NATIONAL RENEWABLE ENERGY LABORATORY

Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison

J. Kurtz, G. Saur, S. Sprik, and C. Ainscough
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5400-60732
September 2014

Contract No. DE-AC36-08GO28308

Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison

J. Kurtz, G. Saur, S. Sprik, and C. Ainscough
National Renewable Energy Laboratory

Prepared under Task No. H279.1710

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Technical Report
NREL/TP-5400-60732
September 2014

Contract No. DE-AC36-08GO28308

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at http://www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) photo by Pat Corkery, NREL 16416, photo from SunEdison, NREL 17423, photo by Pat Corkery, NREL 16560, photo by Dennis Schroeder, NREL 17613, photo by Dean Armstrong, NREL 17436, photo by Pat Corkery, NREL 17721.

NREL prints on paper that contains recycled content.

Acknowledgements

Funding for this report came from the U.S. Department of Energy's Fuel Cell Technologies Office. The authors would like to acknowledge the industry project partners, both developers and end users, for their participation through deployment and providing operation data as well as reviewing the National Renewable Energy Laboratory's composite data products. Their participation and review are essential, and appreciated, for the validation analysis summarized in this report. Special thanks to Sprint, ReliOn, Altergy, Cummins Generator, Deka Batteries, AC Systems, and FAA for their contributions.

List of Acronyms

ARRA	American Recovery and Reinvestment Act of 2009
CDP	composite data product
DOE	U.S. Department of Energy
FC	fuel cell
HSM	hydrogen storage module
kg	kilogram
kW	kilowatt
NFCTEC	National Fuel Cell Technology Evaluation Center
NREL	National Renewable Energy Laboratory

Executive Summary

Over a two-plus year period, the American Recovery and Reinvestment Act of 2009 (ARRA), through the U.S. Department of Energy's Fuel Cell Technologies Office, exceeded its target to install 1,000 fuel cell units across several different applications including backup power to spur commercialization of early market technologies. Fuel cell backup power can provide a critical service in times of emergencies and decrease the economic and productivity losses during other grid instabilities when compared with incumbent technologies. Fuel cells can provide an extended run time similar to that of diesel generators while also providing a low-emission and low-noise solution, which is especially important in urban environments.

By December 2013, more than 1,300 fuel cell units were deployed, of which 852 were providing backup service, mainly to telecommunications towers (Figure ES-1). Project participants provided detailed operational data for 134 of the fuel cell backup power units, and the National Renewable Energy Laboratory's technology validation team analyzed the data.

The data provided a great deal of information regarding deployment numbers, installed capacity, reliability, and operation trends and characteristics. The start reliability of those systems was 99.5%. While some system capacities were larger than 10 kilowatts (kW), 78% of the systems were in the 4–6 kW range. Modules of smaller fuel cell units could be combined to adjust the system size to an individual site's needs. The fuel cells accumulated more than 1,749 hours of operation time with one unit successfully demonstrating a continuous run time of 65 hours during the data collection period. See Appendix B for a breakdown of capacity and site count by state.

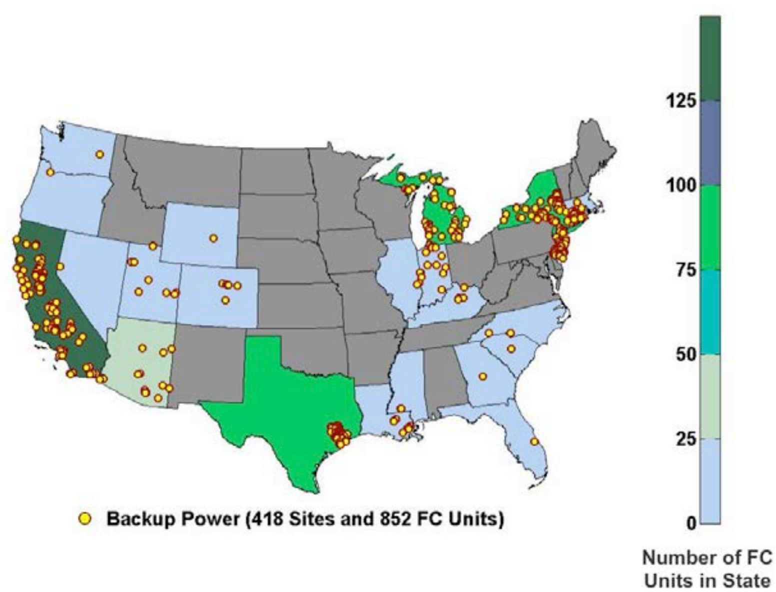
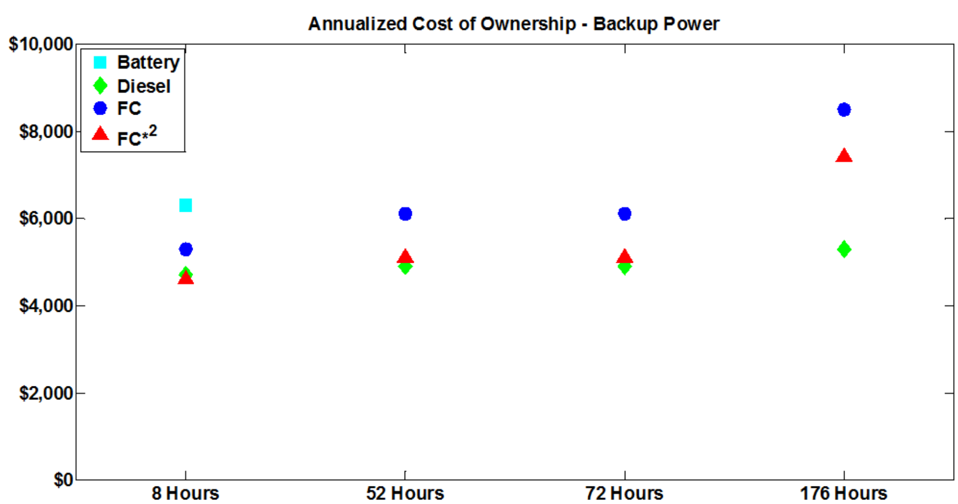


Figure ES-1. Fuel cell backup power locations [1]

An annualized cost of ownership analysis enables a better understanding of the value proposition for fuel cell backup power systems when compared with the incumbent technologies of battery and diesel generator systems. Backup power operation can vary widely based on region, end user, and site-specific requirements, so a number of assumptions are made to compare three different backup power technologies (diesel, battery, and fuel cell) operating in similar circumstances in four run time scenarios (8, 52, 72, and 176 hours). Each run time scenario assumes the system operates for a specific amount of hours annually, for example a system in the 72-hour scenario operates for 72 hours a year. The 72 hours could be accumulated through many shorter run operations or through one continuous operation. It is important to note that the actual use of a telecommunication system is not as simple, or as prescribed, as these run time scenarios.

Cost estimates for capital, permitting and installation, maintenance, and fuel are generated for each of the technologies. Data sources for these cost estimates include ARRA fuel cell systems, quotes, and facility manager experience. This cost of ownership analysis identifies the factors impacting the value proposition for fuel cell backup power and the estimated annualized cost of ownership for three backup power technologies. Figure ES-2 displays the annualized cost estimates for each run time scenario and technology. The battery cost of ownership increases significantly with the higher run time scenarios, and this technology is unlikely to truly be a stand-alone solution for situations that require high run times. A battery system is a common option when 8 hours or less are needed for backup run time.



	8 Hours	52 Hours	72 Hours	176 Hours
Battery	$6300	$24800	$31300	$67200
Diesel	$4700	$4900	$4900	$5300
FC	$5300	$6100	$6100	$8500
FC*2	$4600	$5100	$5100	$7400

NREL cdp_bu_30
Created: Aug-29-14 1:26 PM | Data Range: 2010Q1-2013Q4

1) Refer to the report for complete analysis details and assumptions (http://www.nrel.gov/docs/fy14osti/60732.pdf).
2) Fuel cell system with incentives (FC*), calculated as 30% of expenditures and capped at $3,000/kW of system capacity.

Fuel Cell* includes incentives

Figure ES-2. Annualized cost of ownership for technology and run time scenarios

The diesel generator is consistently one of the lower-cost options, but this technology has some challenges due to the cost of annual maintenance requirements and attributes not captured in the cost of ownership analysis, such as noise and emissions.

The fuel cell system with incentives[1] (denoted FC* in figures) is cost competitive with the diesel generator, particularly in the 8-hour, 52-hour, and 72-hour run time scenarios. The fuel cell system has a higher efficiency and less frequent maintenance schedule than the diesel generator, and the incentives offset the higher capital and installation costs as seen in Table 1 and Table 2. Other backup power technology attributes not tracked in this cost of ownership analysis, but which may be key decision factors along with the cost of ownership, include noise, emissions, equipment footprint, available installation space, and permitting.

