**	**28**
2	MISC	IID	14.11	122
3	REST	IID	11.49	12
4	OFF-LRG	IID	11.43	45
5	**HOSP**	**SMUD**	**9.85**	**146**
6	**HOSP**	**LADWP**	**9.63**	**401**
7	SCHOOL	IID	9.26	45
8	**HOSP**	**Pasadena**	**8.40**	**15**
9	**HOSP**	**SCE**	**8.38**	**952**
10	**HOSP**	**PG&E**	**8.13**	**1,104**
11	OFF-SMALL	IID	8.05	51
12	**HOSP**	**Burbank**	**7.66**	**26**
13	COLLEGE	IID	7.23	11
14	**HOSP**	**SDG&E**	**6.61**	**229**
15	RETAIL	IID	5.87	60
16	REST	Pasadena	5.38	5
17	FOOD	PG&E	4.78	504
18	OFF-LRG	SMUD	4.77	281
19	OFF-LRG	SCE	4.53	1,894
20	REST	PG&E	4.44	217
21	REST	Burbank	4.35	8
22	OFF-LRG	Pasadena	4.33	50
23	REST	SMUD	4.25	24
24	OFF-SMALL	Pasadena	4.16	6
25	OFF-LRG	PG&E	3.94	1,618
26	MISC	Pasadena	3.94	26
27	REST	LADWP	3.90	88
28	REST	SCE	3.79	313
29	FOOD	SMUD	3.78	35
30	COLLEGE	LADWP	3.70	170
31	HOTEL	IID	3.49	12
32	HOTEL	SCE	3.46	369
33	COLLEGE	Pasadena	3.46	8
34	REST	SDG&E	3.46	52
35	OFF-LRG	LADWP	3.45	703
36	OFF-LRG	Burbank	3.36	74
37	OFF-SMALL	Burbank	3.33	10
38	OFF-SMALL	SMUD	3.18	79
39	COLLEGE	Burbank	3.14	15
40	MISC	SCE	3.10	1,566
41	MISC	Burbank	3.09	40
42	HOTEL	SDG&E	2.98	122
43	OFF-LRG	SDG&E	2.86	315
44	SCHOOL	Pasadena	2.83	3
45	MISC	LADWP	2.82	298
46	MISC	SDG&E	2.74	226
47	HOTEL	LADWP	2.65	92
48	SCHOOL	Burbank	2.58	6

Data Source: CEC

2012 Ranking	BLDG TYP	Utility	Cooling EUI	Cooling GWh
1	OFF-LRG	SCE	4.53	1,894
2	OFF-LRG	PG&E	3.94	1,618
3	MISC	SCE	3.10	1,566
4	HOSP	PG&E	8.13	1,104
5	HOSP	SCE	8.38	952
6	OFF-LRG	LADWP	3.45	703
7	RETAIL	SCE	1.56	697
8	MISC	PG&E	1.52	668
9	FOOD	PG&E	4.78	504
10	HOSP	LADWP	9.63	401
11	HOTEL	SCE	3.46	369
12	RETAIL	PG&E	0.87	331
13	OFF-LRG	SDG&E	2.86	315
14	REST	SCE	3.79	313
15	MISC	LADWP	2.82	298
16	OFF-SMAL	PG&E	2.13	282
17	OFF-LRG	SMUD	4.77	281
18	OFF-SMAL	SCE	2.01	248
19	COLLEGE	SCE	2.06	240
20	HOSP	SDG&E	6.61	229
21	MISC	SDG&E	2.74	226
22	REST	PG&E	4.44	217
23	SCHOOL	SCE	1.01	216
24	NWHSE	PG&E	0.56	180
25	COLLEGE	LADWP	3.70	170
26	RETAIL	LADWP	1.48	169
27	COLLEGE	PG&E	1.15	150
28	HOSP	SMUD	9.85	146
29	RETAIL	SDG&E	1.31	131
30	OFF-SMAL	SDG&E	2.34	125
31	HOTEL	SDG&E	2.98	122
32	MISC	IID	14.11	122
33	HOTEL	LADWP	2.65	92
34	REST	LADWP	3.90	88
35	OFF-SMAL	SMUD	3.18	79
36	FOOD	SCE	0.66	76
37	OFF-LRG	Burbank	3.36	74
38	RETAIL	SMUD	1.43	69
39	OFF-SMAL	LADWP	1.94	66
40	NWHSE	SCE	0.15	62
41	RETAIL	IID	5.87	60
42	HOTEL	PG&E	0.49	59
43	COLLEGE	SDG&E	1.70	55
44	SCHOOL	SDG&E	1.16	54
45	SCHOOL	LADWP	1.05	53
46	REST	SDG&E	3.46	52
47	OFF-SMAL	IID	8.05	51
48	OFF-LRG	Pasadena	4.33	50

Data Source: CEC

Table 7: Main Characteristics of Select Commercial Building Templates[6]

Building Code	Description	Square footage	No floors	HVAC System	Base power demand	Average Power demand	Peak Power Demand	Annual E/T ratio	Annual E/T ratio with AC
		(Ft^2)			(kW)	(kW)	(kW)		
SOB	Small Office Building Base Case	50,000	2	Packaged single zone DX coils, with Furnace	11	55	270	31.7	0.45
MOB	Medium Office Building Base Case	90,000	2	Packaged single zone DX coils, with Furnace	100	165	460	44.9	0.45
HOSP	Hospital Base Case	250,000	10	Dual Duct Air Handler with HW Heat, chiller and hot water coils	900	1105	1300	1.1	0.29
COLL	College /School Base Case	250,000	4	Packaged single zone DX coils, with Furnace	70	370	1450	11.5	0.44

3.2.2.2 Heating EUI Rankings

The amount of electricity used for cooling in commercial buildings in California in 2012 was nearly six times larger than the amount of electricity used for heating. Table 8 (below) presents the Heating EUI and Heating GWh rankings by building type-utility combination in the same format that Table 6 (above) used for the top two quartile rankings for Cooling EUI and Cooling GWh.

It can be seen in Table 8 that three of the eight hospital (HOSP)-utility combinations reported in the CEC database have Heating EUIs in the top quartile and an additional four hospital-utility combinations have Heating EUIs in the second quartile. There are three hotel (HOTEL)-utility combinations included in the top quartile based on total Heating GWh compared to only two hospital (HOSP)-utility combinations. There are also two large office building (OFF-LRG)-utility combinations and two college (COLLEGE)-utility combinations included in the top quartile based on total Heating GWh. Three large office building (OFF-LRG)-utility combinations were also included in top quartile of the Cooling EUI rankings, making this building type a prospective future target market.

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[6] National Fuel Cell Research Center, April 23, 2004, Table 5, p. 18.

Table 8: 2012 CEC Data Heating EUI and Heating GWh Rankings for All Reported Utilities

CEC 2012 Heating EUI vs. Heating GWh Rankings, by Building Type and Utility

(All Reported Utilities, Top Two Quartiles)

2012 Ranking	BLDG TYP	Utility	Heating EUI	Heating GWh
1	HOTEL	SCE	4.21	448
2	HOTEL	Pasadena	3.61	4
3	HOSP	SDG&E	3.22	111
4	SCHOOL	SMUD	3.06	59
5	HOTEL	Burbank	2.72	5
6	HOTEL	LADWP	2.53	88
7	COLLEGE	SDG&E	2.40	78
8	HOTEL	SDG&E	1.99	82
9	SCHOOL	IID	1.58	8
10	HOTEL	IID	1.43	5
11	COLLEGE	SCE	0.99	115
12	SCHOOL	Pasadena	0.96	1
13	MISC	IID	0.94	8
14	MISC	SDG&E	0.94	77
15	HOSP	SCE	0.92	105
16	SCHOOL	Burbank	0.90	2
17	COLLEGE	IID	0.77	1
18	OFF-LRG	SDG&E	0.76	84
19	OFF-SMALL	SMUD	0.70	17
20	REST	PG&E	0.68	33
21	MISC	Pasadena	0.67	4
22	OFF-LRG	SCE	0.65	272
23	HOSP	LADWP	0.55	23
24	REST	SDG&E	0.51	8
25	MISC	SCE	0.51	258
26	HOSP	IID	0.49	1
27	COLLEGE	LADWP	0.49	22
28	FOOD	Pasadena	0.49	1
29	MISC	Burbank	0.49	6
30	HOSP	Pasadena	0.48	1
31	FOOD	PG&E	0.46	49
32	REST	SMUD	0.46	3
33	SCHOOL	SDG&E	0.45	21
34	HOSP	Burbank	0.44	2
35	REST	SCE	0.39	32
36	OFF-LRG	LADWP	0.38	78
37	COLLEGE	Pasadena	0.38	1
38	MISC	LADWP	0.37	39
39	COLLEGE	Burbank	0.36	2
40	FOOD	Burbank	0.35	1
41	OFF-LRG	SMUD	0.35	21
42	NWHSE	PG&E	0.34	110
43	OFF-SMALL	Pasadena	0.33	0
44	OFF-LRG	PG&E	0.33	134
45	RETAIL	SMUD	0.32	15
46	OFF-SMALL	PG&E	0.31	41
47	HOSP	SMUD	0.31	5
48	NWHSE	SMUD	0.30	11

Data Source: CEC

==> Also in Heating EUI Top Quartile

2012 Ranking	BLDG TYP	Utility	Heating EUI	Heating GWh
1	HOTEL	SCE	4.21	448
2	OFF-LRG	SCE	0.65	272
3	MISC	SCE	0.51	258
4	OFF-LRG	PG&E	0.33	134
5	COLLEGE	SCE	0.99	115
6	HOSP	SDG&E	3.22	111
7	NWHSE	PG&E	0.34	110
8	HOSP	SCE	0.92	105
9	HOTEL	LADWP	2.53	88
10	OFF-LRG	SDG&E	0.76	84
11	HOTEL	SDG&E	1.99	82
12	COLLEGE	SDG&E	2.40	78
13	OFF-LRG	LADWP	0.38	78
14	MISC	SDG&E	0.94	77
15	RETAIL	PG&E	0.20	74
16	SCHOOL	SMUD	3.06	59
17	FOOD	PG&E	0.46	49
18	MISC	PG&E	0.10	44
19	OFF-SMALL	PG&E	0.31	41
20	MISC	LADWP	0.37	39
21	REST	PG&E	0.68	33
22	REST	SCE	0.39	32
23	FOOD	SCE	0.27	31
24	SCHOOL	SCE	0.12	25
25	HOSP	LADWP	0.55	23
26	COLLEGE	LADWP	0.49	22
27	SCHOOL	SDG&E	0.45	21
28	OFF-LRG	SMUD	0.35	21
29	RETAIL	SCE	0.04	20
30	HOTEL	PG&E	0.16	19
31	COLLEGE	PG&E	0.13	18
32	OFF-SMALL	SMUD	0.70	17
33	SCHOOL	PG&E	0.08	17
34	RETAIL	SMUD	0.32	15
35	NWHSE	SCE	0.03	12
36	NWHSE	SMUD	0.30	11
37	MISC	IID	0.94	8
38	REST	SDG&E	0.51	8
39	SCHOOL	IID	1.58	8
40	HOSP	PG&E	0.05	7
41	FOOD	SDG&E	0.22	7
42	MISC	Burbank	0.49	6
43	REST	LADWP	0.27	6
44	HOTEL	Burbank	2.72	5
45	MISC	SMUD	0.14	5
46	HOTEL	IID	1.43	5
47	FOOD	LADWP	0.17	5
48	SCHOOL	LADWP	0.09	5

Data Source: CEC

4. Identification of the Main Competing Technology in the Primary Target Market

The System's main competing technology to satisfy building cooling and heating load consists of an electric chiller paired with a steam boiler, with the boiler typically fueled with natural gas. The literature review undertaken as part of the market competitiveness analysis confirmed that this is the main competing technology; with little to no discussion found detailing other commercial chilling products. The CEUS reported that only two premises in the CEUS database had both electric and gas chillers.[7] The CEUS results also showed that only 1.5 percent of total natural gas use was used for cooling in California's commercial buildings, with the amount used at colleges twice that used at hospitals and large office buildings.[8] Absorption chiller minimum efficiency standards were included at the end of a table toward the end of the draft 2013 California Building Energy Efficiency Standards, but there was no corresponding discussion.[9]

5. Identification of the Size of the Primary Target Market

In this step, the size of California's hospital commercial building market served by current installed capacity of the System's competing electric chiller technology is estimated at the 30,000 foot level. The size of the market has been regionalized by utility and climate zone; this is the greatest geographic breakdown supported by the existing data. Growth potential for building cooling and heating in California through 2024 (the current time horizon projected by the CEC) is also examined.

