The Role of Firming Generation in Microgrids

A California Case Study

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Energy+Environmental Economics

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1. Executive Summary

Wildfire conditions have recently led to power shutoffs in many parts of California, often for days at a time. As a direct result, customers searching for a solution to avoid or mitigate these power shutoffs have begun to investigate and invest in “microgrids”, small portions of the grid that are able to self-isolate and continue to provide power even when the larger California grid is out. To support these efforts, the California Public Utilities Commission (CPUC) has initiated a proceeding to “facilitate the commercialization of microgrids for distribution customers of large electrical corporations.” This whitepaper examines technology configurations available to customers to provide reliable microgrid solutions while examining the economic and environmental impacts of these options.

Specifically, four microgrid technology configurations were considered: distributed solar paired with either 1) a backup generator 2) battery energy storage 3) a fuel cell or 4) a Mainspring linear generator. Backup generators, battery storage, and fuel cells are established technologies in the market, where as the linear generator, from Mainspring Energy, is a new category of power generation technology that is efficient, low cost, low-emission, fuel-flexible, and dispatchable to ramp up and down. This whitepaper assumes both fuel cells and the Mainspring generator are powered by natural gas while the backup generator is powered by diesel. Each configuration is sized such that the microgrid is capable of providing power to critical electric loads for three days (72 hours) in the event of a grid outage.

This analysis is performed for two customer types – a school and supermarket – in Napa, California. Economics for all technology configurations and customer types were examined from the customer’s perspective, using 20-year net present value as the economic metric. All configurations were modeled using the existing utility tariffs (including net energy metering) and a hypothetical future “microgrid tariff” that fully compensates these technologies for the value they provide to the utility while accounting for a changing California grid.

Key Findings

The key findings of this whitepaper are as follows:

- Some type of firm generation (backup generator, fuel cell, or linear generator) is required to economically meet reliability requirements for 72 hours of backup power
- Solar + Storage is a highly uneconomic configuration due to significant oversizing of the battery system in order to meet reliability requirements
- Solar + Backup Generator is a configuration that provides cost and emission savings relative to the grid (due to solar) while meeting reliability requirements (due to the backup generator)
- Solar + Fuel Cell is an economic configuration for some customer types but is challenged by the fuel cell's high capital cost and lack of fuel cell dispatchability to ramp up during high value hours or ramp down during low value hours
- Solar + Mainspring is the most economic configuration and also provides increased emission savings relative to the solar + backup generator configuration
    - Flexible ramping provides important benefits to the customer and the grid by allowing Mainspring to both shut off or export to the grid when needed
        - Shutting down during hours of negative pricing (e.g. significant solar overgeneration on the grid) reduces curtailment and maximizes environmental benefits
        - Exporting to the grid during hours of energy or capacity needs can help offset the need for less efficient power plants which both reduces emissions and provides economic benefits
    - High-efficiency and near-zero criteria pollutant emissions allows Mainspring to operate on a regular basis to economically offset customer purchases from the grid while saving on emissions

The economics of the four microgrid technology configurations are provided in Figure 1 (school) and Figure 2 (supermarket). These results show that Solar + Mainspring provides the highest net customer benefit over the life of the investment.

Figure 1: Lifecycle Economics of Microgrid Configurations –School

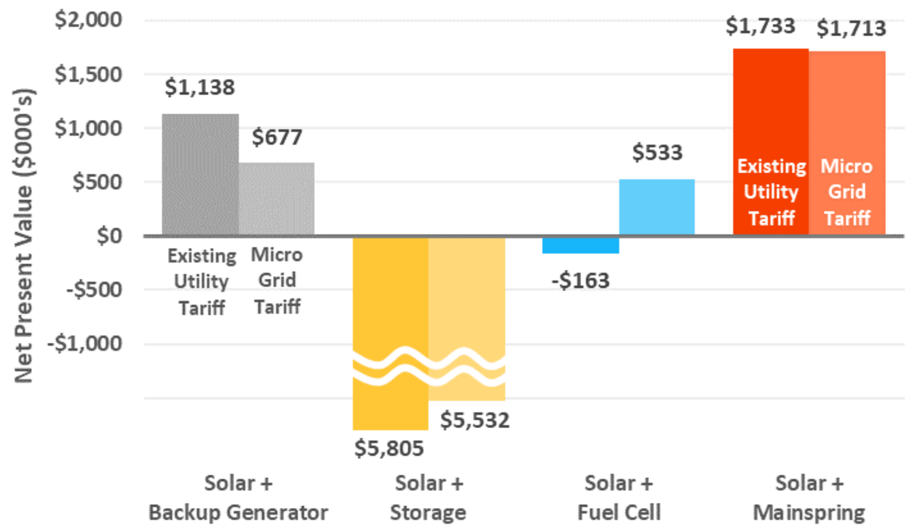
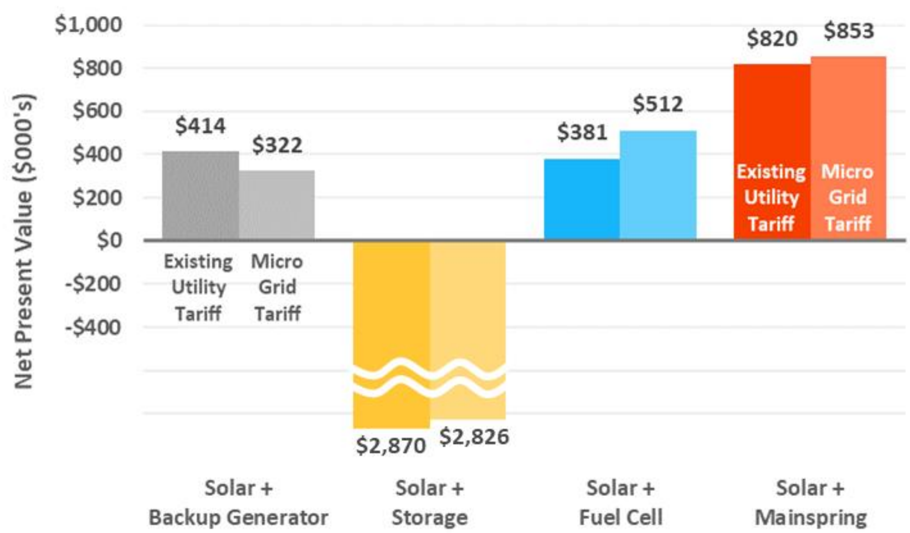