Fuel cell systems are now cost competitive with the incumbent backup power technologies, according to this cost of ownership analysis, especially with incentives. In the 72-hour run time scenario, the cost of ownership of the fuel cell system, without incentives, is approximately 1.2 times higher than that of a diesel generator and more than 5 times lower than that of a battery system. In the same run time scenario, the cost of ownership of the fuel cell system, with incentives, is approximately equal to that of the diesel generator and more than 6 times lower than that of a battery system.

A reduction in capital and installation costs will result in a stronger value proposition for fuel cell systems as backup power solutions. The cost and difficulty associated with the permitting of hydrogen systems are other areas that require development for widespread deployment of fuel cell systems. These permitting challenges can vary greatly across the country and can be addressed by the consistent implementation of codes and standards. For decision makers selecting a backup power system, the initial costs are key drivers, but other aspects to consider are noise, permitting, emissions, run time capability, ease of refueling, footprint, and user comfort with the technology.

[1] "The credit is equal to 30% of expenditures, with no maximum credit. However, the credit for fuel cells is capped at $1,500 per 0.5 kilowatt (kW) of capacity. Eligible property includes fuel cells with a minimum capacity of 0.5 kW that have an electricity-only generation efficiency of 30% or higher." [10]

Table of Contents

List of Figures

List of Tables

1 Introduction

Over approximately a two-year period, more than 1,300 fuel cell units (Figure 1) were deployed in stationary, material handling equipment, auxiliary power, and backup power applications with American Recovery and Reinvestment Act of 2009 (ARRA) co-funding awarded through the U.S. Department of Energy's (DOE's) Fuel Cell Technologies Office. This surpassed an ARRA objective of deploying up to 1,000 fuel cell units. As of June 2013, 852 ARRA-funded fuel cell units were deployed in backup power applications. The prime backup power ARRA awards were to Sprint-Nextel and ReliOn,[2] with a small number of demonstrations to Plug Power. Other project partners included PG&E, AT&T, Robins Air Force Base, Fort Irwin, IdaTech (recently acquired by Ballard), Altergy, Air Products and Chemicals, Inc., Champion Energy, Ericsson Services, Inc., A&E Firms, Black & Veatch, and Burns & McDonnell.

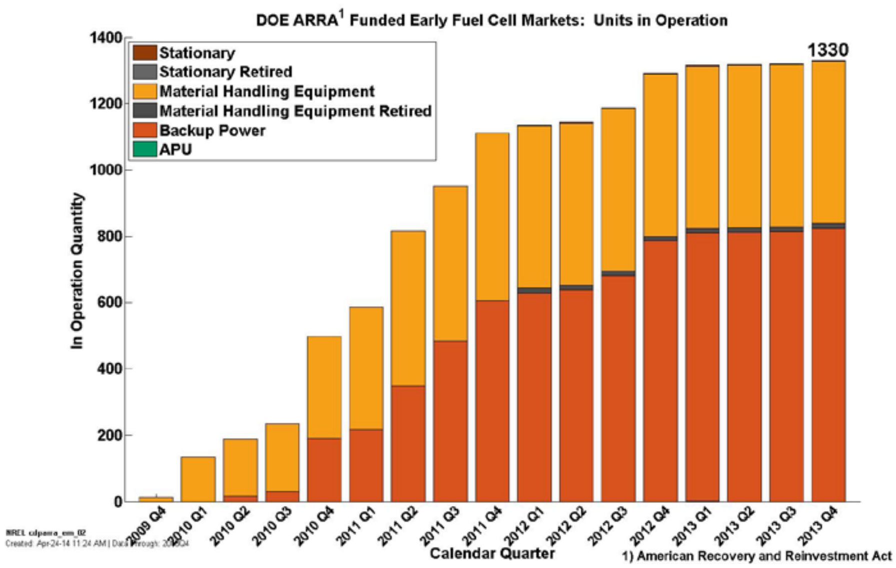


Figure 1. Early market fuel cell deployments funded through ARRA [1]

These ARRA co-funded fuel cell deployments supported hydrogen fuel cell commercialization through an accelerated deployment, impacting many areas of the market, including manufacturing, permitting, installation, hydrogen infrastructure, operation, maintenance, and support services. DOE's Fuel Cell Technologies Office awarded 12 projects with approximately $40 million in ARRA funding and approximately $53 million in industry cost share; of this total, $18.5 million in ARRA funding went to three backup power projects [2]. Project participants included technology developers and end users.

To support the validation and market transformation objectives of the project, the project participants collected and submitted data to the National Fuel Cell Technology Evaluation Center (NFCTEC) at the National Renewable Energy Laboratory (NREL). NREL's objective is to validate hydrogen polymer electrolyte membrane fuel cells used in early market applications as well as their related infrastructure. Building on its experience with the technology validation of

[2] ReliOn was acquired by Plug Power as of April 2014, just before publication of this report. The brand name is being retained by Plug Power and will be used throughout this report.

hydrogen fuel cell vehicles and fueling infrastructure, NREL has been performing technical analyses of hydrogen and fuel cell systems for DOE's Fuel Cell Technologies Office to assess the performance and market potential of fuel cell technologies. While individual company data are kept confidential, NREL publishes aggregated performance analysis results called "composite data products" (CDPs) that show the status and performance of hydrogen and fuel cell technologies without identifying individual companies or their performance. See Appendix A for more details on NREL's data analyses.

NREL uses operational data collected from a number of government co-funded demonstration projects to analyze fuel cells used in material handling equipment and backup power to characterize their performance, maintenance, and operation and to highlight the business case for using fuel cells in these early market applications. This technology validation includes identifying the current status of the technology and its evolution over the duration of the project, assisting DOE's hydrogen research and development activities based on information learned from this project, and helping industry in evaluating progress toward technology readiness.

Deployment of fuel cell systems is a practical option for telecommunications operations that need reliable, long-running backup power at cellular phone signal relay sites, particularly during electric grid power outages. Commercial growth of the wireless telecommunications market in the United States and overseas provides opportunities for domestic and international sales of backup power fuel cells. Telecommunications backup power expenditures are estimated at more than $2 billion annually [3]. Fuel cells for backup power can be installed and operated at new or retrofit sites in different regions.

In addition to the ARRA co-funded fuel cell backup power demonstrations, DOE supported additional demonstration projects with other federal agencies through Interagency Agreements. The Department of Defense and the Federal Aviation Administration are two agencies with fuel cell backup power demonstrations that also submitted operational and deployment data to NREL. All results covered in this report, unless specified as strictly ARRA, will include both ARRA and Interagency Agreement fuel cell backup power sites. Almost all sites (~98%) were co-funded through ARRA. All results from this analysis project, including any other publications and presentations, are available online [4].

The majority of sites (78%) tracked by NREL had capacities of 4–6 kW (Figure 2). There were a few sites with higher capacity in both urban and rural areas. California had the largest number of systems installed. The high concentrations of sites in California and the Northeast are primarily due to the location of project partners and population. Other site location factors include impact, regulations, use, and grid stability.

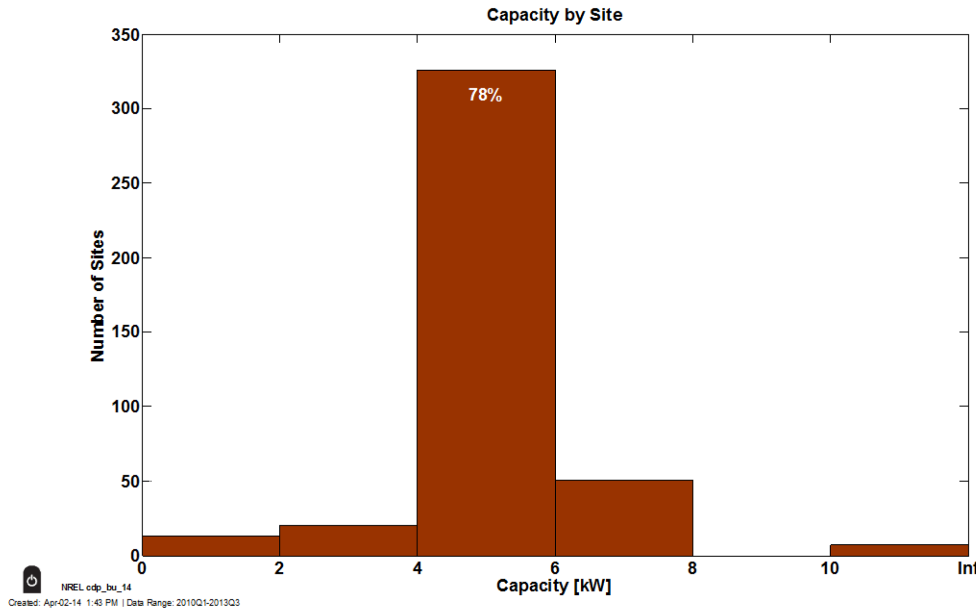


Figure 2. Histogram of site capacities [1]

2 Backup Power Annualized Cost of Ownership Analysis Assumptions

The technologies included in this analysis are a battery system, a diesel generator with a bridge battery system, and a fuel cell system with a bridge battery system. The generator and fuel cell system analyzed both utilize a bridge battery system to ensure uninterrupted power during a grid outage. A power range of 4–6 kW was selected because 78% of the NREL-analyzed systems installed between 2010 and 2012 are in this range. In the diesel generator scenario, a 25–35 kW unit was used because commercial-grade diesel generators are not readily available in the 4–6 kW range. The lifetimes assumed for the battery, diesel, and fuel cell systems are 5, 15, and 15 years, respectively [9]. These lifetimes are based on replacement schedules from the suppliers. All costs are in present value terms, with a discount rate over the lifetime applied to capital purchases. Table 1 lists the key analysis assumptions by technology.