5.1 Analysis of the Number of Commercial Buildings in California

The first step in estimating the size of the market is to estimate the number of hospital buildings in California. The CEC does not forecast the number of commercial buildings, so it was necessary to seek out alternate sources of data.

The U.S. Energy Information Administration (EIA) periodically conducts a Commercial Buildings Energy Consumption Survey of commercial buildings across the United States. This survey, commonly referred to as CBECS, is currently being updated by EIA based on 2012 data (2012 CBECS); only preliminary data are available for the 2012 CBECS. The last complete CBECS report was based on 2003 data (2003 CBECS).

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[7] California Commercial End-Use Survey, 2006, p. 121.

[8] California Commercial End-Use Survey, 2006, Table 8-4, p. 155.

[9] California Utilities Codes and Standards Team, Table 6.8.16, p. 34.

Among other things, CBECS provides an estimate of the total number of commercial buildings by type by census region. California is included in the Pacific census region, along with Washington, Oregon, Alaska, and Hawaii. The 2012 CBECS estimated that there were 929,000 commercial buildings in the Pacific census region, compared to 603,000 in the 2003 CBECS.

Another source of data providing state-by-state estimates of the total number of commercial buildings is the Federal Emergency Management Administration (FEMA), which uses the estimates for disaster impact assessment. FEMA estimated that there were 668,430 commercial buildings in California, based on a large number of data sources including the 2000 census. FEMA also estimated that the total square footage of commercial building space in California associated with that number of commercial buildings was 4,312,278 thousand square feet.

The FEMA estimate of the number of commercial buildings in California alone is ten percent higher than the estimated number of commercial buildings for the entire Pacific census region in the 2003 CBECS. Given this large disparity in the estimated *number* of commercial buildings, a comparison of commercial building square footage was made instead, using the FEMA data for California, 2000 CEC data, and the 2003 CBECS data for the Pacific census region. FEMA estimated California's commercial building square footage at 4,312 million square feet, about 73 percent of the CEC's estimated 5,937 million square feet; the 2003 CBECS estimate for the entire Pacific census region was 13,453 million square feet.

Table 9 compares FEMA's estimated commercial square footage in 2000 with the CEC's square footage estimates for the same year, category-by-category to the greatest extent possible. Differences exist not only in the total amount of commercial square footage estimated in California, but also in how commercial building types are categorized. Table 9 attempts to collapse the FEMA and CEC commercial building type definitions into similar groups, with percentages provided for each grouping used as a point of comparison to get around the significant differences in the estimated total square footage.

Table 9: Comparison of FEMA and CEC 2000 Commercial Building Estimates

	FEMA	FEMA	FEMA			CEC 2000		CEC 2000	
	# Comm Bldgs	Comm Sq. Ft. (MM)	Comm Sq. Ft. (MM)	% of TOTAL		% of TOTAL	Comm Sq. Ft. (MM)	Comm Sq. Ft. (MM)	
TOTALS =	668,430	4,312	4,312	100%		100%	5,937	5,937	
Professional/Tech Svcs (Offices)	161,302	1,020.644	1,557	36%	OFFICES	24%	1421.199		
Banks	12,119	41.047						335.621	OFF-SMALL
Government General Svcs (Offices)	10,236	80.605						1085.578	OFF-LRG
Government Emergency Response (Fire/Police)	1,861	13.981							
Personal/Repair Services (Service Stations)	98,882	400.545							
Entertainment (Restaurants/Bars)	75,374	269.164	269	6%	REST/BARS	3%	154.897	154.897	REST
Retail Trade (Stores)	91,497	650.887	661	15%	RETAIL	16%	945.713	945.713	RETAIL
Theaters	2,625	10.051							
Schools	18,621	159.260	159	4%	SCHOOL	8%	451.584	451.584	SCHOOL
Colleges/Universities	1,446	41.895	42	1%	COLLEGE	5%	275.275	275.275	COLLEGE
Hospitals	2,445	69.699	232	5%	HOSP	5%	279.753	279.753	HOSP
Medical Clinics	42,532	161.924							
Temporary Lodging (Hotel/Motel)	8,223	113.283	113	3%	HOTEL	5%	278.103	278.103	HOTEL
Wholesale Trade (Warehouses)	71,835	637.239	637	15%	WHSE	14%	852.956	805.813	NWHSE
		-						47.143	RWHSE
Churches/Non-Profits	41,203	214.344	642	15%	MISC	22%	1277.902	1025.605	MISC
Institutional Housing (Military, College, Jails)	24,388	392.585						252.297	FOOD
Nursing Homes	3,841	35.126							

Given the significant differences in (i) the estimated total commercial building square footage between FEMA and the CEC, and (ii) the estimated total number of commercial buildings between FEMA and the 2003 CBECS, it was decided to use the FEMA data solely to estimate the average size of different commercial building types in California. Given that (i) FEMA is the only data source for both square footage and total number of commercial buildings by type in California, and (ii) that these data sources were derived in conjunction with each other, the calculated average size of different commercial building types in California using FEMA data should at least be internally consistent.

Table 10 shows the derivation of average building size by commercial building type in California. Colleges/Universities and Hospitals have the largest average square footage per building at 28,973 square feet and 28,507 square feet, respectively.[10] The average square footage of office buildings differs by over 100 percent depending on the building type, ranging from Banks at 3,387 square feet to Government General Services buildings at 7,875 square feet.

Table 10: FEMA Average Size Derivation by Commercial Building Type in California

	FEMA # Comm Bldgs	FEMA Comm Sq. Ft. (000s)	FEMA Average Sq.Ft./Bldg	
TOTALS =	668,430	4,312,278	6,451	
Professional/Tech Svcs (Offices)	161,302	1,020,644	6,328	OFFICES
Banks	12,119	41,047	3,387	
Government General Svcs (Offices)	10,236	80,605	7,875	
Government Emergency Response (Fire/Police)	1,861	13,981	7,513	
Personal/Repair Services (Service Stations)	98,882	400,545	4,051	
Entertainment (Restaurants/Bars)	75,374	269,164	3,571	REST/BARS
Retail Trade (Stores)	91,497	650,887	7,114	RETAIL
Theaters	2,625	10,051	3,829	
Schools	18,621	159,260	8,553	SCHOOL
Colleges/Universities	1,446	41,895	28,973	COLLEGE
Hospitals	2,445	69,699	28,507	HOSP
Medical Clinics	42,532	161,924	3,807	
Temporary Lodging (Hotel/Motel)	8,223	113,283	13,776	HOTEL
Wholesale Trade (Warehouses)	71,835	637,239	8,871	WHSE
Churches/Non-Profits	41,203	214,344	5,202	
Institutional Housing (Military, College, Jails)	24,388	392,585	16,097	MISC
Nursing Homes	3,841	35,126	9,145	

[10] The 2004 CSFCC study used a 10-storey, 250,000 square foot hospital as its typical example of a health care building.

5.2 Cooling versus Total Electricity Output of a HTFC/AC System

The coefficient of performance (COP) for an electric chiller measures the chilling output in thermal kWh (kWh-thermal) generated by each kWh of electricity (kWh-electric) input. For this analysis, a COP of 3.4 is assumed for existing electric chillers. This means that for every kWh-electric consumed by an electric chiller, 3.4 kWh-thermal of chilling is produced, which is the equivalent of 0.967 ton-hours of chilling.[11]

The optimal size of the Absorption Chiller depends on the quantity and quality of the heat that can be captured from a given size of HTFC. The heat is captured from the exhaust gas of the fuel cell using a heat exchanger within the Absorption Chiller. The HTFC/AC System has a COP of 1.28. This means every kWh-thermal of heat from the HTFC that is captured by the Absorption Chiller, 1.28 kWh-thermal of chilling is produced, the equivalent of 0.364 ton-hours of chilling.

The above calculations show that the Absorption Chiller would need 2.66 kWh-thermal of heat input (captured from the HTFC by the Absorption Chiller) to produce the same amount of chilling that 1 kWh-electric produces from an existing electric chiller.[12] The heat produced by the HTFC is a byproduct of the electricity generated by the HTFC. The HTFC's electricity is used to satisfy the building's electricity load and the captured heat used by the Absorption Chiller increases the overall efficiency of the System. This increased efficiency from using heat from the HTFC to produce chilling from the Absorption Chiller is the primary driver of the favorable HTFC/AC System economics as compared to an electric chiller.

Any electrical generator's electric-to-thermal ratio reflects how much useful heat (in kWh-thermal) is produced for every kWh-electric generated.

- Assume that the HTFC has an electric-to-thermal ratio of 1.2, meaning that every 1.2 kWh-electric generated results in 1 kWh-thermal of useful heat.[13] This is equivalent to saying that every 1 kWh-electric generated results in 0.83 kWh-thermal of useful heat.
- Assuming an annual load factor of 85 percent, a 1.4 MW HTFC will produce 1.4 MW x 8760 hours/year x 0.85 = 10,424 MWh/year of electricity.
- At an electric-to-thermal ratio of 1.2, 10,424 MWh/year of MWh-electric will produce 8,652 MWh-thermal of useful heat. (10,424 MWh-electric x 0.83 = 8,652 MWh-thermal.)

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[11] One kWh-thermal of chilling equals 0.28 ton-hours of chilling, using a conversion factor of 3.516 kWh-thermal per ton-hour.

[12] 1 kWh-electric in an electric chiller = 3.4 kWh-thermal out. 1 kWh-thermal into an absorption chiller = 1.28 kWh-thermal out. 3.4 kWh-thermal / 1.28 kWh-thermal = 2.66.

[13] An electric-to-thermal ratio of 1.2 is cited for a generic HTFC in M. Medrano, *et al*., 2008, Table 4.

- 8,652 MWh-thermal of useful heat put into an Absorption Chiller with a COP=1.28 will yield 11,075 MWh-thermal of chilling (8,652 MWh-thermal x 1.28 = 11,075 MWh-thermal).
- Thus, each kWh-electricity produced by the HTFC yields 1.06 kWh-thermal of cooling. (11,075 MWh-thermal / 10,424 MWh-electric = 1.06.)
- An electric chiller would require 3,257 kWh-electric to produce the same 11,075 kWh-thermal of chilling produced by the 1.4 MW HTFC/AC System. (3,257 kWh-electric x 3.4 ≈ 11,075 kWh-thermal.)
- The 2,285 GWh-electric consumed by electric chillers in hospitals served by the eight reported utilities in the 2012 CEC data would have created 7,769 GWh-thermal in cooling, based on a COP = 3.4 as discussed above.
- To convert the 7,769 GWh-thermal in cooling into the equivalent HTFC/AC System capacity, first divide by 1.06 kWh-thermal, the useful thermal output produced by each 1 kWh-electric to get an equivalent 7,329 GWh-electric of HTFC output. Dividing by the number of hours in a year at the HTFC's assumed 85 percent capacity factor yields a technical market potential of 7,329,000 MWh-electric / (8760 hours x 0.85) = 984 MW for hospitals in California.

The electric-to-thermal ratio currently specified by HTFC manufacturers is closer to 2.0, indicating that current HTFCs produce less thermal output per unit of electricity generated. If an electric-to-thermal ratio of 2.0 is plugged into the above calculations in lieu of the 1.2 value, the technical market potential for the HTFC/AC System increases to 1,630 MW for hospitals in California in 2012. By 2024, the CEC projects that hospitals served by the eight reported utilities will consume 3,469 GWh for cooling, a 50 percent increase over the 2,285 GWh used by hospitals for cooling in 2012. Assuming no change in the electric chiller COP or in the range of HTFC electric-to-thermal ratios, this 50 percent increase in GWh used for cooling would result in a corresponding 50 percent increase in the technical potential for HTFC/AC Systems in hospitals by 2024. These results are summarized in Table 11, including the number of 1.4 MW HTFCs (rounded to the nearest 50) that would be required to meet this technical market size. Since the number of 2.8 MW HTFCs would be half that of the number of 1.4 MW HTFCs, results are presented only in terms of 1.4 MW HTFCs.