Figure 2: Lifecycle Economics of Microgrid Configurations –Supermarket



The greenhouse gas emissions of the four microgrid technology configurations are provided in Figure 3 (school) and Figure 4 (supermarket). These results show that all technology configurations reduce greenhouse gas emissions relative to grid power, primarily due to the installation of solar. Because the backup generator is only operated during grid outage conditions, the emission reductions in this case are equivalent to the emission reductions in a "solar only" configuration. Pairing solar with a technology that can operate on a regular basis has the potential to further reduce grid emissions by displacing less efficient and less clean grid resources.

Figure 3: Lifecycle Emission Impacts of Microgrid Configurations –School

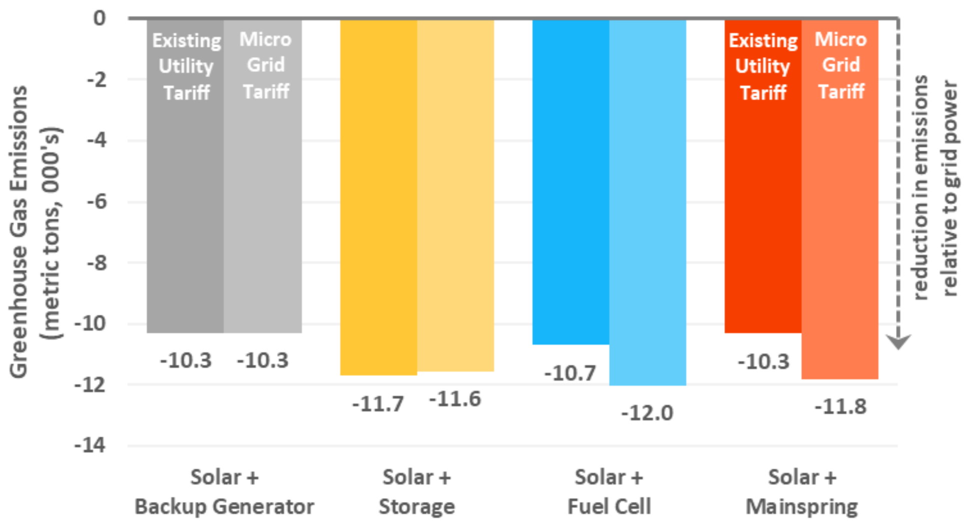
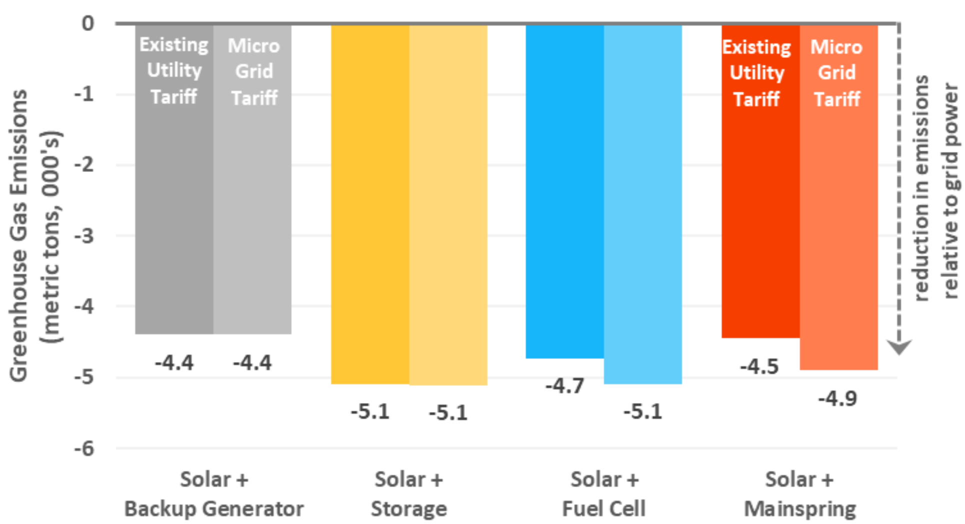


Figure 4: Lifecycle Emission Impacts of Microgrid Configurations –Supermarket



2. Introduction

Recent and growing wildfire risks in California have increased the use of public safety power shutoffs (PSPS) as a necessary byproduct of deenergizing high-risk transmission lines that carry electricity through windy and fire-prone forests throughout the state. Additionally, insufficient bulk-grid power supplies during the summer of 2020 caused utilities to curtail power to some customers. As a direct result, interest in microgrids to avoid or mitigate the impact of grid outages has also grown. In 2018, the California legislature passed SB 1339 that required to California Public Utilities Commission (CPUC) to "facilitate the commercialization of microgrids for distribution customers of large electrical corporations." The CPUC has in turn initiated a microgrid rulemaking (R. 19-09-009) to consider how to implement the requirements.

Microgrids are configurations of technologies that are capable of "islanding" from the larger grid during an outage and providing continuous power. When islanded, microgrids must not only be able to generate power but also control power output to match fluctuating demand. While microgrids can be configured to serve larger groups of customers such as those connected to an entire electrical substation or feeder, this paper explores microgrids for individual commercial customers who are interested in the potential for continuous power during a grid outage. The results of this analysis should also apply to larger microgrids.

This whitepaper is sponsored by Mainspring Energy which has developed a new category of power generation technology — the linear generator — that offers distributed, low emission, dispatchable, and fuel-flexible power. Mainspring's linear generators are dispatchable, with the ability to ramp output up and down, and are fuel flexible, with the ability to dynamically switch between natural gas, renewable natural gas, propane, or hydrogen. This whitepaper compares the feasibility, cost, and environmental impacts of solar-based microgrids combined with alternatives for resiliency including diesel-powered backup generators, battery storage, natural gas-powered fuel cells, and natural gas-powered Mainspring generators. This whitepaper specifically addresses the following microgrid questions:

- Which technology configurations can feasibly and reliably deliver power during a 72-hour grid outage?