Table 1. Key Assumptions[a] by Technology

	Battery	Diesel Generator	Fuel Cell
Capacity (kW)	4–6	25–35 (operated at 6)	4–6
Lifetime [9]	5	15	15
Fuel Storage Capacity	NA	Onsite tank capable of 176-hour scenario	Leased bottles for 8-hour scenario Fill-in-place hydrogen storage capable of 72-hour scenario
Efficiency	90%	~20%[b]	47%
Fuel Cost	6.67 cents per kW (EIA average industrial) [5]	\$3.89 per gallon[c] [6]	\$10 per kg + \$100 fee (8-hour scenario) \$8 per kg + \$50 fee (all other scenarios)
Maintenance	4 visits per year	2–12 visits per year	1 visit per year
Federal Incentive	NA	NA	\$15,000[d]
Discount Rate	1.5%	1.5%	1.5%
Fuel Storage	NA	Not separated in provided data	\$600/year for a 6 cylinder rent (8-hour scenario) \$18,900 capital for 72-hour storage module (all other scenarios)

[a] Assumptions are based on the average of provided data from suppliers and end users, unless otherwise referenced.
[b] Diesel generator spec sheet references [7, 8].
[c] A delivery fee would also be included for the diesel fuel. That fee was not provided in the diesel cost estimates and is not included in this analysis.
[d] The incentive is 30% of the up-front costs (includes capital and install), capped at \$3,000/kW capacity. This analysis assumes an average capacity of 5 kW [10].

The operation of backup power systems can vary widely due to location, integration design, and control strategy. In order to minimize the impact of the variety of operating conditions, four annual run time scenarios were selected for analysis: 8, 52, 72, and 176 hours, which are the same run times used in the Battelle report, "Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets" [9]. A 72-hour continuous run time scenario was a hydrogen sizing criterion for the ARRA backup power installations.

Data for the analysis comes from the following sources:

- The first source, and fuel cell data source, is the ARRA co-funded fuel cell backup power suppliers.
- The second source is commercial product price estimates for batteries and diesel-powered generators.
- The third source is feedback from facility operators, which was used for data validation.

The reported data are average values from all input sources. See Table 2 for the breakdown of capital, permitting/installation, maintenance, and fuel costs by technology and run time scenario.

Table 2. Capital, Permitting and Installation, Maintenance, and Fuel Costs[a] for All Technology and Run Time Scenarios

Run Time Scenario	Technology	Capital Cost[b]	Permitting and Installation Cost	Annual Maintenance Cost	Annual Fuel Cost
8 hour	Battery[c]	$16,800	$12,000	$300.00	$2.00
	Diesel generator	$28,300	$24,000	$800.00	$27.00
	Fuel cell	$30,700	$29,300	$100.00	$23.00
	Fuel cell*[d]	$21,500	$29,300	$100.00	$23.00
52 hour (~2 days)	Battery[c]	$70,200	$45,000	$700.00	$12.00
	Diesel generator	$28,300	$24,000	$800.00	$178.00
	Fuel cell	$47,600	$29,300	$100.00	$170.00
	Fuel cell*[d]	$34,200	$29,300	$100.00	$170.00
72 hour (3 days)	Battery[c]	$88,600	$57,000	$900.00	$17.00
	Diesel generator[e]	$28,300	$24,000	$800.00	$246.00
	Fuel cell[e]	$47,600	$29,300	$100.00	$216.00
	Fuel cell*[d,e]	$34,200	$29,300	$100.00	$216.00
176 hour (~1 week)	Battery[c]	$192,000	$120,000	$2000.00	$42.00
	Diesel generator	$28,300	$24,000	$800.00	$602.00
	Fuel cell	$76,000	$29,300	$100.00	$455.00
	Fuel cell*[d]	$61,000	$29,300	$100.00	$455.00

[a] Costs are based on the averages of provided data from suppliers and end users, unless otherwise referenced.
[b] Capital costs assume the system has enough capability to operate continuously for each run time scenario.
[c] Battery installation and maintenance are assumed to scale with the battery capital costs because of the increase in support equipment (e.g., cabinets and cooling). The cost to recharge a depleted battery string is included here. Additional costs will be required to maintain the battery charge when not in use.
[d] There are two fuel cell system scenarios, with (*) and without federal tax credits [10] for fuel cell purchases.
[e] The average capital $/kw for a diesel system is between $800/kW and $1,100/kW and for a fuel system (without storage) is $5,700/kW.

The incentives for the fuel cell system were calculated as 30% of expenditures and capped at $3,000/kW of system capacity [10] (e.g., $15,000 for a 5 kW system if the total system cost was greater than $50,000). The eligible costs for this incentive include capital and installation costs. The installation and permitting costs are assumed to be relatively constant for the different run time scenarios because the largest drivers of these costs are the variability of each site and regional permitting requirements. These costs do include estimates for site acquisition. The permitting costs are a large percentage of the expense for a fuel cell installation, primarily because authorities having jurisdiction may not have familiarity or experience with hydrogen fuel cell installations. The incentives for fuel cell systems were applied to capital and installation costs.

The capital costs include all equipment required for operation, for example, the storage tank, bridge battery, and transfer switch for a diesel generator. The capital cost for batteries [12] varies greatly based on the run time scenarios and operation lifetime. Longer continuous run times result in a high battery cost because of the large number of batteries and supporting infrastructure required. Batteries must also be oversized to accommodate power degradation over the operation lifetime of 5 years. The capital cost for the diesel generator remains constant for the different run time scenarios because the generator system, including the tank, is assumed oversized for the low run time scenarios.

There are two changes to the fuel cell system for different run time scenarios that affect the capital cost. The 8-hour scenario assumes the hydrogen storage unit is a pack of rented hydrogen gas bottles that are swapped out when the gas is low; the other three run time scenarios assume the fuel cell system has a hydrogen storage module (HSM) that is purchased and refilled in-place instead of using the bottle swap. Figure 3 and Figure 4 display examples of the HSM and the replaceable hydrogen cylinders options.

Figure 3. Fill-in place HSM and example fill [11]

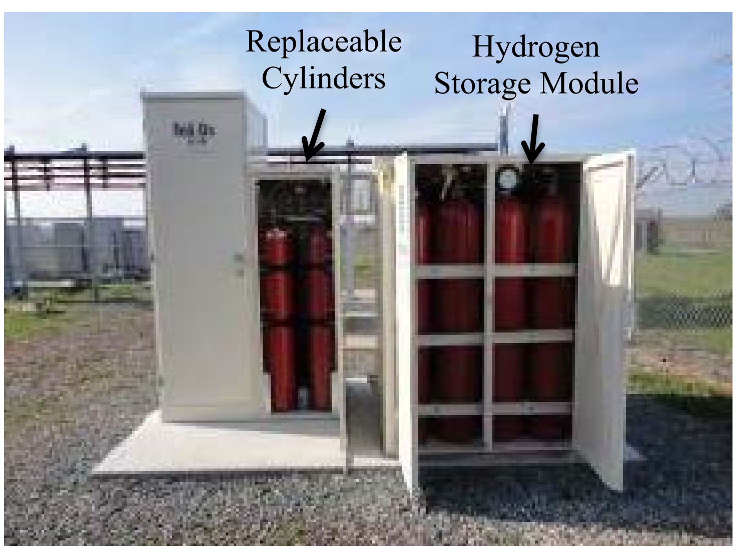


Figure 4. Example ReliOn fuel cell system with replaceable cylinders and an HSM [11]

The 176-hour scenario increases the amount of on-site storage to 2.5 times that of the 72-hour scenario. Figure 5 shows a breakdown of the capital cost for the fuel cell system and HSM for the four run time scenarios. Note there is a small increase in the fuel cell cost for the 8-hour scenario, compared with the other run times. This is due to an enclosure for the hydrogen storage tanks.