Table 11 reflects the statewide total technical potential for HTFC/AC Systems in hospitals. Table 12 allocates the statewide total technical potential from Table 11 by utility and climate zone (rounded to the nearest 5) based on a HTFC electric-to-thermal ratio of 1.2 to give a more granular view of the potential market for HTFC/AC Systems.

Table 11: Technical Market Size Based on HTFC Electric-to-Thermal Ratio

HTFC Electric-to-Thermal Ratio	2012: Technical Potential for HTFC/AC Systems	2012: # of 1.4 MW HTFCs Supported by Technical Potential	2024: Technical Potential for HTFC/AC Systems	2024: # of 1.4 MW HTFCs Supported by Technical Potential
1.2	984 MW	~700	1,476	~1,050
2.0	1,630 MW	~1,150	2,445	~1,750

Table 12: Regional Technical Market Size Based on HTFC Electric-to-Thermal Ratio of 1.2

Utility and (Climate Zone)	2012: Technical Potential for HTFC/AC Systems (MW)	2012: # of 1.4 MW HTFCs Supported by Technical Potential	2024: Technical Potential for HTFC/AC Systems (MW)	2024: # of 1.4 MW HTFCs Supported by Technical Potential
SCE (8)	146.7	105	211.9	150
PG&E (4)	126.8	90	181.2	130
PG&E (3)	110.0	80	161.7	115
PG&E (5)	89.3	65	132.6	95
SCE (9)	88.0	65	142.9	100
LADWP (12)	82.6	60	123.3	90
SDG&E (13)	77.7	55	113.7	80
SCE (10)	76.9	55	133.5	95
LADWP (11)	53.3	40	77.5	55
SMUD (6)	49.6	35	74.5	55
PG&E (2)	38.6	30	55.8	40
SCE (7)	11.6	10	18.8	15
PG&E (1)	9.7	10	13.1	10
IID (15)	9.4	10	15.4	10
Burbank (14)	9.0	5	12.9	10
Pasadena (16)	5.0	5	7.2	5
Total	984 MW	~700	1,476	~1,050

The technical market size represents that maximum market size based on only on the required need for cooling by hospitals in California and the technical operating parameters of the HTFC/AC System. Hospitals will only install HTFC/AC Systems if such systems make sense in economic and reliability terms. The economic market size takes into account the HTFC/AC System economics and reduces the technical market size by winnowing out those HTFC/AC Systems that would be uneconomic in any given circumstance. The relationship between the technical, economic, and market potential is illustrated in Figure 2.

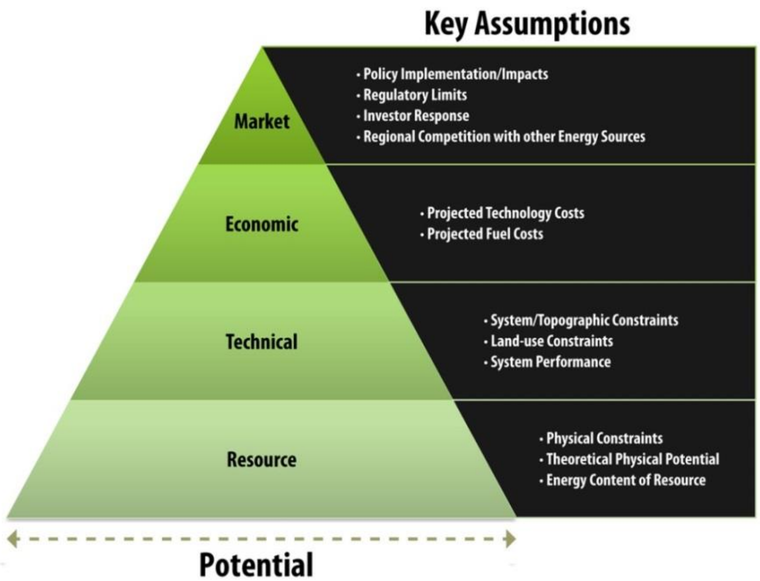

Figure 2: Pyramid of "Potential" Definitions[14]

It is shown in the *Economic Model and Analysis Report* that the levelized cost of energy (LCOE) of any System goes down as the capacity factor of the installation goes up. The more the System operates, the greater will be its output of useful products and the lower will be its LCOE, all else equal. The LCOE will be minimized when the HTFC operates around-the-clock as a base load generator and the Absorption Chiller maximizes use of the high-quality heat from the HTFC to produce chilling. The more chilling produced by the Absorption Chiller, the lower the LCOE of the System because the ton-hours of chilling increase the quantity of useful products generated without increasing the fuel input costs (since the fuel for the Absorption Chiller is the heat generated by the HTFC).

6. Economic Analysis

The key market for high-temperature fuel cell and absorption chiller (HTFC/AC) systems is identified as being hospitals with high cooling-to-electric demand ratios. The remainder of this paper describes the economic analysis carried out to characterize the economic viability of HTFC/AC technology in real-world scenarios. Simulations were run to (1) characterize the optimal HTFC/AC system equipment portfolio for different building types, and (2) statistically distinguish the relative importance of key economic and engineering assumptions built into the model.

6.1 Economic Analysis Assumptions

Unless otherwise noted, the default values shown in Table 13 were used as inputs to this analysis.

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[14] Source: National Renewable Energy Laboratory, http://www.nrel.gov/gis/re_potential.html

Table 13: Default Code Inputs

Parameter	Default Value	Description
Fc_baseload_eff	47	Fuel cell fuel to electricity efficiency at full load
COP	1.28	Absorption Chiller coefficient of performance
Parasitic_power_fraction	10/100	Assumed parasitic losses due to auxiliary plant equipment
Fixed O&M	200	$ per rated kW per year to operate and maintain the system
Variable O&M	0.21	$/MWh to operate and maintain the system
Annual Starts	4	Number of times the fuel cell is started per year
Start-Up Fuel per Start	10	MMBtu/MWh
Stack Life	5	Years between stack replacements
Economic Life	20	Economic life of the project in years
CO2_toggle	1	CO_2 tax rate starts at a flat $/ton rate (CO2_ton_flat) and increases with inflation
CO2_ton_flat	20	CO_2 tax rate for year one in $/short ton CO_2
Ng_cec_forecast	0	Natural gas price starts at a flat rate (ng_start_price) and increases with inflation
Ng_start_price	5	Natural gas rate for year one in $/MMBtu
Elec_import_forecast	0	Electricity import price starts at a flat rate (elec_import_price) and increases with inflation.
Elec_import_price	120	Electricity import rate for year one in $/MWh
Export_rate	30	The owner is compensated at this rate plus inflation for electricity exported to the grid
Elec_chiller_cop	3.4	Electric chiller coefficient of performance
Elec_chiller_sizing	Tailoring	Electric chiller is sized by the program to meet a certain percentage of the chilling demand not met by the absorption chiller
Elec_chiller_percent_of_max	100	In the tailoring strategy, the electric chiller is sized by the program to meet this percentage of cooling not met by other equipment
Boiler_eff	80/100	Natural gas boiler efficiency
Boiler_sizing	Tailoring	Natural gas boiler is sized by the program to meet a certain percentage of the heating demand not met by any other equipment
Boiler_percent_of_max	100	In the tailoring strategy, the natural gas boiler is sized by the program to meet this percentage of heating not met by other equipment
Own_type	1	Merchant owned system
Tax_loss_carryover_toggle	0	Tax losses are recognized in the year they occur
Equity_percent	33/100	Percent of the total assets financed by shareholders or investors
Return_rate	13.25/100	Required rate of return to the shareholders or investors on the percent financed by equity
Loan_interest	5.91/100	Interest rate on the debt owed by the owner to the bank
tes_size	200	Maximum ton-hours of cooling that can be stored in the TES

The model simulates Fuel Cell Energy's DFC line of molten carbonate fuel cells, which range from 300 kW to 2.8 MW capacities. The published thermal-to-electric efficiency of the fuel cell line is 47%. Capital (over-night construction) costs of $3600, $3300, and $3000/kW were applied to the 300 kW, 1.4 MW, and 2.8 MW fuel cells, respectively.

The absorption chiller modeled in the economics code is a direct exhaust fired double effect lithium bromide chiller. The rated coefficient of performance (COP) of the line of absorption chillers is 1.28. Capital (over-night construction) costs of $600, $570, and $540/ton were applied to the 40, 200, and 400 refrigeration ton absorption chillers, respectively.

Parasitic loads are simplistically modelled in the economics code as a set percentage of fuel cell output. It is very difficult to estimate the electricity required to power all of the auxiliary loads of an HTFC/AC system because they will vary with each installation and with operating conditions. For example, the size of pump that is installed to supply the building with chilled water will be a function of the size and length of piping selected, as well as the flow and temperature requirements of the system. A 1.4 MW HTFC/AC system being installed at the University of California, Irvine Medical Center has a name-plate parasitic load of 47 kW, which is 3.36% of its rated output. A conservative parasitic power fraction of 10% is assumed in typical model runs to account for degradation over time and variations in design and operating conditions.

Natural gas plants operating on a Brayton Cycle constitute 44% of California's electricity generation portfolio.[15] According to the 2010 version of the Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID), the average natural gas plant in California emits 1,100 pounds of CO_2 per megawatt-hour of electricity produced (based on average emissions from plants with utilization greater than one percent in eGRID PLNT10).[16] The FuelCell Energy line of stationary, molten carbonate fuel cells emits 980 lb-CO_2/MWh. This study assumes that grid electricity is associated with 1,100lb-CO_2/MWh since DG is most likely to offset typical NG plants.

CO_2 price is the $/short-ton-$CO_2$ value assigned to any CO_2 produced to serve the loads of the building. Emissions could come from the fuel cell, the natural gas boiler, or from the grid when it provides imported electricity to the building or electric chiller. The CO_2 price in California is currently $13/ton.[17] The California Energy Commission's Cost of Generation Model 3.62 predicts that the price of CO_2 will

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[15] California Energy Almanac, Total Electricity System Power, 2013. http://energyalmanac.ca.gov/electricity/total_system_power.html

[16] Emissions & Generation Resource Integrated Database (eGRID), Ninth edition with 2010 data (Version 1.0) Released 02/24/2014.

[17] BGC Carbon Market Daily, BGC Environmental Brokerage Services website January 22, 2015. http://www.bgcebs.com/Register/?page=http://www.bgcebs.com/myBGC-EBS/dailys/&id=37951

rise to $135/ton in 25 years. A CO_2 rate of $20/ton is generally assumed in order for the evaluations to be applicable to near-term, future HTFC/AC installations.

The rate for natural gas purchased for a small commercial building through the Southern California Gas Company in January 1, 2015 is $6.32/MMBtu, down 14.6% from December 1, 2014.[18] A natural gas price of $5/MMBtu is typically assumed in this work in order for the evaluations to reflect slightly lower prices in the near-term future.

The average electricity price for the University of California, Irvine Medical Center was $130/MWh in 2014.[19] An electricity import price of $120/MWh is assumed in this work in order for the HTFC/AC levelized cost of electricity comparisons to be conservative relative to the competing scenario.

The rate that a utility is willing to pay for electricity exported to the grid by a distributed generation unit depends upon numerous factors including utility policies, currently available infrastructure, grid capacities in the region, and legal issues. Electricity export rates are generally assumed to be $30/MWh in this thesis in order to provide a conservative analysis. For reference, the net energy metering surplus compensation rate for Southern California Edison was $45.12/MWh in March 2015.[20]

6.2 Interpreting Model Results

The actual annual cost of operating a power plant changes throughout the year. Levelized cost refers to the constant value that is equivalent to the average annual total cost, over the life of the asset, incorporating standard present value discounts. Levelized cost of electricity, commonly referred to by its acronym LCOE, is a metric used in this and other economic studies to compare the cost of generation from different power sources. LCOE is a composite of numerous inputs including both fixed and variable costs which are all levelized for ease of compilation and comparison. Fixed costs such as capital, financing, insurance, Ad Valorem, and fixed operating and maintenance are included as well as variable costs associated with fuel and variable operating and maintenance (O&M). Capital encompasses all of the construction costs including land purchase, permitting, interconnection, original equipment, etc. Financing costs cover the debt and equity of the project. Insurance covers the premium for the power plant itself and is based on a first-year estimate which escalates over time. Ad Valorem covers the annual property tax of the power plant. Fixed O&M includes staffing, overhead, equipment, and other annual costs associated with the plant regardless of how much it operates. Variable O&M changes as a

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[18] Gas Price Information for Commercial and Industrial Rates, January 22, 2015. http://www.socalgas.com/for-your-business/prices/

[19] Email correspondence, Nato Flores, P.E. Consultant at University of California, Irvine Medical Center dated January 22, 2015.