- What are the costs and benefits of different technologies and configurations?

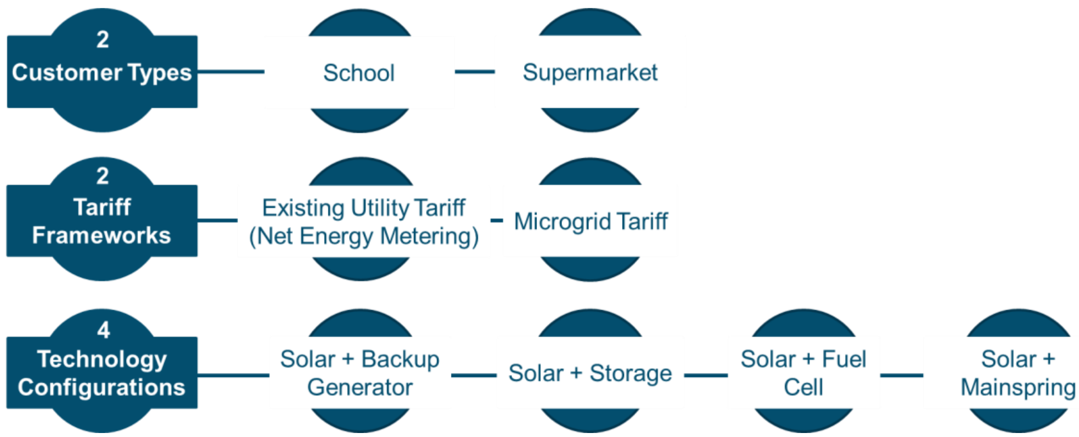
- What are the environmental impacts of various technologies and configurations?

3. Analysis

Scenarios

E3 analyzed microgrid configurations for two customer types, two utility tariff frameworks, and four different technology configurations for a total of sixteen (2 x 2 x 4) cases.

Figure 5: Microgrid Configurations



All scenarios were analyzed for customers in the Pacific Gas & Electric service territory in Napa, California using applicable load profiles, solar profiles, and customer rates. Napa was chosen for its potential for power shutoffs due to proximity to fire risk as well as high solar potential. This section provides an overview of each customer type, utility tariff framework, and technology configuration with additional detail provided in the Appendix.

Customer Type

E3 analyzed microgrids for two utility customer types: a secondary school and a supermarket. These customer types were chosen based on their significant community impact due to power outages. Schools have been designated by the CPUC as “critical facilities”, while supermarkets are critical for community food supply and can incur significant food spoilage costs.[1] Hourly

[1] Pg 76 https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M296/K598/296598822.PDF

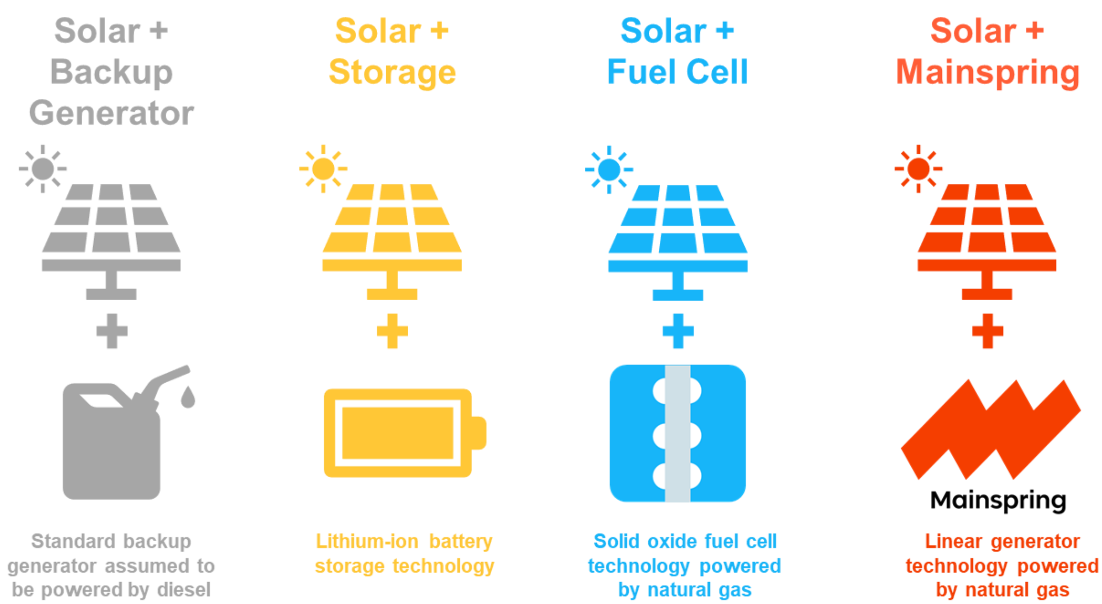
electricity load profiles for these building types in Napa, CA were compiled from the U.S. Department of Energy commercial building database.[2]

Figure 6: Customer Types

Technology Configurations

E3 analyzed four plausible microgrid technology configurations that are either being actively pursued or installed by customers or are under consideration for various state policies including in the California legislature and at the CPUC.