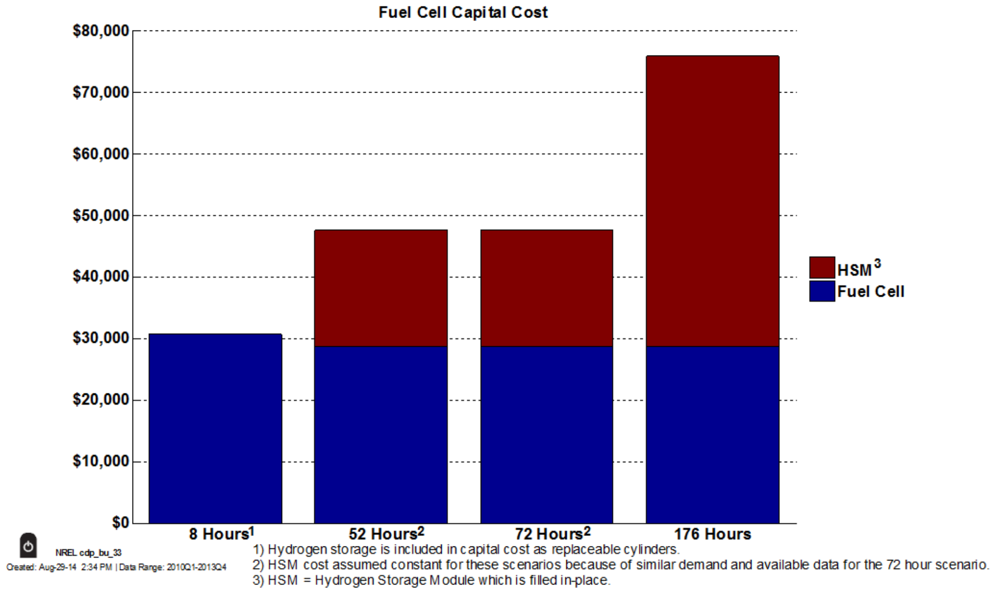


Figure 5. Breakdown of hydrogen storage and fuel cell capital costs

The capital costs of the fuel cell system for the 52-hour and 72- hour run time scenarios are the same because the HSM is assumed to be the same size. This assumption is based on available data for the 72-hour HSM costs (and not specifically for the 52-hour scenario) because of how close the run hours are in the two scenarios. The cost difference between two scenarios is only in the cost of the hydrogen consumed.

All costs are presented as annualized costs per system in present value terms. Capital, permitting, and installation costs are amortized over the expected equipment lifetime. Equipment is maintained and replaced as necessary, with equipment replacement costs assumed to remain constant in real dollar terms. A similar analysis was completed for another key early market for fuel cells and reports on the cost of ownership analysis for fuel cell material handling equipment [13].

As costs are considered in present value terms, a discount rate is applied to capital purchases. For this analysis, the discount rate of 1.5% is used, based on U.S. Treasury bond rates as reported by the U.S. Treasury. In particular, the 1.5% real rate is the one-year average (from September 2010 to September 2011, when the cost of ownership analysis was initially conducted) of daily U.S. Treasury long-term real rates reported for U.S. Treasury Inflation Protected Securities. The Treasury Department [14] notes that the "Long-Term Real Rate Average is the unweighted average of bid real yields on all outstanding TIPS [Treasury Inflation Protected Securities] with remaining maturities of more than 10 years and is intended as a proxy for long-term real rates."

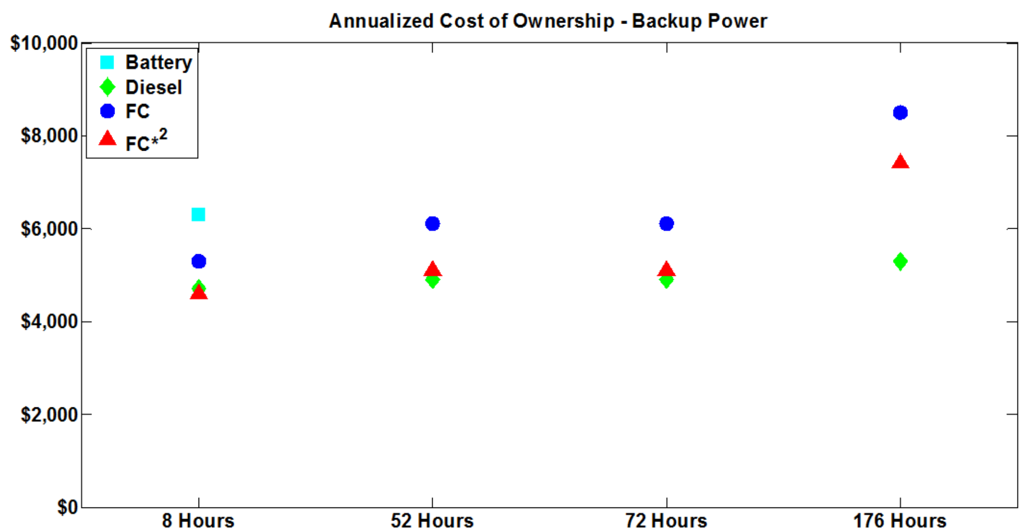
These investments are generally not directly profitable, but are either required investments or hedge against losses due to power outages, which are less quantifiable.

The annual maintenance can vary significantly by site, even for one technology type. This variation is primarily due to ambient conditions like temperature and whether the unit is indoors or outdoors. Another factor for maintenance is extended time of inactivity. Fuel cell backup power systems are programmed to run periodically (for example every 4 weeks) to ensure the system is hydrated and fully operational. Remote monitoring, conditioning runs, and annual maintenance have an estimated annual cost of $100 per year for the fuel cell system. Battery systems have a trickle charge when not in operation, thus they do not require a periodic conditioning run, but they do typically require a maintenance check every 3 months. The estimated annual maintenance cost for a battery system is $300 per year and increases relative to the increasing battery sizes and capital costs. Diesel generators require the most maintenance of the technologies compared in this study; the maintenance expenses vary depending on recommended maintenance and actual maintenance practices. The range of estimated annual maintenance for diesel generators is from $400 per year to more than 4 times that value. Recommended maintenance for diesel generators includes monthly operation and checks as well as regular fuel and part replacements. The estimated annual maintenance cost for a diesel generator is $800 per year.

Annual fuel (or electricity) costs are very dependent on the run time scenarios, and the assumptions are specific to each technology case. Round-trip efficiency for the battery systems is assumed to be 90% with an electricity cost of 6.67 cents. The diesel fuel consumption is assumed to be 0.9 gallons per hour with a diesel cost of $3.89 per gallon. An assumption is that the larger diesel systems can turn down to this low power level with a low efficiency. The fuel cell system case has a few hydrogen cost variations, such as leased hydrogen bottle storage or fill-in-place hydrogen storage, and a different per-kilogram price and delivery fee for low or high annual hydrogen consumption. An average efficiency of 47% is assumed for the fuel cell system. For the run time scenarios greater than 8 hours, high annual hydrogen consumption, a cost of $8 per kilogram, a $50 delivery fee, and a fill-in-place HSM are assumed. For the 8-hour run time scenario, low annual hydrogen consumption, a cost of $10 per kilogram, a $100 delivery fee, and leased hydrogen bottle storage are assumed. The 176-hour run time scenario assumes the onsite storage is 2.5 times the cost of the 72-hour storage solution. This option also requires an increase in the footprint for storage. If the increased footprint (or increased capital cost) is not preferred for the customer, a storage solution could be to use the 72-hour storage option with two deliveries of hydrogen to ensure 176-hour annual operation.

3 Backup Power Cost of Ownership Analysis Results

This cost of ownership analysis serves the purpose of understanding the factors impacting the value proposition for fuel cell backup power and the estimated annualized cost of ownership for three backup power technologies. Figure 6 displays the annualized cost estimates for each run time scenario and technology. The battery cost increases significantly with the higher run time scenarios, and this technology is unlikely to truly be a stand-alone solution for situations that require high run times. The cost breakdown graphs that follow (except for the 8-hour breakdown figure) will exclude the battery to allow for comparison of the other technologies. Note that the fourth technology included in these comparisons is the fuel cell system with incentives.



Battery	$6300	$24800	$31300	$67200
Diesel	$4700	$4900	$4900	$5300
FC	$5300	$6100	$6100	$8500
FC*2	$4600	$5100	$5100	$7400

NREL cdp_bu_30
Created: Aug-29-14 1:26 PM | Data Range: 2010Q1-2013Q4

1) Refer to the report for complete analysis details and assumptions (http://www.nrel.gov/docs/fy14osti/60732.pdf).
2) Fuel cell system with incentives (FC*), calculated as 30% of expenditures and capped at $3,000/kW of system capacity.

Figure 6. Annualized cost of ownership technology comparison for multiple run time scenarios (battery cost is only plotted for the 8-hour scenario)

Figure 7 is a radar chart designed to show more detail of the annual cost comparison between technologies. The first three run time scenarios have similar costs for the different technologies, where diesel is the lowest cost option. The fuel cell cases (both with and without incentives) are more expensive than diesel engines in the 176-hour run time scenario and cost competitive in the other three scenarios. The higher cost in the 176-hour run time scenario is primarily due to the increase in capital cost for the HSM.