[20] Southern California Edison Net Surplus Compensation Rate, NSCR Energy Prices, March 2015.

function of the operation of the power plant and includes costs for yearly maintenance, overhauls, water supply and other consumable. And finally, fuel costs include the amount spent on fuel for both operation and start up. All costs are reported on a present value basis.

6.3 Characterizing HTFC/AC Portfolios for Actual Buildings

6.3.1 Multipurpose Science and Technology Building

The Multipurpose Science and Technology Building (MSTB) is a generic office building on the main campus of UC Irvine that is used for classrooms, laboratories, and offices. The average electricity demand of MSTB is 83.5 kW, the average heating demand is 27.1 kW and the average cooling demand is 17.6 kW (5 refrigeration tons). In order to get a baseline for comparison, the competing scenario was run which simulated the current configuration of utilities at MSTB. The equipment portfolio of the competing system consists of electricity imports from the grid, a natural gas boiler for heating, and an electric chiller for cooling. The LCOE of the competing scenario at MSTB is $133.46/MWh.

The average power demand of the building is only 83.5 kW, so each of the molten carbonate fuel cells considered are oversized for this application and would export a majority of the electricity produced. For the MSTB, a basic portfolio consisting of a 300 kW fuel cell, a 40 refrigeration ton absorption chiller does not meet any of the building's heating demand but satisfies 99% of its chilling demand while exporting 69% of the electricity generated. The LCOE of this system is $123/MWh. If a 30 kW heat recovery unit (HRU) is included in the equipment portfolio, the LCOE of the system is reduced slightly as more useful energy is produced from the system, but with the dynamic heating load profile at MSTB, the HRU only meets 18.5% of the heating load. The Heat Recovery Unit (HRU) has an extremely low LCOE because it constantly recovers heat from the fuel cell exhaust throughout its years of operation and requires comparatively little installation and operating costs. Since the HRU decreases the LCOE for this case, it is left in the equipment portfolio and supplemented with a natural gas boiler to meet the building heating demand as shown in the results of Figure 1.

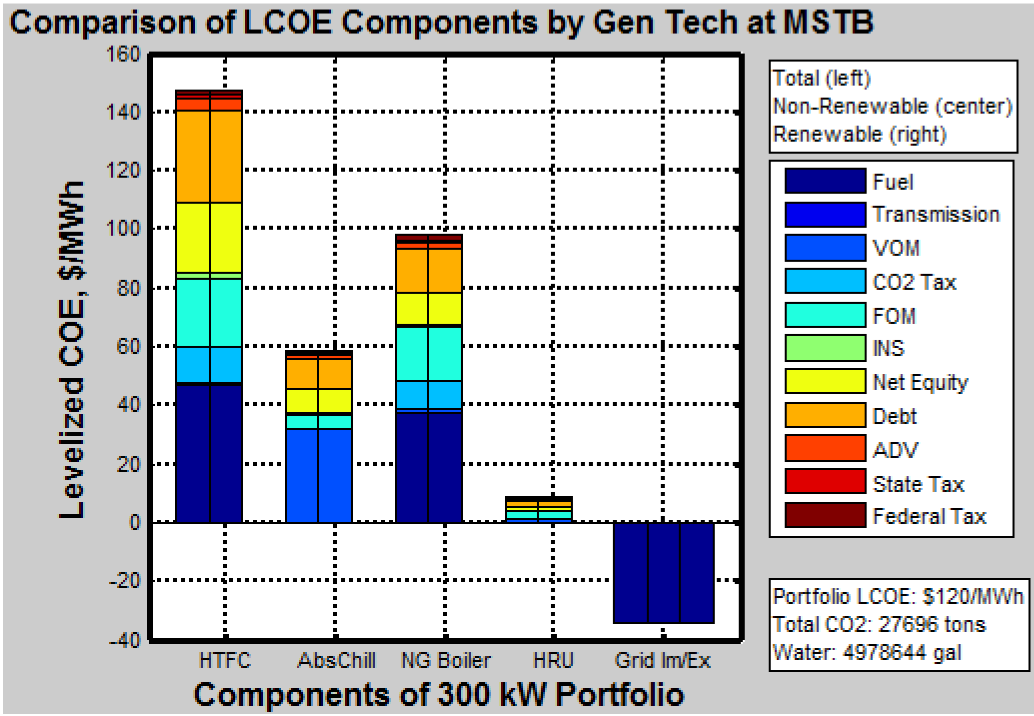

Figure 1: MSTB 300 kW Portfolio with HRU and NG Boiler

This scenario represents the least amount of distributed generation equipment with the smallest capacity required to meet all of the loads of the MSTB (except 1% of the cooling). The LCOE of this scenario is $14/MWh (10%) less than the competing scenario.

Next the 1.4 MW portfolios are evaluated for installation at MSTB. The smallest portfolio that has the potential to meet all of the heating, cooling, and power demands of the building is the simple fuel cell, absorption chiller, and heat recovery unit setup. The LCOE of this scenario is $111.3/MWh, but only 75% of the heating demands are met. Cooling demands are met 99.5% of the time, so an electric chiller is not required. When a natural gas boiler is added to the portfolio, the LCOE is $111.4/MWh. In this case, the HRU provides 3/4 of the heating while the natural gas boiler is designed to meet 1/4 of the heating demand. The installation of this equipment at MSTB would save the owner $22.1/MWh (17%) on energy costs over the next 20 years.

Over %91 of the electricity produced by the fuel cell is exported back to the grid, and in the default scenario the owner receives $30/MWh plus inflation for this exported electricity. The installation cost for the 300 kW fuel cell is assumed to be $3600/kW. Economy of scale reduces this cost for the 1.4 MW fuel cell to $3300/kW. Since this installation price per kilowatt is lower, and more revenue is generated from exports, the 1.4 MW system more economically viable than the 300 kW system. Economies of scale further reduce the installation cost of the fuel cell to $3000/kW for a 2.8 MW unit. In this case, the fuel cell produces enough exhaust to run a 400 refrigeration ton absorption chiller so there is extra cooling capacity available. Also, the HRU is large enough to accommodate all of the MSTB heating loads, so that no natural gas boiler is required. Revenue from exports, reduced installation rate and a smaller equipment portfolio each contribute to the very low LCOE for this portfolio. This scenario is $27.7/MWh (21%) less than the competing system at MSTB.

This equipment portfolio offers no backup source of cooling or heating for the absorption chiller and natural gas boiler. In each of the preceding scenarios, which include a natural gas boiler, the boiler is sized to meet the heating load that is not met by the heat recovery unit. If the owner wished to add redundancy to the system they could add an electric chiller and a natural gas boiler sized to meet 100% of the required heating and cooling loads. Adding this redundant equipment hardly affects the LCOE as the overall cost is allocated on a per-megawatt basis, and the system produces a large amount of energy. A 2.8 MW fuel cell with a 400 ton absorption chiller, a heat recovery unit, and a full backup natural gas boiler and electric chiller would have an LCOE of $106.9.

Each of the preceding scenarios assumes the owner received $30/kWh for exported electricity. While this rate is conservatively one-quarter of the assumed rate for imported electricity, in some situations the electric utility may deny the owner the ability to collect any money for exported electricity. Zero returns on exports would drastically reduce the economic viability of each of the three portfolios to $140/MWh, $142/MWh, and $138/MWh for the 300 kW, 1.4 MW, and 2.8 MW portfolios respectively.

None of the HTFC/AC portfolios at MSTB are economically competitive with using grid electricity, a natural gas boiler and an electric chiller when the owner is not being reimbursed for electricity exports from the fuel cell. The 300 kW fuel cell portfolio was 10% more economical than the competing system when exported electricity had a $30/MWh return rate, but is 6% more expensive than the competing scenario when exports are not reimbursed. Similarly, the 1.4 MW portfolio goes from being 17% more economical to being 8% more expensive, and the 2.8 MW portfolio goes from being 21% more economical to being 4% more expensive. The 2.8 MW portfolio is slightly less expensive than the 1.4 MW portfolio when exports are not reimbursed as the savings from exclusion of a natural gas boiler are more prominent.

In order to determine the minimum payback on exported electricity required for an HTFC/AC system at MSTB to break-even with traditional power, heating, and cooling, the exported electricity payback rate was varied for each fuel cell portfolio until the LCOE of the HTFC/AC system matched the LCOE of the competing portfolio. The LCOE of the 300 kW equipment portfolio closely matches the competing system when the owner is receiving $10/MWh on exported electricity. The 1.4 MW and 2.8 MW portfolios require at least $8/MWh and $4/MWh return on exported electricity in order to be competitive.

California Senate Bill 32 sets the groundwork for the state's plan to cap greenhouse gas emissions. The bill is implemented under regulations set forth by the California Air Resources Board. In Article 5 of the Air Resources Board "Final Regulation Order on California Cap on Greenhouse Gas Emissions and Market-Based Compliance Mechanisms," section 95852.2, fuel cells are explicitly exempt from CO_2 taxes. The HTFC/AC system simulated at MSTB with zero CO_2 taxes has a portfolio LCOE of $108.5/MWh, 19% lower than the competing scenario.

In conclusion, a 2.8 MW fuel cell with a 400 ton absorption chiller, an HRU, and an optional backup electric chiller and natural gas boiler could be installed at a building with a similar load profile to the Multipurpose Science and Technology Building and be economically competitive with the existing infrastructure if a reasonable rate of return is achieved for electricity exports. The high revenue on electricity exports and lower installation rates associated with such a large unit will make this distributed generation option economically feasible. However, the logistics of constructing such a large system next to a relatively small building in a populated area could pose some challenges to the adoption of this technology by the distributed generation market. Also, if the owner is not receiving returns on exported electricity, the megawatt class fuel cells become economically uncompetitive. Since distributed generation owners are typically in the business of offsetting their own loads rather than exporting electricity, the smaller 300 kW HTFC/AC system is advisable as it is the smallest unit capable of meeting all of the loads at MSTB. The actual situation at MSTB is that the owner would receive no reimbursements for exported electricity, but would also not be taxed on the CO_2 produced by the fuel cell. In this case, the 300 kW HTFC/AC system with a natural gas boiler and heat recovery unit would be economically advisable.

6.3.2 Long Beach Veterans Affairs Hospital

The Long Beach Veteran's Affairs Hospital (LBVA) is a 237-bed comprehensive tertiary care facility with an average power demand of 3.51 MW, an average cooling demand of 1924 kW (547 refrigeration tons), and an average heating demand of 1,938 kW. The competing scenario at LBVA of a natural gas boiler, an electric chiller, and electricity from the grid has an LCOE of $102.9268/MWh and produces 514,556 short tons of CO_2. The 300 kW system could be installed at LBVA to supplement the existing infrastructure and reduce overall CO_2 emissions by 6% at an LCOE of $101.1/MWh.

A 1.4 MW fuel cell is capable of providing 40% of the building's electricity demand on average. It can also drive a 200 ton absorption chiller, which is capable of satisfying 94% of the building's cooling demand. The portfolio LCOE for a 1.4 MW HTFC/AC distributed generation system which satisfies all of the cooling and heating loads of the hospital by using an electric chiller to supplement the absorption chiller has an LCOE of $100/MWh.

A 2.8 MW fuel cell is capable of providing 80% of the building's electricity demand on average. It also can drive a 400 ton absorption chiller which is capable of satisfying all of the building's average cooling demand, but spikes in cooling demand require an electric chiller. The portfolio LCOE for a 2.4 MW HTFC/AC distributed generation system which satisfies all of the cooling and heating loads of the hospital has an LCOE of $98/MWh, which is similar to the LCOE of a 1.4 MW system, and is competitive with the existing infrastructure. There is a slight decrease in the LCOE of the 2.8 MW system compared to the 1.4 MW system because the increased revenue from exports and decreased installation cost on a per-megawatt basis.

The 2.8 MW portfolio saves the investor 5.2% on energy charges when levelized over the 20 year life of the project. If California Senate Bill AB-32 is assumed to be in effect, and the CO_2 emissions from the fuel cell are not taxed, the portfolio would be even more economically advisable with an LCOE of $93.1/MWh, which is 9.5% less than competing scenario.