Figure 7: Microgrid Technology Configurations



[2] https://openei.org/doe-opendata/dataset/commercial-and-residential-hourly-load-profiles-for-all-tmy3-locations-in-the-united-states

For all technology configurations, solar was assumed to be installed on 70% of available rooftop area based on commercial building estimates from the National Renewable Energy Laboratory (NREL), which is 50% higher than the default NREL assumption.[3] For the school, this resulted in 968 kW of solar, and for the supermarket this resulted in 413 kW of solar. The 18% solar capacity factor assumed in this whitepaper provided enough energy to offset 54% of annual school load and 40% of annual supermarket load.[4]

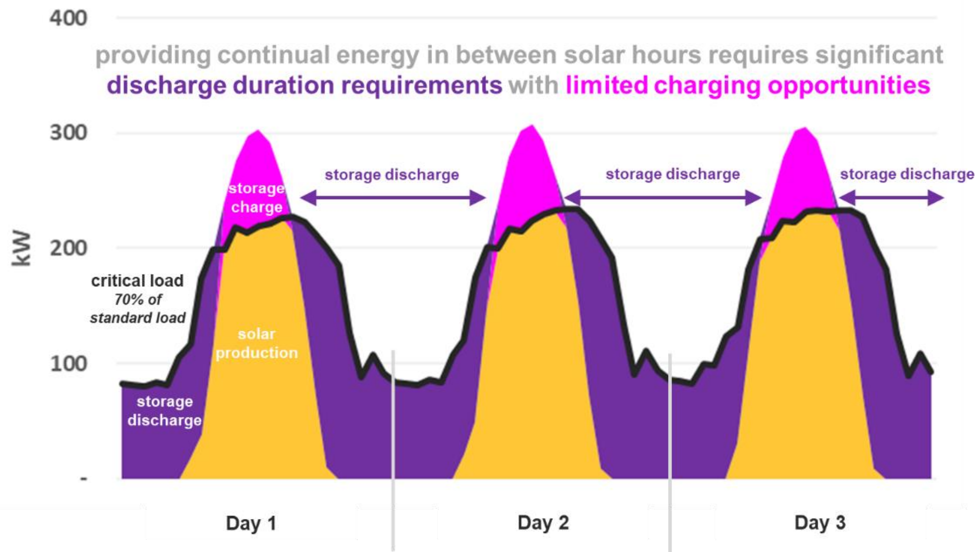
The non-solar portion of each microgrid configuration was sized in order to ensure each microgrid could deliver uninterrupted power to critical loads for each customer for 72 hours in the event of a grid outage, with critical load assumed to be 70% of normal customer load.

For the fuel-based firm technologies (backup generator, fuel cell, Mainspring), each generator was sized to ensure it can meet peak critical customer load (net of solar) during microgrid islanding operations. The 72-hr duration of the outage did not impact the sizing of these technologies. Battery storage was sized to meet peak customer load (net of solar) without running out of charge for any 72-hr period within the year, including high load and low solar conditions. This "duration" requirement presents a significant challenge for battery storage and is illustrated in Figure 8.

[3] https://www.nrel.gov/docs/fy16osti/64793.pdf

[4] Solar capacity factor is based on the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) solar simulations as described in Appendix.

Figure 8: Solar + Storage Microgrid Operation - Supermarket



The sizing for the technology configurations for both customer types is provided in Table 1. Notably, battery storage must be sized with a duration of 40 hours for the supermarket and 37 hours for the school in order to maintain reliability during any 72-hour grid outage. The batteries did not need 72-hr duration because the batteries don't need to output at full capacity for the entire grid outage period due to solar generation and fluctuating load. For reference, most battery storage systems installed in California today have a duration of approximately 4 hours or less.

Table 1: Microgrid Technology Configurations

Technology Configuration	Supermarket	School
Solar + Backup Generator	413 kW solar	968 kW solar
	200 kW diesel generator	500 kW diesel generator
Solar + Storage	413 kW solar	968 kW solar
	200 kW / 8,000 kWh battery (40 hr duration)	500 kW / 18,500 kWh battery (37 hr duration)
Solar +	413 kW solar	968 kW solar

Fuel Cell	1 x 200 kW fuel cell	2 x 250 kW fuel cells
Solar + Mainspring	413 kW solar	968kW solar
	1 x 250 kW linear generator	2 x 250 kW linear generators

It is important to note that increasing the assumed grid outage period from 72-hrs to 96-hrs, as the CPUC has proposed in its microgrid proceeding, would increase the required battery storage duration even further than shown above.[5] Additionally, the analysis assumes that grid outages occur with sufficient notice to fully charge the battery. To the extent that this is not the case, the battery would require even longer durations or not provide full reliability.

Utility Compensation Framework

Aside from the obvious benefit of being able to provide power during a grid outage, microgrid technologies can also provide economic benefits to customers by lowering their utility bill. Both the school and supermarket customers are assumed to take service from Pacific Gas & Electric under the medium general demand-metered time-of-use electricity tariff (B-19). To model these economic benefits, E3 assumed two tariff frameworks: 1) the existing utility tariff which compensates resources via net energy metering (NEM) and 2) a new hypothetical microgrid tariff that does not yet currently exist but is being contemplated by the CPUC through the microgrid proceeding. Both the linear generator and fuel cell are assumed to take natural gas service on the gas transportation service to electric generation tariff (G-EG).

Existing Utility Tariff

The existing utility tariff compensates distributed energy resources via net energy metering (NEM) that allows solar and battery storage to sell electricity back to the grid for credits equal to the retail rate, less non-bypassable charges. Fuel cells are eligible to participate in a fuel cell-specific version of NEM, called FC-NEM, and sell electricity back to the grid for credits equal to only the generation component of the retail rate. Mainspring linear generators are not eligible for either NEM tariff, but due to their dispatchability, they are able to track customer load (net