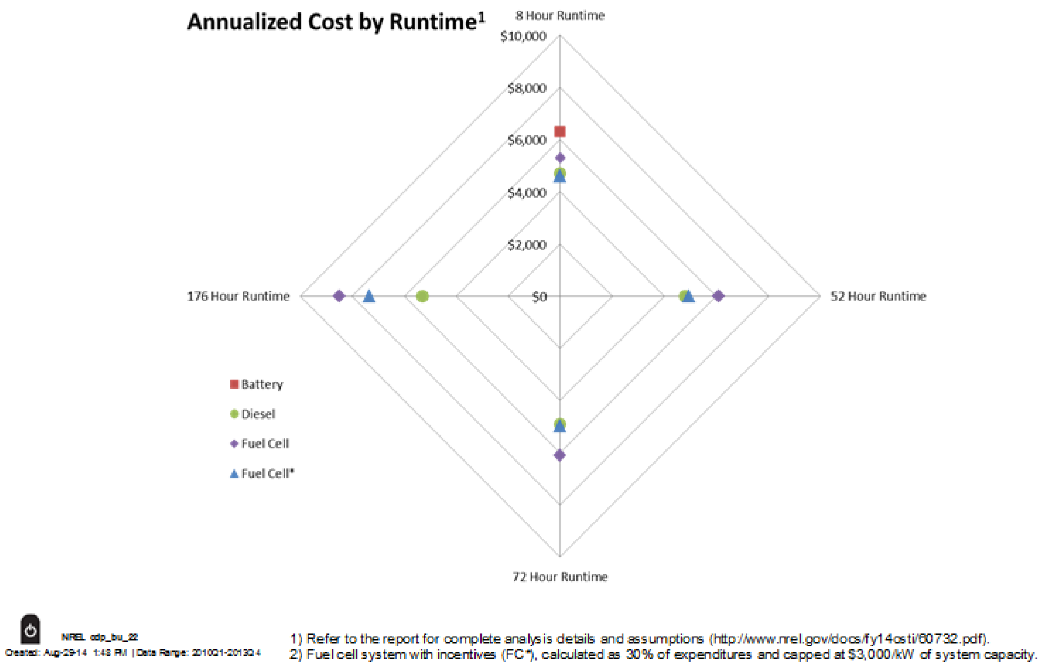


Figure 7. Backup power technology annualized cost comparison by run time scenario

The next four figures show the cost breakdown for each run time scenario. The cost breakdown categories are the same for Figure 8 through Figure 11 and include the amortized capital and installation costs and annual fuel and maintenance costs. Figure 8 details the 8-hour scenario, where the capital and installation costs dominate the annual cost of ownership. Maintenance costs are quite small for the fuel cell and battery systems when compared with the diesel system; however, the diesel system has the lowest capital and installation costs of the technologies. This scenario assumes the hydrogen storage system is leased bottles that are swapped out during a hydrogen fill. The leased bottle storage has a number of challenges in cost and in the actual swap out. The next scenarios assume a fill-in-place hydrogen storage system that is much simpler to fill than it is to swap bottles, but it does increase the initial cost and footprint. Another option for this short run time scenario is to purchase the hydrogen cylinders, adding approximately $2,500 to the upfront cost, and then only pay for the cylinder swap when needed. The fuel cell system with incentives cost of ownership is similar to the diesel generator cost of ownership. The incentives offset the higher capital costs, and the fuel cell system has high efficiency and a long operation lifetime, all of which contribute to the lowest cost of ownership in this run time scenario. The fuel costs for the diesel and battery technologies in the 8-hour run time are actually greater than zero (see Table 2). These fuel costs are rounded to zero in Figure 8 because the analysis is limited to two significant digits in the annualized cost of ownership.

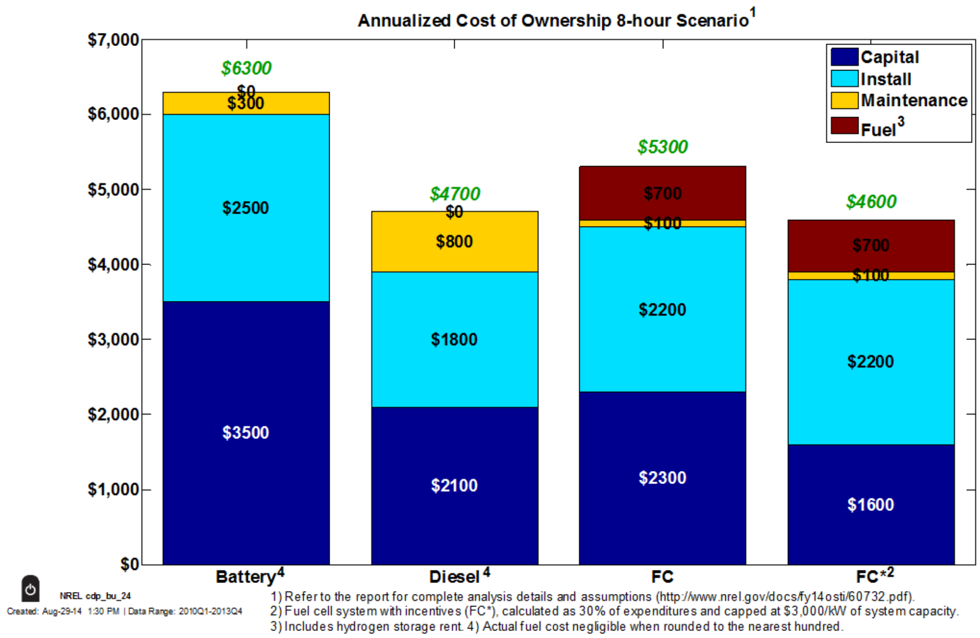


Figure 8. 8-hour scenario annual cost breakdown

Figure 9 shows the breakdown of the 52-hour run time scenario. The annualized cost of ownership for a battery-only system is more than $18,000 and is not graphically displayed for comparison purposes. The breakdown trend is similar to the 8-hour scenario, but the hydrogen bottle rental is no longer a high annual cost. In its place is an amortized HSM. This increase in initial cost for the fuel cell system is on par with the decrease in annual maintenance cost for the diesel generator. The result is an annual cost of ownership that is basically the same for a diesel generator and a fuel cell system with incentives. This also holds true for the 72-hour run time scenario shown in Figure 10. In both of these scenarios, the fuel cell system only requires one hydrogen delivery and utilizes the high hydrogen consumption price option. In both the 52-hour and 72-hour run time scenarios, all three system options have a similar annualized cost of ownership. The incentives for the fuel cell system are important to offset the capital costs that include a fill-in-place HSM. The fuel cost is the lowest for the diesel system, while the maintenance cost is lowest for the fuel cell system.