The cooling load of the LBVA is 547 refrigeration tons on average, so the 400 ton absorption chiller is usually fully loaded by the hospital. However, the standard deviation of the cooling profile at LBVA is 595 tons, so the load is very dynamic, frequently rising above the average demand. The electric chiller is sized to meet all of the excess cooling demand not met by the absorption chiller. Electricity used to run the electric chiller along with the associated CO_2 emissions created by the grid increase the overall LCOE of the portfolio. The addition of a thermal energy storage tank could curtail the cooling demand of the electric chiller by storing excess cooling produced by the absorption chiller during times of low cooling demand, and later dispatching that cooling to meet loads when then are above the capacity of the absorption chiller. An economic model is run using the 2.8 MW system to see what impact the addition of a thermal energy storage tank has on the economics of the HTFC/AC application. For this example, the tank is assumed to be able to deliver cooling at a rate of 300 refrigeration tons to the hospital. This is based on a rough estimate 750 gallons per minute of chilled water flowing through an 8" steel pipe between the tank and the hospital. The water is assumed to increase in temperature by 10^{o}F across the air conditioning coils. The thermal energy storage tank capacity is assumed to be 500 ton-hrs. This is based on the amount of excess cooling typically provided by the absorption chiller when cooling loads of the building are low. The LCOE of this portfolio is $98.05/MWh, which is only slightly higher than the 2.8 MW portfolio without a thermal energy storage tank. While the tank is expensive to install, it saves roughly 100 short tons of CO_2 emissions by reducing the utilization of the electric chiller

In conclusion, while the addition of any size HTFC/AC system reduces energy costs for the LBVA, the 2.8 MW fuel cell coupled with a 400 refrigeration ton absorption chiller, heat recovery unit, natural gas boiler, and electric chiller portfolio is the most cost effective solution. Even if the owner does not receive incentives for exported electricity, and is taxed \$30/MWh on CO_2 emissions from the fuel cell, the HTFC/AC system is 5.2% more economical than the existing infrastructure. A breakdown of LCOEs for each component is shown in Figure 4.

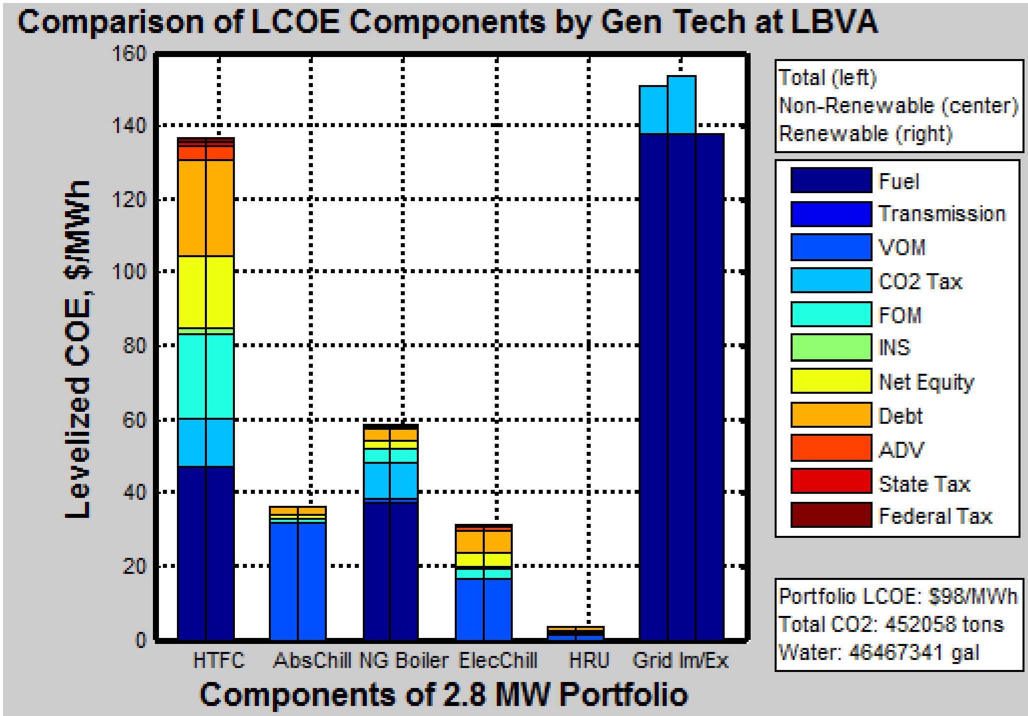

Figure 4: LBVA 2.8 MW Portfolio

6.3.3 South Coast Air Quality Management District Building

The South Coast Air Quality Management District building (SCAQMD) is a relatively efficient office building with an average power demand of 253 kW, an average cooling demand of 176 kW (50 refrigeration tons), and an average heating demand of 294 kW. The competing scenario at SQAMD of a natural gas boiler, an electric chiller, and electricity from the grid has a very low LCOE of \$85.52/MWh and produces 51,697 short tons of CO_2. A 300 kW fuel cell system could be installed at SCAQMD and would only require grid support 30% of the time when electricity demands are high. The 40 refrigeration ton absorption chiller coupled to the fuel cell is capable of handling 94.8% of the total cooling load and the heat recovery unit can handle 6.2% of the heating load. With the addition of a natural gas boiler and an electric chiller, the system is capable of handling all of the cooling and heating loads of the building at an LCOE of \$85.3/MWh as shown in Figure 5.

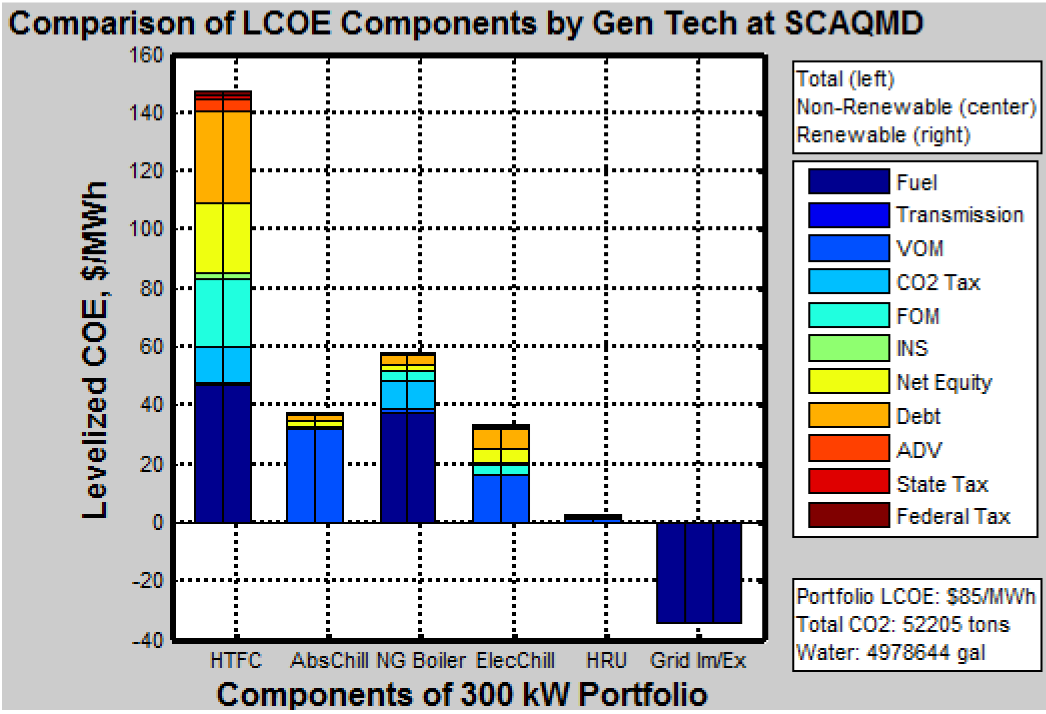

Figure 5: SCAQMD 300 kW System

If CO_2 taxes are not applied to the fuel cell, the LCOE of this system drops to $81.3/MWh which is almost 5% more economical than the competing system. If the owner is not being reimbursed for exported electricity, the LCOE rises to $86.9/MWh.

A 1.4 MW fuel cell is capable of providing all of the building's electricity. It also can drive a 200 ton absorption chiller which is capable of satisfying 99% of the building's cooling demand, so the addition of an electric chiller would be optional. The portfolio LCOE for 1.4 MW and 2.8 MW HTFC/AC distributed generation systems deployed at SCAQMD are $95/MWh and $96/MWh respectively. The return on exported electricity is not enough to justify installation of the larger HTFC/AC portfolios at SCAQMD.

The competing scenario at SCAQMD has a very low LCOE because the load profile of the building is relatively flat, thus making it very hard for HTFC/AC systems to compete.

If CO_2 taxes were not applied to the 1.4 and 2.8 MW portfolios above, their LCOEs would drop to $82.8/MWh and $82.7/MWh respectively, so when CO_2 taxes are applicable to the fuel cell, the most economically competitive equipment portfolio at the SCAQMD is the 300 kW fuel cell with a 40 ton absorption chiller, a natural gas boiler, an electric chiller, and a heat recovery unit. The larger units can only compete with the relatively low LCOE of the competing scenario if there are no CO_2 taxes applied to the fuel cell.

6.3.4 Comparison of Building Types

The three building load profiles analyzed above represent potential real world applications of HTFC/AC technology. In order to simplify the task of characterizing LCOE trends, three dummy load profiles were created which simulate the perfect building for each size equipment portfolio. The Test 300 data set represents a building which draws a flat 300 kW electric load, 40 refrigeration ton cooling load, and 30 kW heating load which can be precisely served by the 300 kW fuel cell, 40 ton absorption chiller, and heat recovery unit portfolio. Similarly, the Test 1400 data set represents a building tailored to the power, cooling, and heating loads of the 1.4 MW fuel cell, 200 ton absorption chiller, and 140 kW heat recovery unit portfolio. Test 2800 is tailored for the 2.8 MW fuel cell, 400 ton absorption chiller, and 280 kW heat recovery unit portfolio. The competing scenario was run for each tailored building load profile in order to see what the LCOE would be for a typical grid-reliant setup. Then, each of the fuel cell portfolios was run using each of the tailored load sets. The portfolio was adjusted to ensure all of the loads of the building were being met. An electric chiller and a natural gas boiler were added to the 300 kW portfolio when analyzing the 1.4 and 2.8 MW buildings, and to the 1.4 MW portfolio when analyzing the 2.8 MW building. The result of this exercise is shown below in Figure 6.

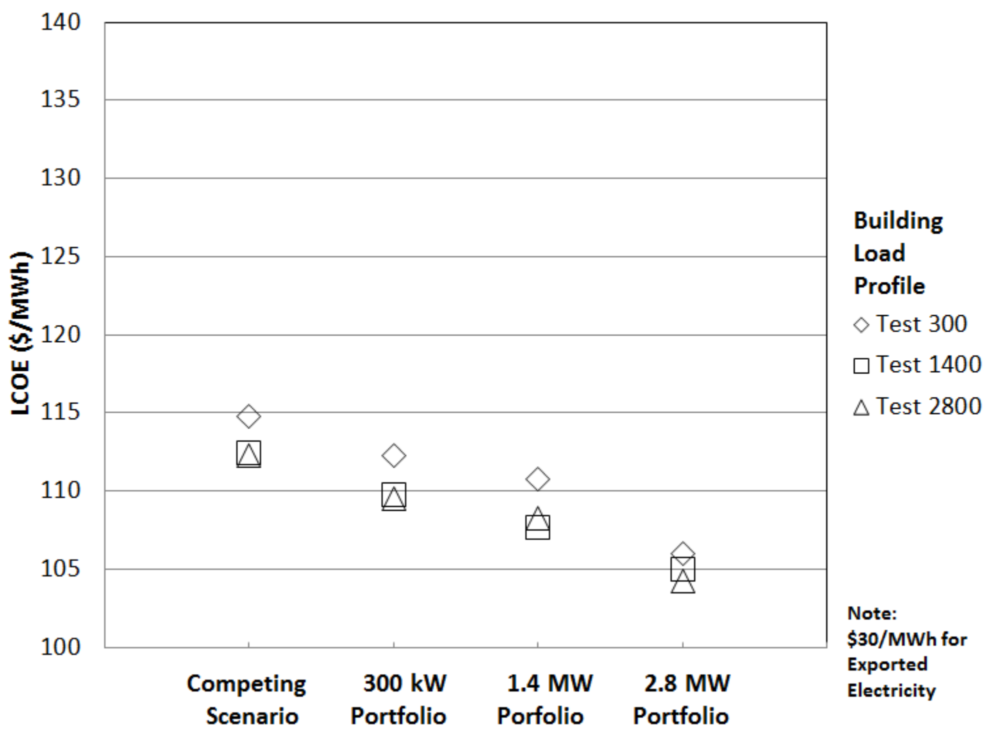

Figure 6: Tailored Building Results

The first conclusion is that HTFC/AC systems make economic sense when they are deployed at buildings that can accept all of their electricity, cooling, and heating products without relying on the grid for supplemental electricity. Also, bigger fuel cell capacities lead to smaller LCOEs when the owner is being reimbursed for exported electricity. In this case, the owner is being reimbursed $30/MWh for exports back to the grid. However, they are not receiving the entire $30/MWh back for exported electricity as increased production means increased CO_2 taxes and other maintenance and operation costs. In the base case, the CO_2 tax rate is assumed to be $20/ton of CO_2. Since the fuel cells have a CO_2 emissions factor of 0.49 tons per MWh, there is a tax charge of $9.8/MWh of generation. Therefore, the owner is realizing a return of $20.2/MWh on exported electricity. If the CO_2 tax rate were increased to $61.2/ton the export return of $30/MWh would be cancelled out and there would be no incentive at all to export.