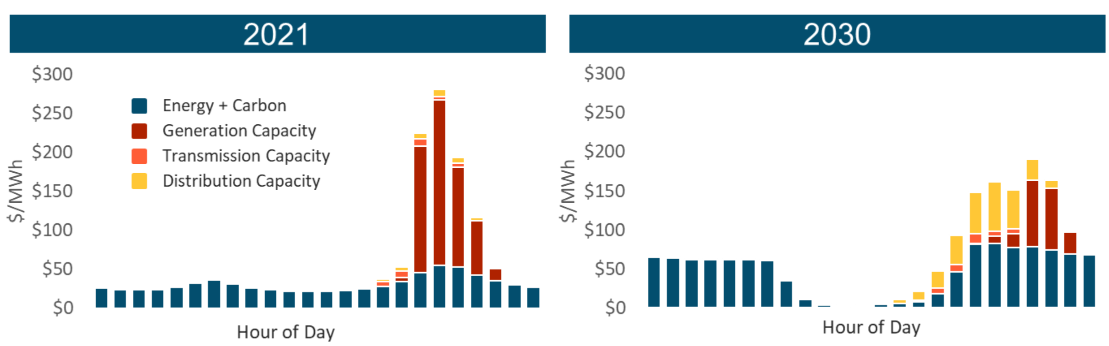
[5] https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M344/K038/344038386.PDF

of solar) and generate without exporting energy back to the grid. Under the existing utility NEM tariffs, solar, storage, and fuel cell technologies are exempt from utility standby charges, but Mainspring generators are required to pay these charges, which are included in this analysis. If Mainspring generators were exempt from standby charges, the economic returns would be stronger for customers. In all cases, annual generation from microgrid technologies is limited to annual customer load.

Microgrid Tariff

The CPUC is currently exploring a potential "microgrid tariff" that would seek to fully compensate microgrid technologies for the services they provide to the grid. This tariff would be consistent with FERC Order 2222. E3 assumed that a hypothetical microgrid tariff would allow all technologies to dispatch to reduce grid consumption (effectively compensated at the retail rate) and sell back (export) electricity to the grid at the full value of the utility's avoided cost. Unlike with net energy metering, there would be no limit to the quantity of electricity that could be exported to the grid since it would be compensated at full utility avoided cost. To calculate utility avoided costs, E3 relied upon a combination of internal market price forecasts developed using the AURORA production simulation model and the 2020 CPUC avoided cost calculator. Hourly avoided costs are calculated for each year over the analysis period (2022-2041). Annual average avoided cost values for 2021 (present) and 2030 are shown in Figure 9.

Figure 9: Average Avoided Cost Microgrid Tariff Values for 2021 and 2030



Key Assumptions

The whitepaper assumes the microgrid is installed in 2022 with a 20-year lifetime. Due to its shorter life, battery storage must be replaced after 10 years, while solar is provided salvage value credit due to its longer expected life of 30 years.

Key financial and operating assumptions are provided in the Appendix. Financial assumptions are based on publicly available sources, including Lazard Levelized Cost of Storage Analysis – Version 6.0 and Lazard Levelized Cost of Energy Analysis – Version 11.0. Costs are reduced to account for expected cost declines through 2022, when the microgrids are assumed to be installed. The solar, battery, and fuel cell are eligible for a 26% federal investment tax credit (ITC), while the Mainspring linear generator and the diesel-powered backup generator are not.

Hourly marginal carbon emissions for the grid are calculated over the entire analysis period (2022-2041) using an implied marginal heat rate methodology based on the hourly energy price. Energy prices are based on E3 internal market price forecasts developed using the AURORA production simulation model. When microgrid technologies generate energy when connected to the grid, they reduce the need for grid generation and avoiding carbon emissions. The marginal carbon emission formula used in this analysis is provided below.

$$MHR = \frac{EP - VOM}{NGP + CP * ER + DA}$$

Where:

$\mathrm{MHR} = \text{Marginal heat rate (MMBtu/MWh)}$

$\mathrm{EP} = \text{Energy Price (\$/MWh)}$

$\mathrm{VOM} = \text{Variable Operations \& Maintenance (\$/MWh)}$

$\mathrm{NGP} = \text{Natural Gas Price (\$/MMBtu)}$

$\mathrm{CP} = \text{Carbon Price (\$/ton)}$

$\mathrm{ER} = \text{Emission Rate (ton/MMBtu)}$

$\mathrm{DA} = \text{Deliver Adder for natural gas (\$/MMBtu)}$

The marginal heat rate is capped at a maximum of 12.5 MMBtu/MWh and a minimum of 6.0 MMBtu/MWh, except to the extent that the calculated marginal heat rate is less than or equal to 0.0, in which case 0.0 is used. In other words, this analysis assumes natural gas generation is on the margin in all hours except when renewables are being curtailed.

Modeling Approach

E3 modeled the optimal operation of the four microgrid configurations to minimize customer bills using the E3 RESTORE model, E3's in-house dispatch optimization tool that is capable of dispatching solar, battery storage, a fuel cell, and the Mainspring linear generator against a set of fixed prices such as electricity tariffs and utility avoided costs.[6] A more detailed description of the RESTORE model is provided in the Appendix.

Each microgrid technology configuration is optimally dispatched in RESTORE given its operating constraints, which are described below.

- **Solar + Backup Generator:** Because the backup generator is assumed to be powered by diesel, this technology does not dispatch to provide customer bill savings. It only dispatches during grid outage conditions for backup power because local air districts do not permit diesel and other high-emission generators to operate outside of grid-outage events. Because of this, customer bill savings and grid emission reductions are equivalent to a "solar only" scenario.
- **Solar + Storage:** Storage charges and discharges to both arbitrage time-of-use electricity charges and minimize customer demand charges. In the microgrid tariff, storage can charge during hours of excess solar production to avoid lower price exports. By charging during low grid emission hours and discharging during high grid emission hours, storage can provide incremental emission reductions relative to solar alone.
- **Solar + Fuel Cell:** The solid oxide fuel cell is assumed to operate 24/7 at part load due to operational limitations that prevent ramping without causing significant degradation. The fuel cell is assumed to operate at part load in order to 1) ensure it has enough excess capacity to meet full reliability requirements during islanding operations and 2) ensure annual generation from the fuel cell and solar do not exceed annual customer load (for the existing utility tariff scenario only, because of both solar NEM and FC-NEM). For this reason, the 200 kW supermarket fuel cell is shown to output at 98 kW steady output in the figure