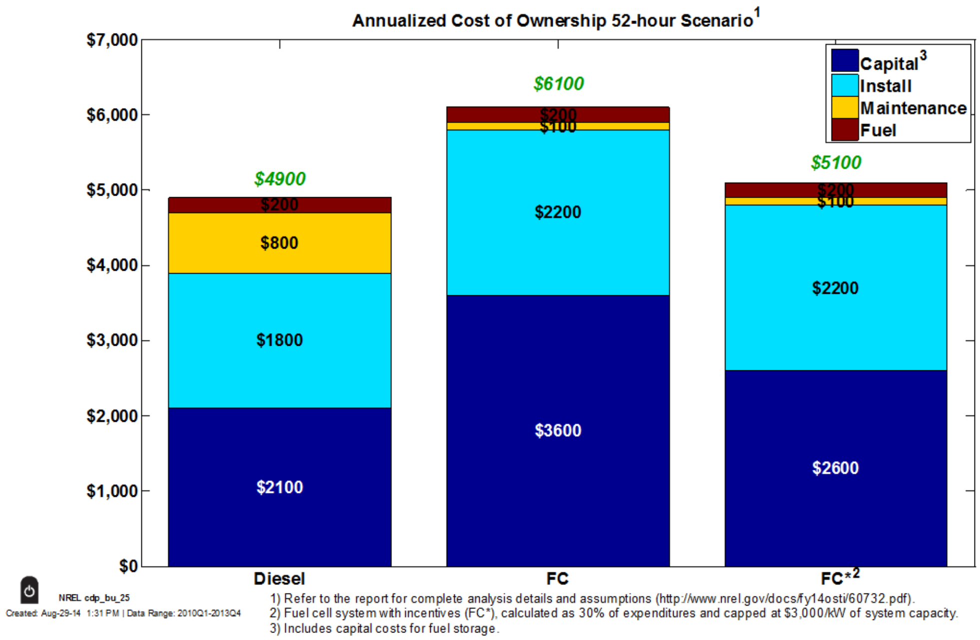


Figure 9. 52-hour scenario annual cost breakdown

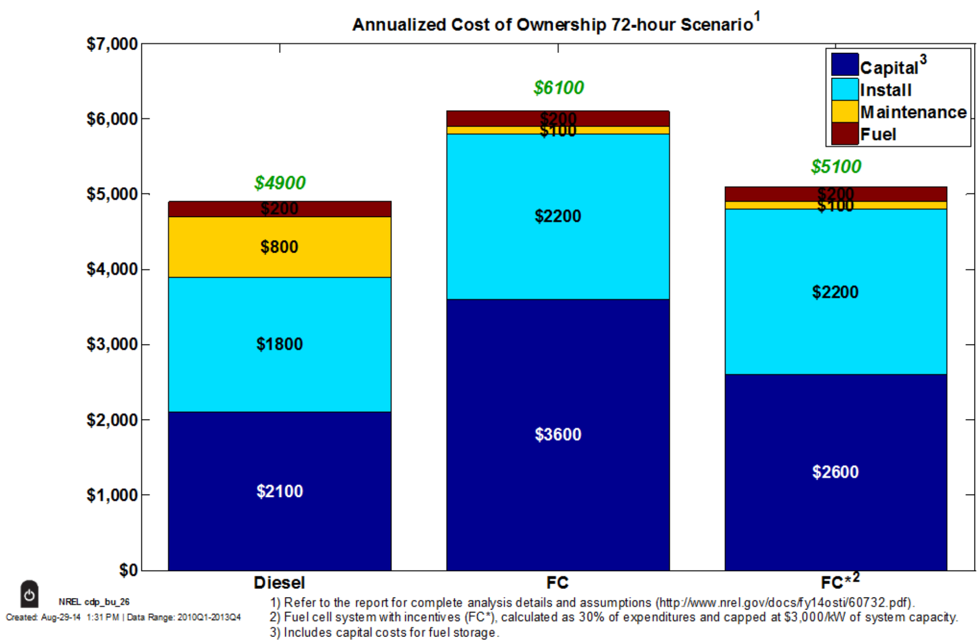


Figure 10. 72-hour scenario annual cost breakdown

The 176-hour run time scenario cost breakdown is shown in Figure 11. The biggest difference in this scenario when compared with the 52-hour and 72-hour scenarios is the increase in cost for the HSM. The assumed increase is based on a linear scale-up for the storage cost and results in a higher initial cost for the fuel cell system. It is assumed that the diesel generator storage tank size will cover this long run time scenario. A diesel generator is the lowest-cost option in this long run time scenario. Additional reductions in cost for hydrogen delivery and storage are needed if a fuel cell system is to compete with the incumbent technology in this run time scenario.

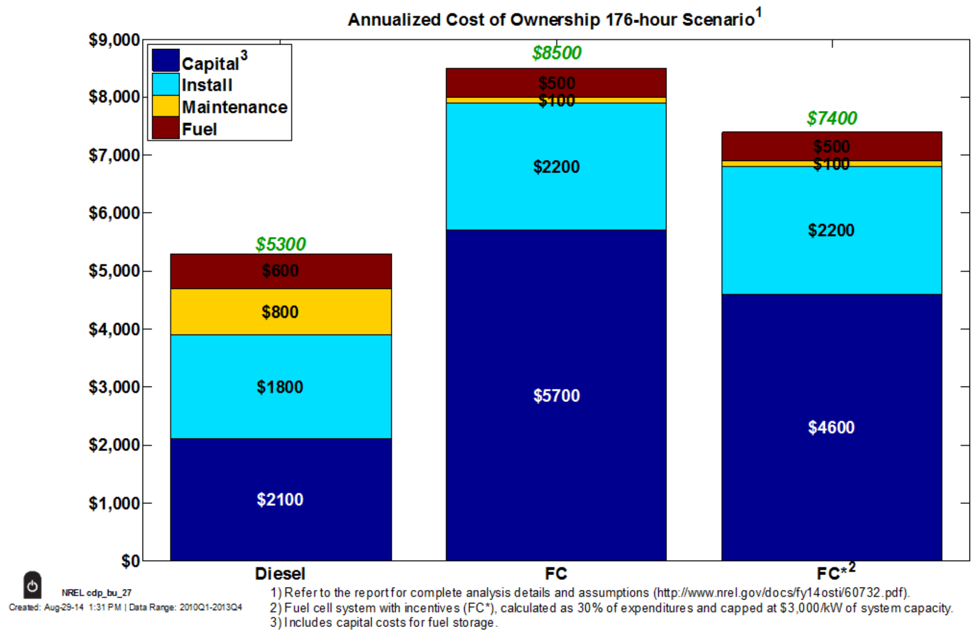


Figure 11. 176-hour scenario annual cost breakdown

In order to capture the variability of assumptions and input data, a sensitivity study of capital costs, installation costs, discount rate, operation life, maintenance costs, and fuel/electricity costs was completed for the 72-hour run time scenario. The data ranges (Table 3) are based on the input data ranges.

Table 3. 72-Hour Sensitivity Ranges

Category	Technology	Low	High
Capital	Battery	$78,000	$98,000
	Diesel generator	$27,000	$30,000
	Fuel cell	$41,000	$54,000
	Fuel cell*[a]	$29,000	$39,000
Install	Battery	$53,000	$60,000
	Diesel generator	$20,000	$28,000
	Fuel cell	$19,000	$41,000
	Fuel cell*[a]	$19,000	$41,000
Discount Rate	All	1.0%	2.0%
Operation Life	Battery	3	8
	Diesel generator	10	20
	Fuel cell	10	20
	Fuel cell*[a]	10	20
Maintenance	All	Half	1.5
Fuel/Electricity	Battery	$0.05/kWh	$0.1/kWh
	Diesel	$3.00/gal	$5.00/gal
	Hydrogen	$5.00/kg	$11.00/kg

[a] Fuel cell system with incentives.

See Figure 12 for the annualized cost of ownership ranges from the 72-hour sensitivity study. The inputs that have the largest range in cost of ownership are capital costs, install costs, and operation life. These three have the greatest variation with input data and uncertainty. For example, the fuel cell operation life of 15 years is an input assumption that has not been validated through NREL's technology validation activity of fuel cell backup power systems in real-world operation. Fuel cost, discount rate, and maintenance have relatively small ranges and impact on the annualized cost of ownership. These have a small impact on the annualized cost of ownership partly because the systems operate for very little time during a year. This emphasizes the importance of the initial capital and installation costs on the perceived and actual cost of ownership of backup power systems. For reference, the average annualized cost of ownership (see Figure 10) has been identified as a red line. Appendix C includes the battery cost ranges in addition to those shown in Figure 10.