If the same model runs are performed assuming the owner is not reimbursed for exporting electricity to the grid, LCOE trends change dramatically as shown in Figure 7.

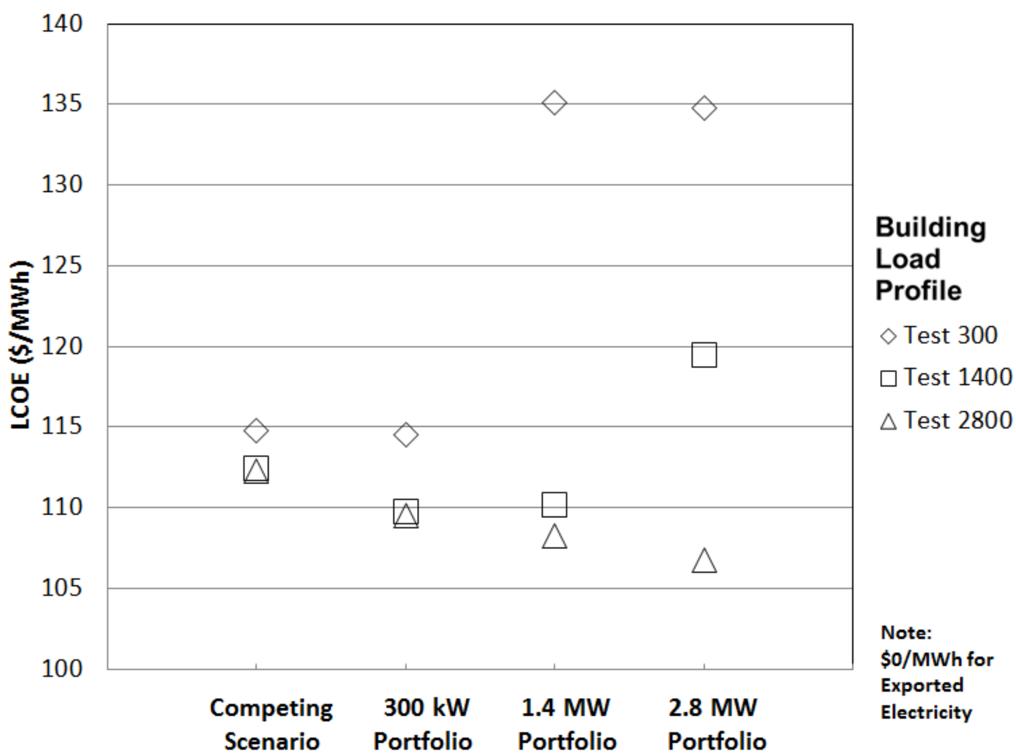

Figure 7: Tailored Building Results with Zero Return on Exports

There is a heavy penalty for installing fuel cells with extra capacity when there are no export reimbursements. These results also suggest that installing an HTFC/AC portfolio that is smaller than the building demand at all times leads to the lowest LCOE, which makes sense since the equipment is utilized to its maximum potential to meet the building demands for cooling, heating, and power. The Test 300 building benefits slightly from the installation of a 300 kW fuel cell, but the 1.4 MW and 2.8 MW fuel cells cause an increase in LCOE of 17%. The Test 1400 building also benefits from the installation of a 300 kW or a 1.4 MW fuel cell, but a 2.8 MW fuel cell would increase the LCOE by nearly 6%. The large Test 2800 building sees the biggest benefit from installing a HTFC/AC system, with the savings increasing with fuel cell size up to 7%. These findings agree with predictions, but do not completely agree with the results of the real-world building analysis done in prior sections of this Thesis, specifically, the results of the SCAQMD analysis. To determine why the megawatt-class HTFC/AC portfolios at SCAQMD do not follow the trends outlined above, the load characteristics of each of the buildings must be compared.

As Table 14 shows, the biggest savings occur at the buildings with the highest competing scenario LCOEs. Since the SCAQMD already has such a low LCOE, it will be difficult for any HTFC/AC system to make economic sense. As was shown previously, the 300 kW portfolio is the most economic HTFC/AC solution at just 0.26% lower than the competing scenario.

Table 14: Best Case HTFC/AC Scenarios

		HTFC/AC System LCOE	
Building	Competing Scenario LCOE ($/MWh)	Savings with Exports $30/MWh	Savings with Exports $0/MWh
MSTB (300 kW)	133.4	10.5%	-4.6%
LBVA (2.8 MW)	102.9	5.2%	5.2%
SCAQMD (300 kW)	85.5	0.26%	-1.6%
Test 300	114.76	7.6%	7.6%
Test 1400	112.4	6.6%	6.6%
Test 2800	112.3	7.15%	7.15%

Table 15 summarizes the load characteristics of each of the three buildings analyzed in this work. The heating or cooling thermal-to-electrical load ratio (T/E) is the ratio of the average heating or cooling demand to the average electricity demand of the building and is an indication of how much of a specific thermal product is demanded relative to electric power. The relative standard deviation is the standard deviation of the load profile divided by the average demand; it gives an indication of the variability of the load profile.

Table 15: Building Load Statistics

	Power		Cooling			Heating		
Building Name	Avg. Demand (kW)	Relative Standard Deviation (%)	Avg. Demand (tons)	T/E Ratio	Relative Standard Deviation (%)	Avg. Demand (kW)	T/E Ratio	Relative Standard Deviation (%)
MSTB	83.5	29.7	5	.210	227.6	27.1	.325	253.6
SCAQMD	252.9	35.0	49.9	.694	135.2	293.5	1.16	103.5
LBVA	3510	16.2	547.1	.548	108.8	1937.7	.552	96.1

The heating and cooling loads of the SCAQMD are so small and variable that the returns gained on exported electricity are offset by the extra cost of installing and maintaining a 200 or 400 ton absorption chiller and associated heat recovery unit.

The optimal HTFC/AC equipment portfolio and building load profile combination will leverage the cooling and heating made available by recovery of energy from the exhaust gas of the fuel cell. If the HTFC/AC system is properly sized for the building (i.e., its thermal and electrical products are being utilized to their maximum potential) and is installed in California under AB-32's CO_2 tax exemption for fuel cells, it will be highly competitive with the existing infrastructure regardless of the return rate on exported electricity. If CO_2 taxes do apply to the fuel cell, then a closer look at the electricity exporting agreement between the owner and their electric utility will reveal whether the HTFC/AC system is economically advisable.

6.3.5 Analysis of Key Model Assumptions

Various financial inputs were evaluated in order to characterize the importance of deviations from the assumptions in a real-world HTFC/AC deployment, and to evaluate the impact of future changes in financial conditions on HTFC/AC economics. The analysis focused on an equipment portfolio consisting of a 2.8 MW fuel cell, 400 ton absorption chiller, 280 kW heat recovery unit, natural gas boiler, electric chiller and grid imports and exports and used the Long Beach Veteran's Affair's (LBVA) hospital as a representative installation building. The fuel cell is run at base load capacity, with any extra generation exported to the grid. The grid is also used to support any electricity loads not met by the fuel cell.

6.3.5.1 Responses Considered

The analysis considered the responses listed in Table 16.

Table 16: Sensitivity Analysis Responses

Response	Units
Levelized Cost of Electricity	$/MWh
CO_2 Reduction	tons/year
Savings	$/MWh

Levelized cost of electricity (LCOE) refers to the constant annual cost that is equivalent on a present value basis to the actual annual costs of electricity.

The integrated economic and technical model calculates fuel cell CO_2 production by multiplying the fuel cell's natural gas flow rate (MMBtu/hr) by and a conversion factor which correlates the CO_2 produced by the fuel cell with MWh of energy produced at the rated 47% fuel to electricity conversion efficiency. CO_2 emissions from imported electricity are included by multiplying the US Environmental Protection Agency National Average CO_2 emission rate for conventional natural gas plants of 1135 lb/MWh by the total megawatt-hours of electricity imported.[21] Emissions from parasitic loads are not considered by the model. Since the rate of CO_2 production is higher on a per MWh basis for a conventional natural gas plant, CO_2 emissions for the overall service of the building are reduced with increased utilization of the fuel cell.

Savings and CO_2 emissions reduced are values calculated based on a competing system consisting of grid imported electricity, a natural gas boiler, and an electric chiller. Savings is the $/MWh difference between the competing scenario and the HTFC/AC scenario given the same electricity and natural gas price inputs. CO_2 Reduction represents the short tons of CO_2 emissions not emitted (reduced) per year when the HTFC/AC system takes the place of the competing system.

6.3.5.2 Factors Evaluated

Four continuous factors were considered as shown in Table 17Table, along with one categorical factor, which is shown in Table 18.

Table 17: Numerical Factors

Factor Code	Factor	Units	Default	Minimum	Maximum
A	Natural Gas Price	$/MMBtu	5	2.5	10
B	CO_2 Price	$/Ton	20	0	40
C	Electricity Import Price	$/MWhr	120	120	240
D	Electricity Export Price	$/MWhr	30	0	120

[21] US Environmental Protection Agency, Clean Energy, Natural Gas. http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html#footnotes

Table 18: Categorical Factor

Factor Code	Factor	Level 1	Level 2	Level 3
E	Ownership Type	1 Merchant Owned	2 Investor-Owned Utility	3 Public-Owned Utility

The price for natural gas purchased for a small commercial building through the Southern California Gas Company in January 1, 2015 is $6.32/MMBtu, down 14.6% from December 1, 2014.[22] A natural gas price of $5/MMBtu is assumed in previous sections of this work in order for the evaluations to reflect even lower prices in the near-term future. For this analysis the natural gas price was varied from $2.5 to $10/MMBtu to simulate conditions should the price of gas continue to decrease, or increase by a factor of two.

CO_2 price is the \$/ton-CO_2 value assigned to any CO_2 produced as a result of serving the heating, cooling, and power loads of the building. Emissions could come from the fuel cell, the natural gas boiler, or from the grid when it provides imported electricity to the building or auxiliary equipment. The CO_2 price in California is currently $13/ton.[23] The California Energy Commission's Cost of Generation Model 3.62 predicts that the price of CO_2 will rise to $135/ton in 25 years. A CO_2 price of $20/ton is assumed in previous sections of this work in order for the evaluations to be applicable to near-term, future HTFC/AC installations. The sensitivity analysis carried out in this section considers a range of CO_2 prices; low-end considers no CO_2 taxes and high-end considers $40/ton to simulate a scenario in which prices are double that of the previous evaluations in this work.

The average electricity price for the University of California, Irvine Medical Center was $130/MWh in 2014.[24] An electricity import price of $120/MWh is assumed in previous sections of this work in order for the HTFC/AC levelized cost of electricity comparisons to be conservative relative to the competing scenario. For this analysis, the electricity import rate was varied from $120 to $240/MWh to simulate the price of electricity increasing by a factor of two relative to the base case scenarios.