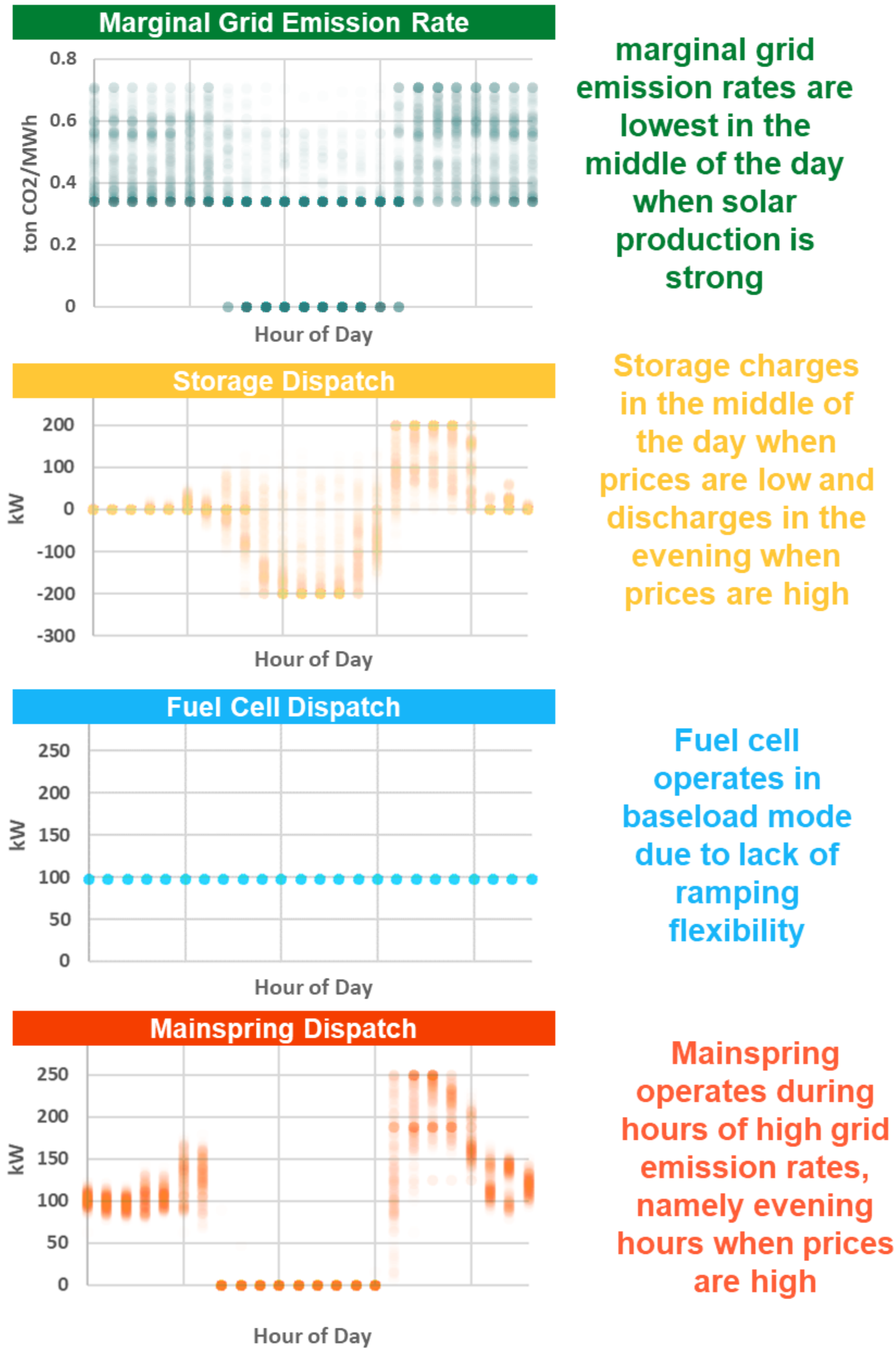
[6] https://www.ethree.com/tools/restore-energy-storage-dispatch-model/

below. During a grid outage, it is assumed that the fuel cell can track load sufficiently to match changing customer load, albeit with potential degradation issues.

+ **Solar + Mainspring:** The Mainspring linear generator is able to flexibly ramp up and down and dispatch to minimize customer energy and demand charges while not offsetting onsite solar or renewable energy from the grid. For modeling simplicity, Mainspring power output was modeled as zero between 7 am and 4 pm (the hours in which onsite solar is likely generating and renewable energy is most likely the marginal grid resource). Annual generation from solar and Mainspring is limited to annual customer load (for the existing utility tariff scenario only, because of solar NEM).

Figure 10 shows how the microgrid technology configurations are dispatched in the RESTORE model in 2030 as well as the marginal grid emission rates in that year.

Figure 10: Marginal Grid Emissions and Technology Operation – Supermarket – 2030 – Existing Utility Tariff



4. Results

Economic Results

E3 calculated customer economics for each microgrid technology configuration. The results are presented in Figure 11 through Figure 14. Customer costs include the net present value of upfront capital cost and ongoing operational cost (primarily fuel). The benefits include net present value of reductions in the customer's electricity bill (energy and demand charge savings) as well as any incentive payments. The results demonstrate the following:

- **Solar + Backup Generator** provides a net economic benefit to customers. The positive economics are entirely driven by solar which is either compensated through net energy metering or the microgrid tariff. The customer bill savings from solar are sufficient to fund the cost of a backup generator which can provide reliability during a grid outage but cannot be utilized to offset a customer's electricity bill.
- **Solar + Storage** yields a significant net economic cost to customers. The large net cost is primarily driven by long duration of battery storage required for reliability during microgrid operations (40 hours for the supermarket and 37 hours for the school). Duration is provided by increasing the number of battery packs, and costs scale largely with the number of cells installed. For example, a 40-hour duration battery is roughly ten times more expensive than a 4-hr duration battery, the most commonly installed duration for commercial applications.
- **Solar + Fuel Cell** yields a mixed net economic return for customers. The significant capital and maintenance cost of the fuel cell is generally offset by the energy and demand charge savings provided by the solar and fuel cell, although this technology configuration does yield a net cost under some configurations.
- **Solar + Mainspring** provides the highest net economic benefit to customers of all the technology configurations. This is largely driven by Mainspring's low capital and operating cost and dispatchability. The dispatchability of the linear generator provides flexibility to not offset onsite or grid solar energy production (i.e., avoids curtailment) and flexibility to generate during the most value hours to maximize customer energy and demand charges.