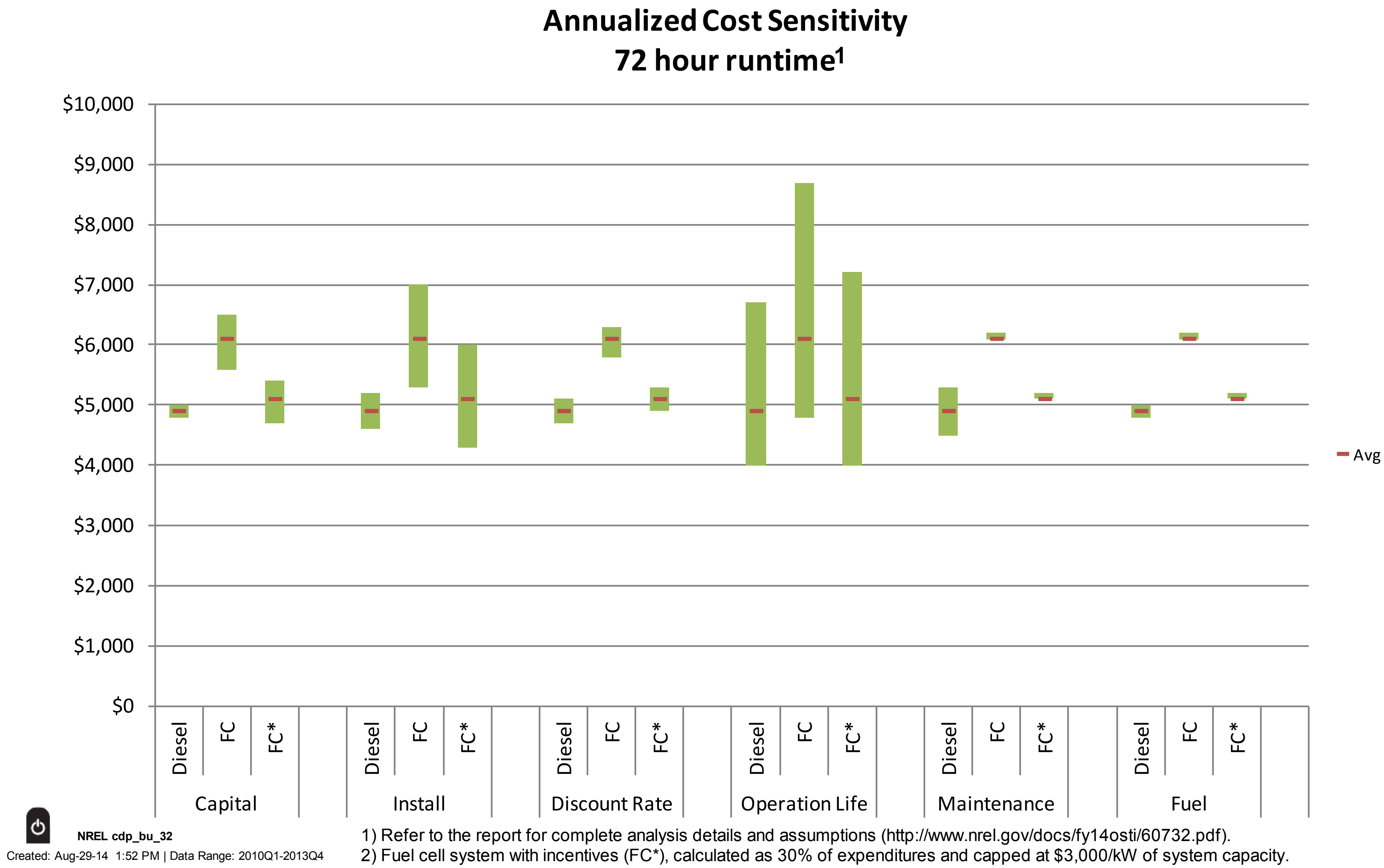


Figure 12. 72-hour sensitivity analysis results

4 Conclusions

This annual cost of ownership analysis provides an understanding of the different costs associated with three different backup power technologies: battery, diesel generator, and fuel cell systems. Data for the analysis comes from a few sources. The first source, the fuel cell data source, is the ARRA co-funded fuel cell backup power system suppliers. The second source is commercial product price estimates for batteries and diesel-powered generators. The third source is feedback from facility operators, which was used for data validation. The reported data are average values from all input sources. The capital and installation costs for each technology were amortized over an operation period of 5, 15, and 15 years for battery, diesel generator, and fuel cell systems, respectively, and in a target power range of 4–6 kW, except for the diesel generator, which had a power range of 25–35 kW because of commercial product size constraints, reliability requirements, and purchase standards. Four run time scenarios were selected—8, 52, 72, and 176 hours—and the technology case included a fuel cell system with and without federal tax incentives.

The diesel generator is consistently one of the lower-cost options, but this technology has some challenges with the cost of annual maintenance requirements and attributes not captured in the cost of ownership analysis, such as noise and emissions. Operating a diesel generator at low loads is inefficient and may also increase costs not addressed here, such as required load banks for turndown limitations, very low efficiency, and/or poor reliability. The fuel cell system with incentives is cost competitive with the diesel generator, particularly in the 8-hour, 52-hour, and 72-hour run time scenarios. A battery system is a likely selection for telecommunication sites that require 8 hours of run time, but the annualized cost of ownership quickly gets very high for the longer run time scenarios.

Fuel cell systems are now cost competitive with the incumbent backup power technologies, according to this cost of ownership analysis; however, a reduction in capital and installation costs (including hydrogen storage costs) will result in a stronger value proposition for fuel cell systems as backup power solutions. Another area that requires development for widespread deployment of fuel cell systems involves the permitting of hydrogen systems, specifically the inconsistency of how requirements are implemented from site to site and how long the process takes. For decision makers selecting a backup power system, the initial cost is a key driver, but other aspects to consider are permitting, emissions, run time capability, ease of refueling, noise, footprint, and user comfort with the technology.

5 References

1. Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G.; Post, M.; Peters, M. *Fall 2013 Composite Data Products – Backup Power*. NREL/TP-5400-60949. Golden, CO: National Renewable Energy Laboratory, December 2013. http://www.nrel.gov/docs/fy14osti/60949.pdf.

2. *Highlights from U.S. Department of Energy's Fuel Cell Recovery Act Projects*. Washington, DC: U.S. Department of Energy, February 2014. http://energy.gov/eere/fuelcells/downloads/highlights-us-department-energys-fuel-cell-recovery-act-projects.

3. Colbow, K. "Fuel Cells in Extended Duration Emergency Backup Power." Ballard Power Systems presentation, October 2010. http://www.fuelcellseminar.com/media/5229/dem42-1_colbow.pdf.

4. "Early Fuel Cell Market Demonstrations." National Renewable Energy Laboratory, 2013. http://www.nrel.gov/hydrogen/proj_fc_market_demo.html.

5. "Electric Power Monthly. Table 5.6.A. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector." U.S. Energy Information Administration, November 20, 2013. http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.

6. "Gasoline and Diesel Fuel Update." U.S. Energy Information Administration, August 2013. http://www.eia.gov/petroleum/gasdiesel/.

7. "Kubota Diesel 25,000 Watt." Central Maine Diesel, 2014. Accessed March 2014: http://www.centralmainediesel.com/stats/PRINTABLE/KB2500.asp?pa.

8. "28EOZD 1-Phase Diesel." Kohler Power Systems, 2014. Accessed March 2014: http://www.kohlerpower.com/onlinecatalog/pdf/g2143.pdf.

9. Mahadevan, K.; Judd, K.; Stone, H.; Zewatsky, J.; Thomas, A.; Mahy, H.; Paul, D. *Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets.* Columbus, OH: Battelle, April 2007. http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pemfc_econ_2006_report_final_0407.pdf.

10. "Database of State Incentives for Renewables and Efficiency." U.S. Department of Energy, 2014. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1.

11. Maxwell, M.; Painter, D. "PEM Fuel Cell Systems Providing Power to Commercial Cellular Towers and an Electric Utility Communications Network." Presented at the DOE Hydrogen and Fuel Cells Program 2012 Annual Merit Review and Peer Evaluation Meeting on May 16, 2012. http://www.hydrogen.energy.gov/pdfs/review12/h2ra006_maxwell_2012_p.pdf.

12. Gagge, J.; Shaffer, D. “Energy Storage Options to Meet the FCC Katrina Mandate.” The Battcon 2008 Proceedings; 2008, Marco Island, Florida. http://www.battcon.com/PapersFinal2008/GaggePaper2008PROOF_3.pdf.

13. Ramsden, T. *An Evaluation of the Total Cost of Ownership of Fuel Cell-Powered Material Handling Equipment.* NREL /TP-5600-56408. Golden, CO: National Renewable Energy Laboratory, April 2013. http://www.nrel.gov/docs/fy13osti/56408.pdf.

14. “Resource Center: Daily Treasury Real Long-Term Rates.” U.S. Department of the Treasury, 2014. www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=reallongtermrate.

Appendix A

Working in collaboration with DOE and industry project partners, NREL acts as the central data repository for the data collected from fuel cell demonstration projects, including assessments of fuel cell electric vehicles, fuel cell buses, fuel cell powered material handling equipment, stationary power, and fuel cell backup power. To protect proprietary and business-sensitive data that have been supplied by industry partners, DOE's Fuel Cell Technologies Office within the office of EERE established a National Fuel Cell Technology Evaluation Center (NFCTEC) at NREL to house sensitive data and enable data analysis (see Figure A-1).

Individual system, fleet, and site analysis results are aggregated into public results called composite data products (CDPs) that show the status and progress of the technology without identifying individual companies or revealing proprietary information. Prior to publication, the project's industry partners review the CDPs and provide their input and approval. CDPs enable NREL to publish in-depth analyses without identifying individual companies or their performance. These CDPs report on the progress of the technology and the deployment projects, focusing on the most significant results.

While the raw data are secured by NREL to protect commercially sensitive and proprietary information, individualized data analysis results are provided as detailed data products (DDPs) to the partners who supplied the data. These DDPs identify individual contributions to CDPs and are intended to assist companies as they refine and improve fuel cell technologies but are not made available to the public. Those interested in providing data or updates may do so via techval@nrel.gov. More information is available at www.nrel.gov/hydrogen/proj_tech_validation.html.