It is typical for electric service providers to discourage distributed generation owners from exporting electricity back to the grid, as the existing infrastructure is typically not designed to handle reverse power

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[22] Gas Price Information for Commercial and Industrial Rates, January 22, 2015. http://www.socalgas.com/for-your-business/prices/

[23] BGC Carbon Market Daily, BGC Environmental Brokerage Services website January 22, 2015. http://www.bgcebs.com/Register/?page=http://www.bgcebs.com/myBGC-EBS/dailys/&id=37951

[24] Email correspondence, Nato Flores, P.E. Consultant at University of California, Irvine Medical Center dated January 22, 2015.

flow. This is especially the case when the amount of electricity being exported is constantly varying. On the other hand, there is a possibility that returns on exported electricity can become a reality in the near future as distributed generation becomes more common and as the electricity grid of the United States gets updated to accommodate the associated changes in load and generation patterns. Smart Grid innovations may play a big role in supporting the introduction of more distributed and renewable power generation that can be exported to the grid. Therefore, this analysis considers a range of export returns from zero up to the typically assumed import price of $120/MWh.

Ownership type 1 represents a merchant-owned system, ownership type 2 represents an investor-owned utility, and ownership type 3 represents a public-owned utility. The financial assumptions for each of the three ownership types are compared in the Economic Parameters shown in Table 19.

Table 19: Economic Parameter Assumptions for the Three Ownership Types

Ownership Type	Owner	Equity Percent (%)	Return Rate (%)	Loan Interest Rate (%)
1	Merchant	33	13.25	5.91
2	Investor-owned Utility	55	10.04	5.28
3	Public-owned Utility	0	0	3.20

6.3.5.3 Design of Experiments (DOE)

The statistical design-of-experiments (DOE) program Design-Expert 9, version 9.0.1.0 by Stat-Ease Incorporated was used to optimize an experiment that uses the least number of model runs possible to fully characterize each of the factors and second order interactions. Extra model runs for lack of fit were not included because the Matlab® model being analyzed is not subject to experimental error. An ANOVA was performed on each of the responses, and the model terms were individually checked for significance.

Table 20: Design of Experiments

Design Summary				
File Version	9.0.1.0			
Study Type	Response Surface		**Runs**	25
Design Type	I-optimal	Coordinate Exchange	**Blocks**	No Blocks
Design Model	Quadratic		**Build Time (ms)**	4289

The numerical result of the DOE is a predictive model for each response. The model is written in the form of an equation which sums the products of each of the factor inputs and their respective regression coefficients. In the post-ANOVA phase of the analysis, the predictive model is created in both actual and coded terms. Coded terms set the minimum value of the input factor to -1 and the maximum value to +1. Coding eliminates the factor's units and visually gives equal weight to each factor regardless of its magnitude. For the coded predictive model equation, the coefficient represents the change in the response as the factor level is changed by one coded unit.

6.3.5.4 Results of Key Model Assumptions DOE

A Design of Experiments (DOE) test was performed to evaluate the impact of key economic assumptions in determining HTFC/AC economic viability. Values for factors were selected based on predictions of future utility rates and possible ownership scenarios.

The GHG (CO_2) emissions rate for the competing system is 25,728 short-tons per year and the HTFC/AC system scenario emits 22,603 short-tons per year. Therefore, inclusion of the HTFC/AC system in the utility infrastructure for LBVA leads to a total reduction of 62,497 shot-tons of CO_2 over the 20 year life of the project.

The LCOE is most influenced by the price of natural gas (Factor A). The final equation for LCOE in terms of coded-factors is shown below in Equation 1.

LCOE = 108.2 + 18.77 *A + 8.30 *B + 8.55 *C + 0.03 *D + 3.98 *E[1] + 3.70 *E[2] ………… Eqn. 1

Figure 16 shows a graphical representation of what happens to the LCOE of the HTFC/AC portfolio when each factor is varied individually. The left-hand end of the "A" line represents the change in LCOE when factor A, natural gas price, is set to its minimum value of $2.5/MMBtu. The right-hand end of the "A" line represents the change in LCOE when natural gas price is set to its maximum value of $10/MMBtu. Factors B and C, CO_2 price and electricity import price, each have a similar effect on LCOE. Factor D, electricity export price has a negligible impact on LCOE for this scenario as the hospital is normally able to utilize the entire 2.8 MW created by the fuel cell and electricity is rarely exported to the grid.

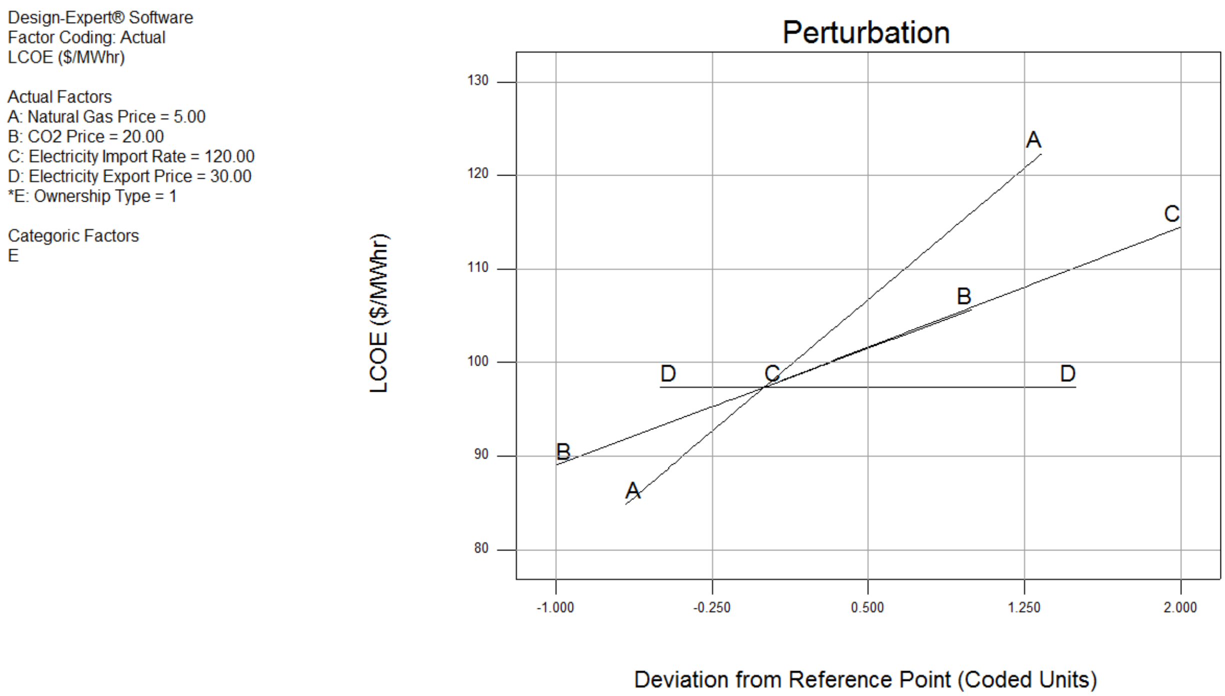

Figure 16: Perturbation Results for LCOE

The savings realized by installation of the HTFC/AC portfolio is most influenced by the imported electricity rate (Factor C). The final equation for savings in terms of coded-factors is shown below in Equation 2.

Savings = 31.75 – 13.7*A + 0.1 *B + 27.9 *C - 0.08 *D - 3.15 *E[1] - 3.15 *E[2] …………… Eqn. 2

Figure 17 shows a graphical representation of what happens to the savings accrued from utilization of the HTFC/AC system when each factor is varied individually. Factors B and D, CO_2 price and electricity export price, each have negligible impacts on savings since electricity is rarely exported in this scenario and since both the HTFC/AC scenario and the competing scenario benefit from CO_2 price reductions. When natural gas price is increased, the savings produced by the HTFC/AC system decreases significantly.

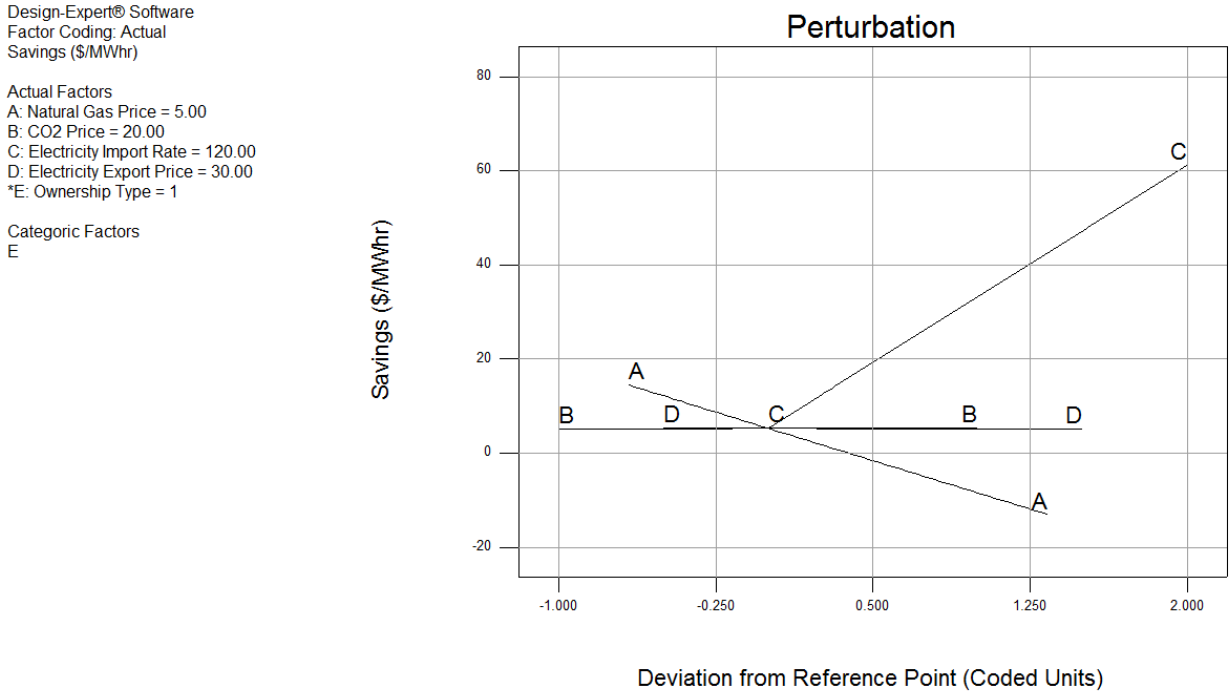

Figure17: Perturbation Results for Savings

Installing an HTFC/AC system in a building similar to LBVA with low natural gas prices and high electricity prices will yield the most significant savings. The relationship between natural gas price, electricity import price, and savings is shown in Figure 18.

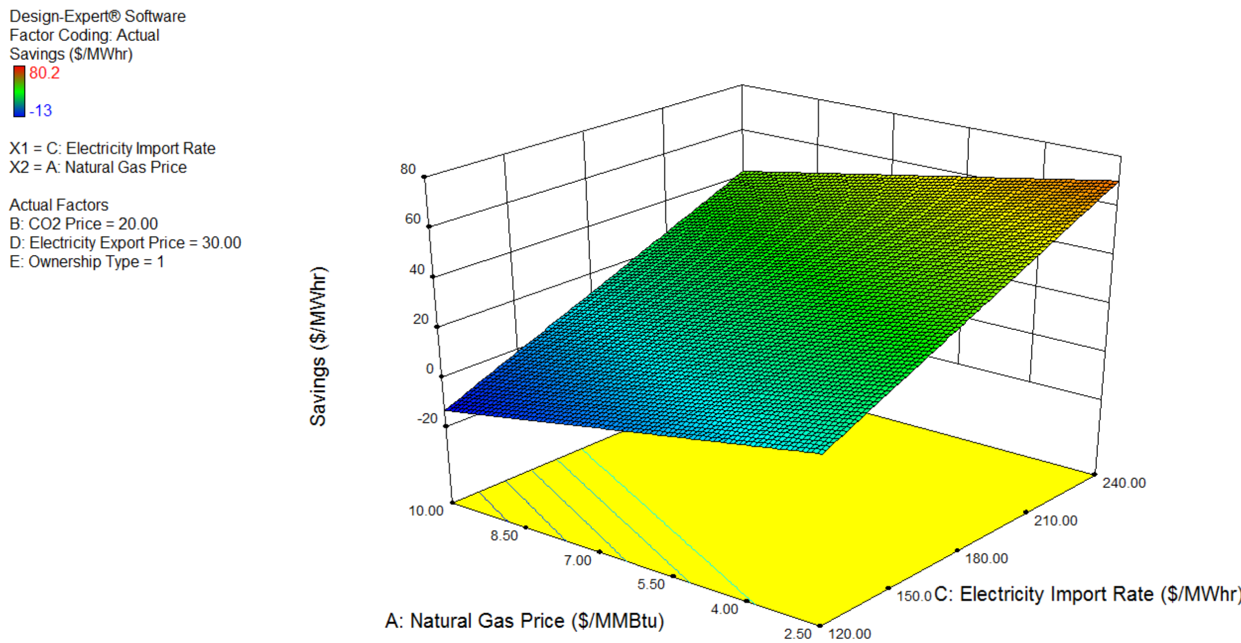

Figure18: Relationship between Natural Gas Price, Electricity, and Savings

The economics of HTFC/AC technology is highly impacted by ownership type. Merchant-owned systems (Ownership Type 1) and Investor-Owned Utilities see moderate savings from the installation of HTFC/AC technology while Public-Owned Utilities realize much more significant savings. Figure 19 shows the difference in LCOE for the same system when each ownership type is considered. The savings associated with each of the three scenarios are shown in Figure 20. It is apparent that the lower LCOEs realized by HTFC/AC systems owned by Public-Owned Utilities translates to substantial savings.