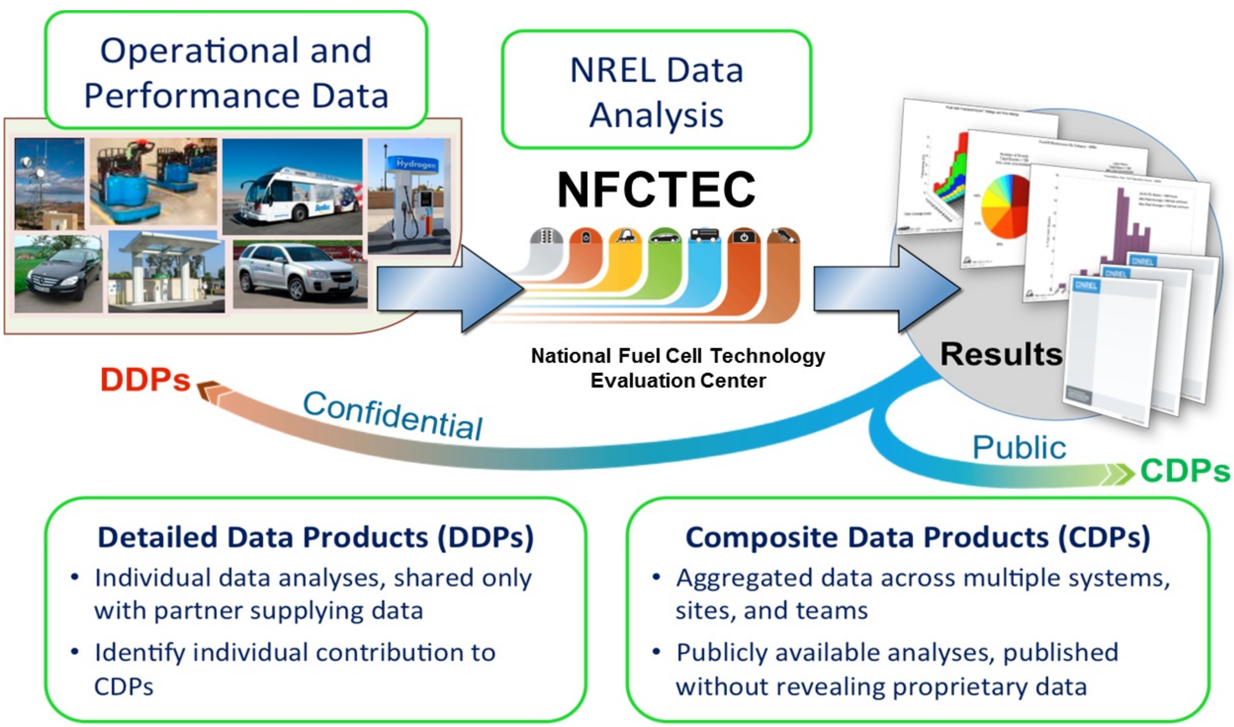


Figure A-1. NREL's aggregated data analysis using the NFCTEC

Appendix B

State	kW	Sites
Arizona	84	19
California	635	130
Colorado	25	6
Connecticut	130	28
Florida	6	1
Georgia	50	1
Illinois	4	2
Indiana	50	16
Kentucky	22	4
Louisiana	40	8
Massachusetts	10	1
Michigan	168	41
Mississippi	10	2
Nevada	2	1
New Jersey	181	40
New York	238	55
North Carolina	10	2
Oregon	2	1
South Carolina	50	1
Texas	238	48
Utah	36	9
Washington	1	1
Wyoming	2	1
Totals	1993	418

NREL cdp_bu_03
Created: Apr-18-14 7:50 AM | Data Range: 2010Q1-2013Q4

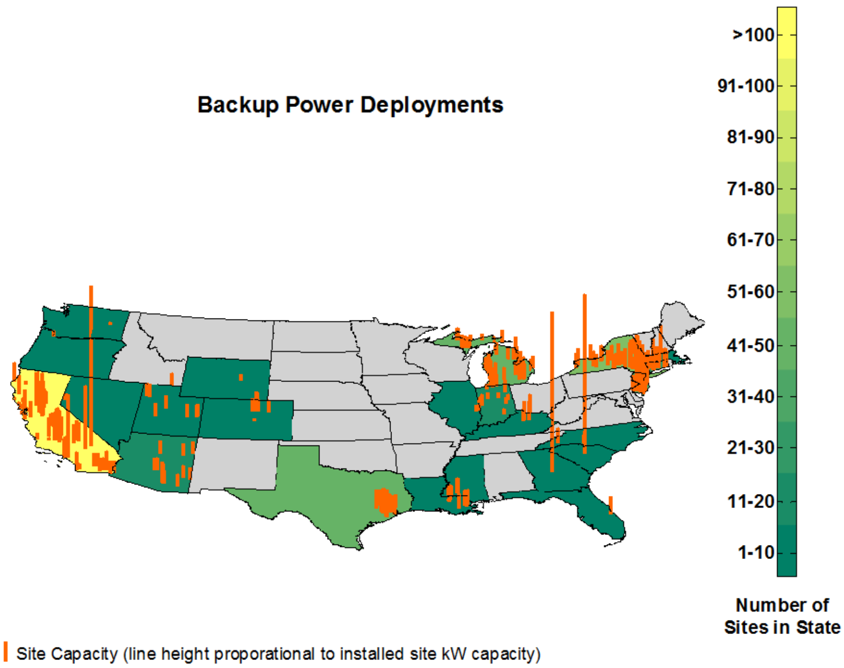


Figure B-1. Backup power deployments with station capacity and site count

Appendix C

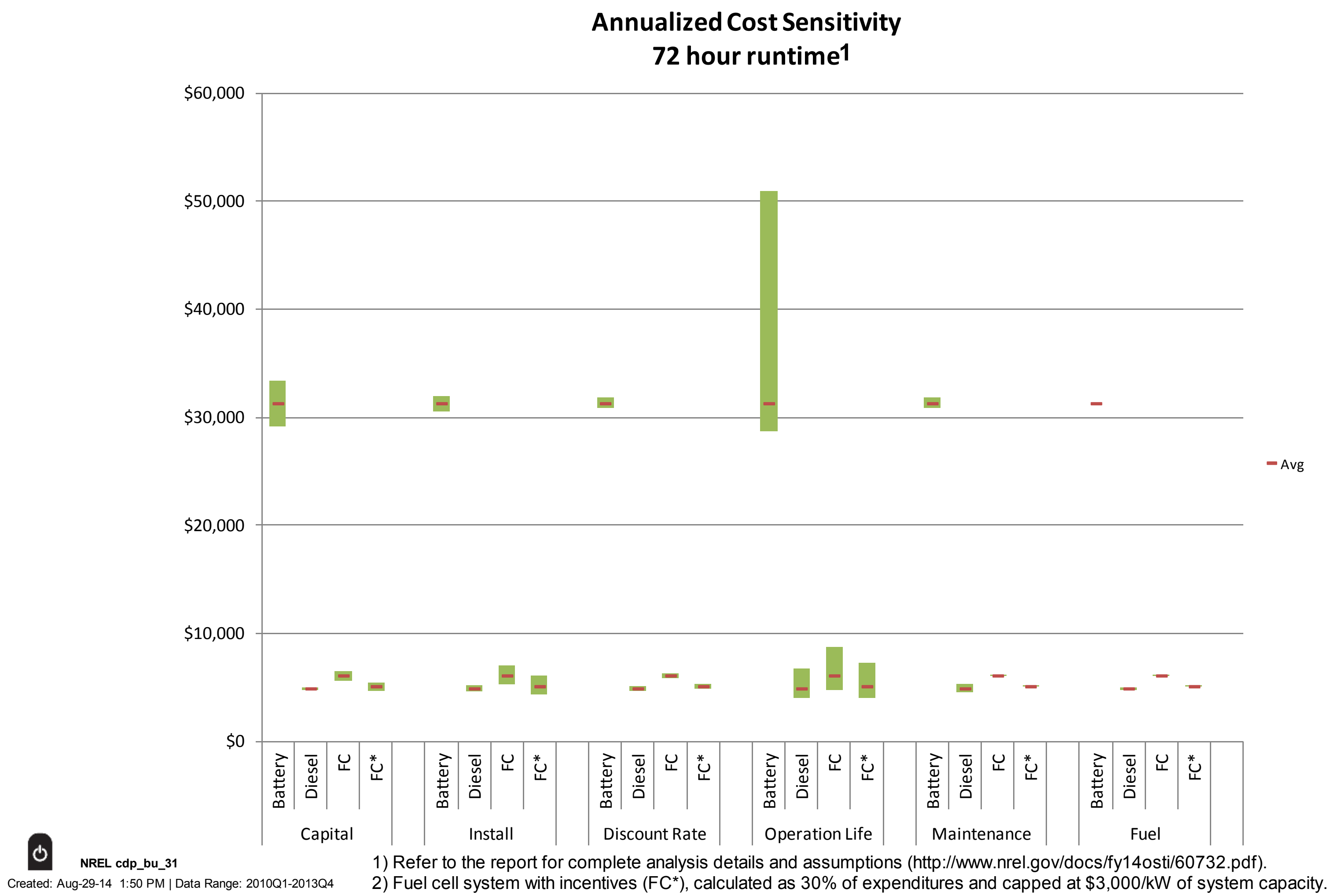


Figure C-1. 72-hour sensitivity analysis results that includes battery values