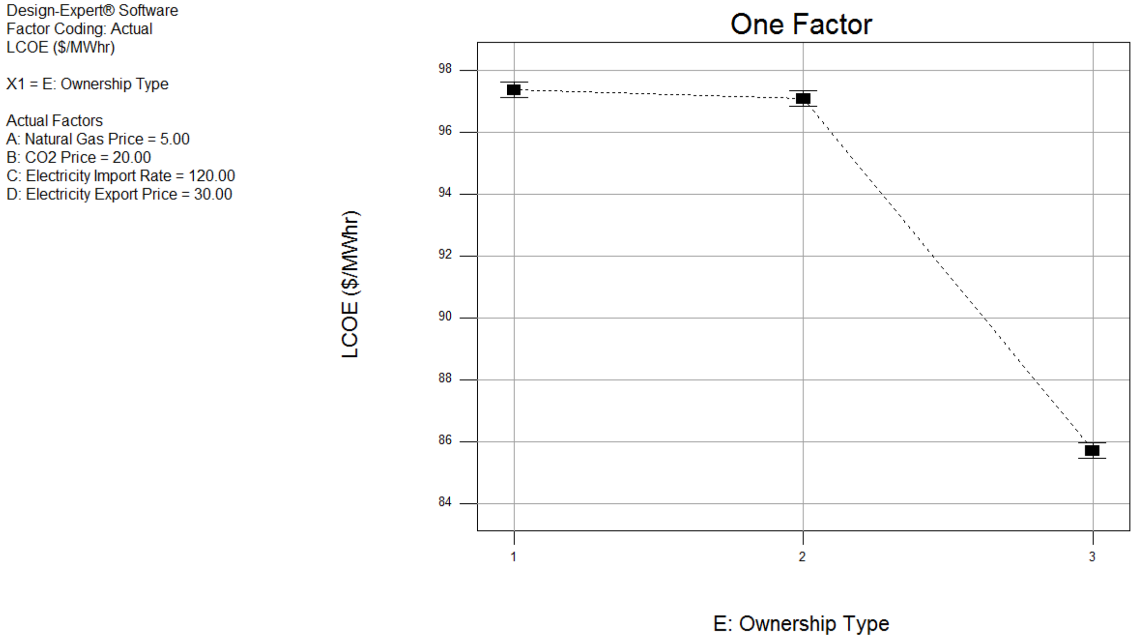

Figure 19: LCOE Based on Ownership Type

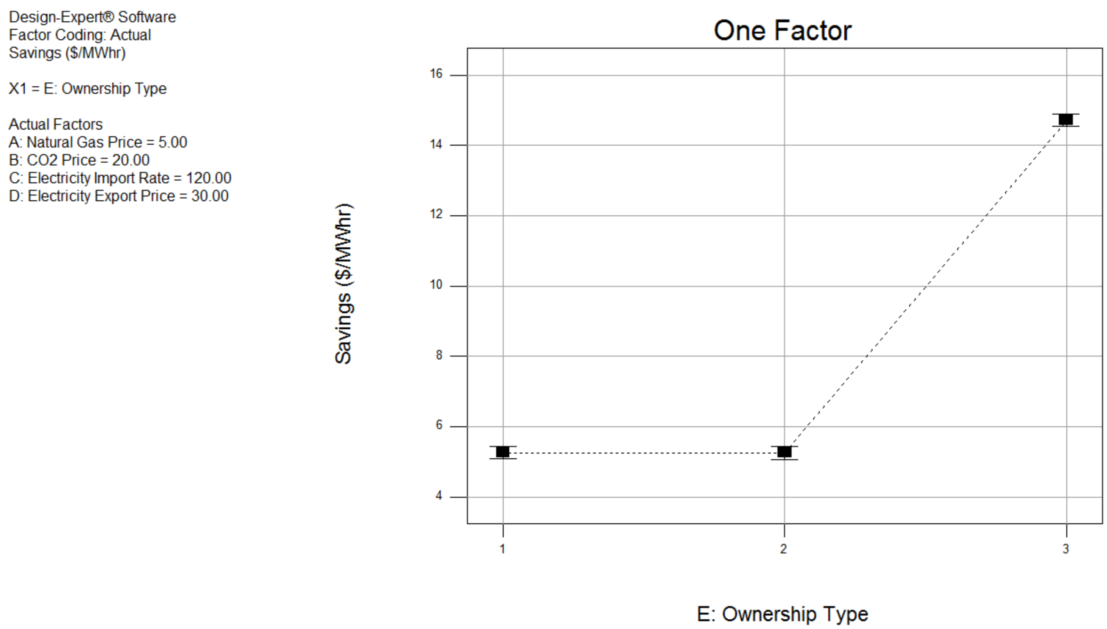

Figure 20: Savings Based on Ownership Type

7. Conclusions and Recommendations

- Hospitals are identified as the primary target market in the System Market Analysis based primarily on their cooling intensity and on their 24/7 requirements for cooling, heating, and electricity.

The technically feasible size of the 2024 market for Systems in California is 1,476 MW of fuel cell capacity, based primarily on System performance. The economic potential will be smaller than the technical potential and will depend on each hospital's specific location, its operating characteristics, and the underlying technology portfolio and input costs. The market potential will be smaller still and will be determined by policy, regulations, competing technologies, and market viability.

- High Temperature Fuel Cell and Absorption Chiller (HTFC/AC) systems that are properly sized for the building they serve are economically preferable to traditional grid-based building utilities for certain buildings in in southern California.

If a HTFC/AC system in southern California is properly sized for the building (i.e., the electric and thermal products of the HTFC/AC system are fully utilized) it is economically beneficial for the building owner to install such a distributed generation system. If the fuel cell is oversized and exporting electricity to the grid, or if the thermal output of the system is underutilized, or the financial conditions differ greatly from those assumed in this study, then the economic viability of the HTFC/AC system requires a closer look.

- Installing an HTFC/AC system in a building with low natural gas prices and high electricity prices will yield the most significant savings.

Installation of HTFC/AC technology reduces a buildings reliance on grid-provided electricity and thereby reduces the owner's vulnerability to varying electric prices. At the same time, it increases the owner's vulnerability to varying natural gas prices. If natural gas prices rise faster than electricity prices, HTFC/AC technology will lose its advantage over traditional building utilities in the scenarios evaluated at LBVA. However, traditionally electricity prices are far more volatile than are natural gas prices.

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Attachment A: Comparison of 2012 CEC Cooling EUI and Cooling GWh Rankings

CEC 2012 Cooling EUI vs. Cooling GWh Rankings, by Building Type and Utility

(All Reported Utilities, Bottom Two Quartiles)

2012 Ranking	BLDG TYP	Utility	Cooling EUI	Cooling GWh
49	OFF-SMALL	SDG&E	2.34	125
50	RETAIL	Pasadena	2.32	13
51	FOOD	IID	2.31	9
52	OFF-SMALL	PG&E	2.13	282
53	COLLEGE	SCE	2.06	240
54	OFF-SMALL	SCE	2.01	248
55	OFF-SMALL	LADWP	1.94	66
56	HOTEL	Pasadena	1.87	2
57	RETAIL	Burbank	1.79	20
58	COLLEGE	SDG&E	1.70	55
59	RETAIL	SCE	1.56	697
60	MISC	PG&E	1.52	668
61	NWHSE	IID	1.50	20
62	HOTEL	Burbank	1.50	3
63	RETAIL	LADWP	1.48	169
64	RETAIL	SMUD	1.43	69
65	RETAIL	SDG&E	1.31	131
66	FOOD	Pasadena	1.30	2
67	COLLEGE	SMUD	1.25	12
68	SCHOOL	SDG&E	1.16	54
69	COLLEGE	PG&E	1.15	150
70	FOOD	Burbank	1.07	3
71	SCHOOL	LADWP	1.05	53
72	MISC	SMUD	1.01	38
73	SCHOOL	SCE	1.01	216
74	NWHSE	Pasadena	0.95	3
75	RETAIL	PG&E	0.87	331
76	NWHSE	Burbank	0.74	4
77	NWHSE	SMUD	0.72	27
78	FOOD	SDG&E	0.68	20
79	FOOD	SCE	0.66	76
80	NWHSE	PG&E	0.56	180
81	HOTEL	SMUD	0.53	6
82	FOOD	LADWP	0.53	15
83	HOTEL	PG&E	0.49	59
84	SCHOOL	SMUD	0.22	4
85	NWHSE	SDG&E	0.16	11
86	SCHOOL	PG&E	0.16	34
87	NWHSE	SCE	0.15	62
88	NWHSE	LADWP	0.14	16
89	RWHSE	SMUD	0.14	0
90	RWHSE	Pasadena	0.13	0
91	RWHSE	IID	0.11	0
92	RWHSE	SCE	0.10	2
93	RWHSE	Burbank	0.10	0
94	RWHSE	LADWP	0.09	0
95	RWHSE	SDG&E	0.07	0
96	RWHSE	PG&E	0.06	2

Data Source: CEC

2012 Ranking	BLDG TYP	Utility	Cooling EUI	Cooling GWh
49	SCHOOL	IID	9.26	45
50	OFF-LRG	IID	11.43	45
51	MISC	Burbank	3.09	40
52	MISC	SMUD	1.01	38
53	FOOD	SMUD	3.78	35
54	SCHOOL	PG&E	0.16	34
55	HOSP	IID	14.63	28
56	NWHSE	SMUD	0.72	27
57	HOSP	Burbank	7.66	26
58	MISC	Pasadena	3.94	26
59	REST	SMUD	4.25	24
60	RETAIL	Burbank	1.79	20
61	FOOD	SDG&E	0.68	20
62	NWHSE	IID	1.50	20
63	NWHSE	LADWP	0.14	16
64	FOOD	LADWP	0.53	15
65	HOSP	Pasadena	8.40	15
66	COLLEGE	Burbank	3.14	15
67	RETAIL	Pasadena	2.32	13
68	HOTEL	IID	3.49	12
69	REST	IID	11.49	12
70	COLLEGE	SMUD	1.25	12
71	COLLEGE	IID	7.23	11
72	NWHSE	SDG&E	0.16	11
73	OFF-SMALL	Burbank	3.33	10
74	FOOD	IID	2.31	9
75	COLLEGE	Pasadena	3.46	8
76	REST	Burbank	4.35	8
77	SCHOOL	Burbank	2.58	6
78	OFF-SMALL	Pasadena	4.16	6
79	HOTEL	SMUD	0.53	6
80	REST	Pasadena	5.38	5
81	NWHSE	Burbank	0.74	4
82	SCHOOL	SMUD	0.22	4
83	SCHOOL	Pasadena	2.83	3
84	HOTEL	Burbank	1.50	3
85	FOOD	Burbank	1.07	3
86	NWHSE	Pasadena	0.95	3
87	HOTEL	Pasadena	1.87	2
88	RWHSE	SCE	0.10	2
89	FOOD	Pasadena	1.30	2
90	RWHSE	PG&E	0.06	2
91	RWHSE	LADWP	0.09	0
92	RWHSE	SMUD	0.14	0
93	RWHSE	IID	0.11	0
94	RWHSE	SDG&E	0.07	0
95	RWHSE	Burbank	0.10	0
96	RWHSE	Pasadena	0.13	0

Data Source: CEC

Attachment B: Cost Module Flow Chart