Figure 11: Microgrid Economics – Existing Utility Tariff - Supermarket

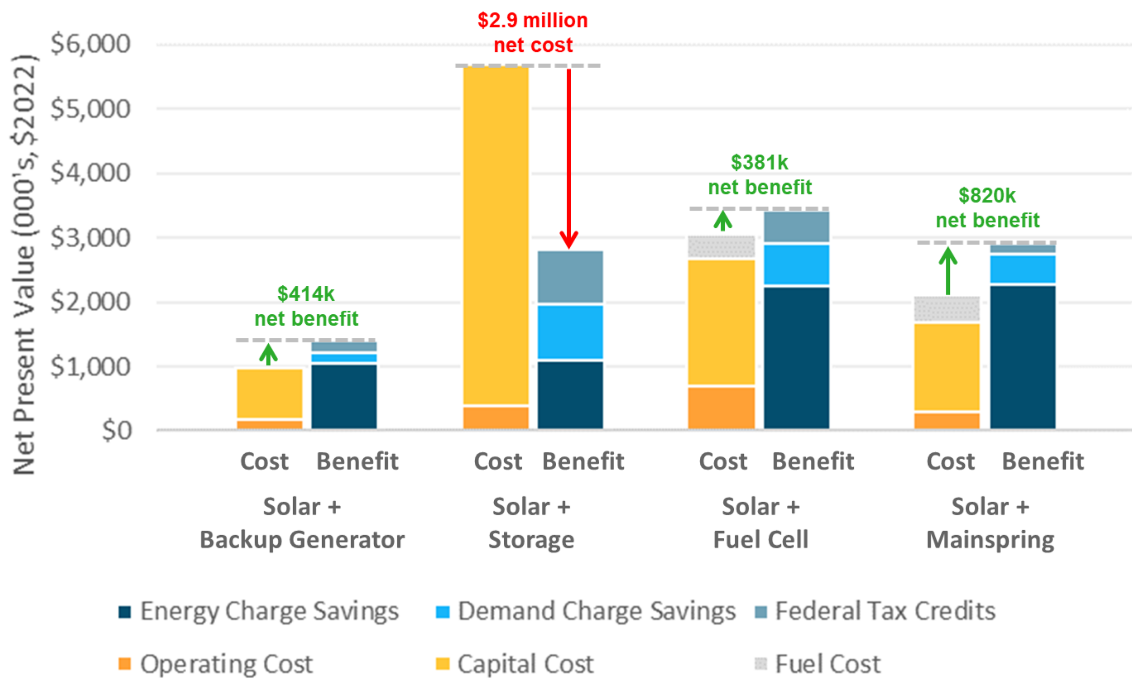


Figure 12: Microgrid Economics – Microgrid Tariff – Supermarket

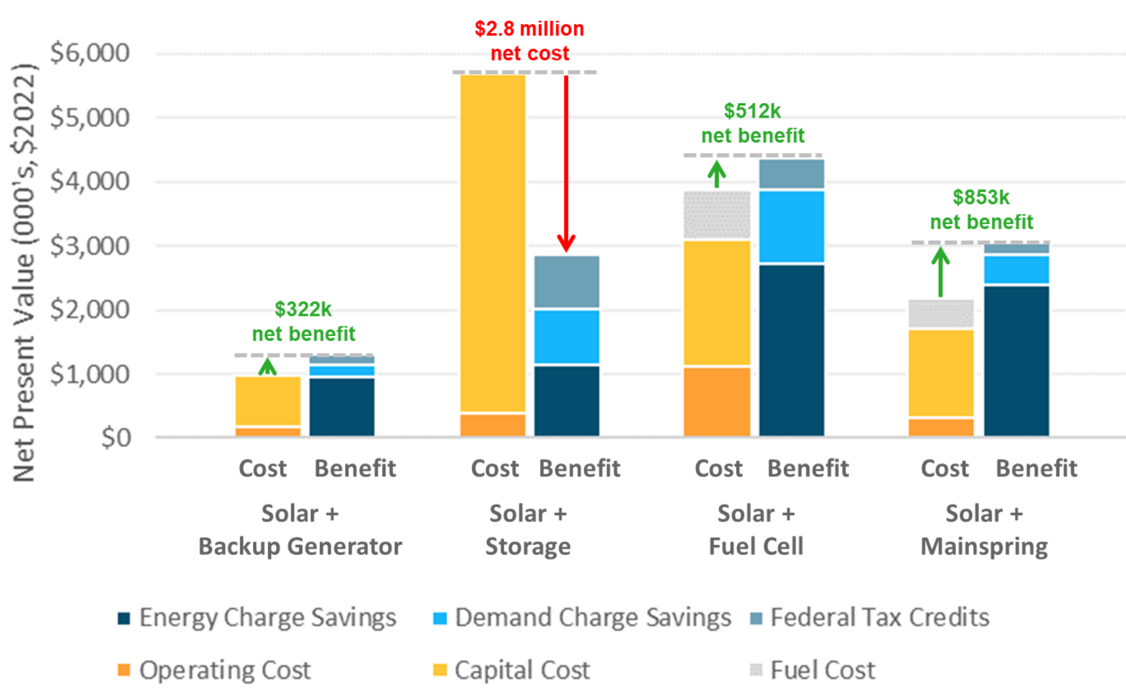


Figure 13: Microgrid Economics – Existing Utility Tariff – School

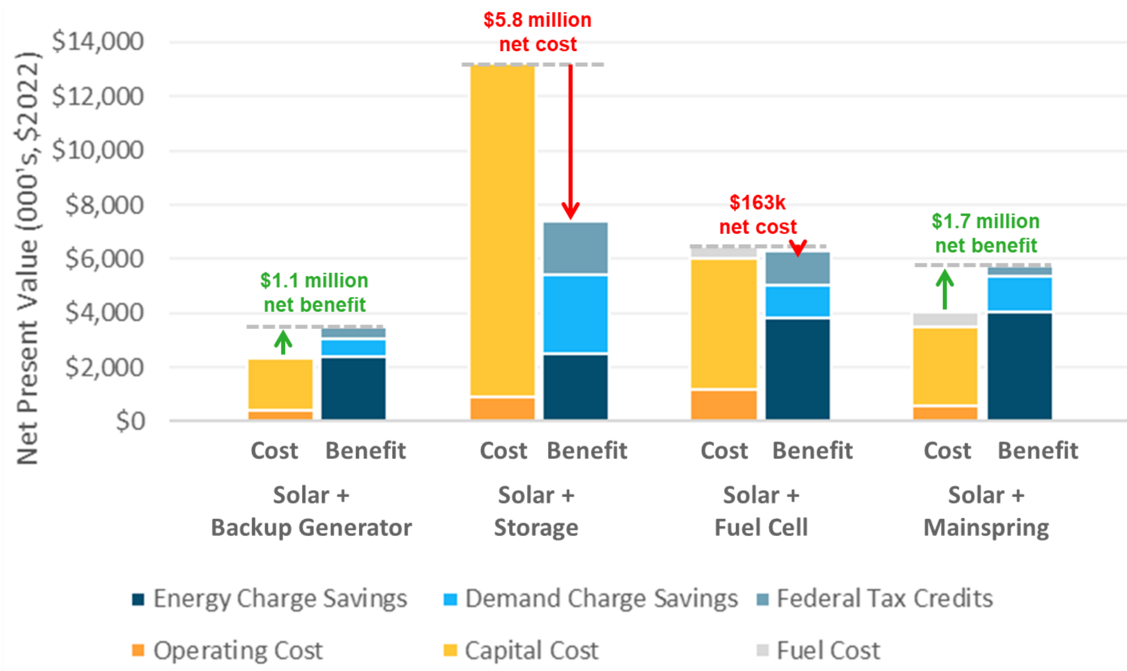
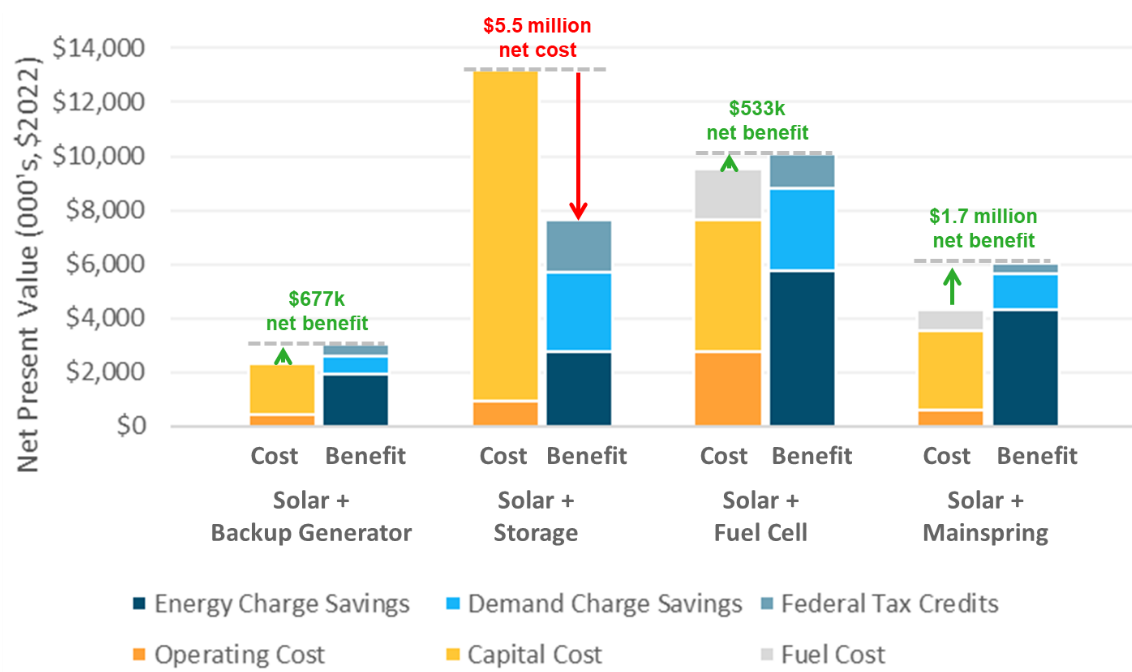


Figure 14: Microgrid Economics – Microgrid Tariff - School



Environmental Results

All microgrid technology configurations analyzed in this whitepaper reduce greenhouse gas emissions relative to grid power, primarily due the solar component of each configuration. As shown in Figure 145 and Figure 16, the results demonstrate the following:

- **Solar + Backup Generator** provides greenhouse gas emission reductions but provides the least among all technology configurations analyzed. Because the backup generator is not able to dispatch outside of grid outages, the emission savings in this case are equivalent to a "solar only" scenario.
- **Solar + Storage** provides incremental greenhouse gas emission reductions relative to the "solar only" scenario because it is able to charge during low emission hours in the middle of the day and discharge during high emission hours in the evening and morning. This technology configuration provides the highest emission reductions of all configurations analyzed in this whitepaper.
- **Solar + Fuel Cell** provides incremental greenhouse gas emission reductions relative to the "solar only" scenario because high-efficiency fuel cells are able to offset the need for lower-efficiency generators from the grid during evening hours. This benefit is somewhat offset by the fuel cell running 24/7, including during the middle of the day when it is displacing solar energy and increasing emissions.
- **Solar + Mainspring** provides greenhouse gas emission reductions relative to the "solar only" scenario because it generates in the morning and evening when its high efficiency is offsetting lower-efficiency generators from the grid while never displacing solar energy.

Figure 15: Lifecycle GHG Emissions – Supermarket

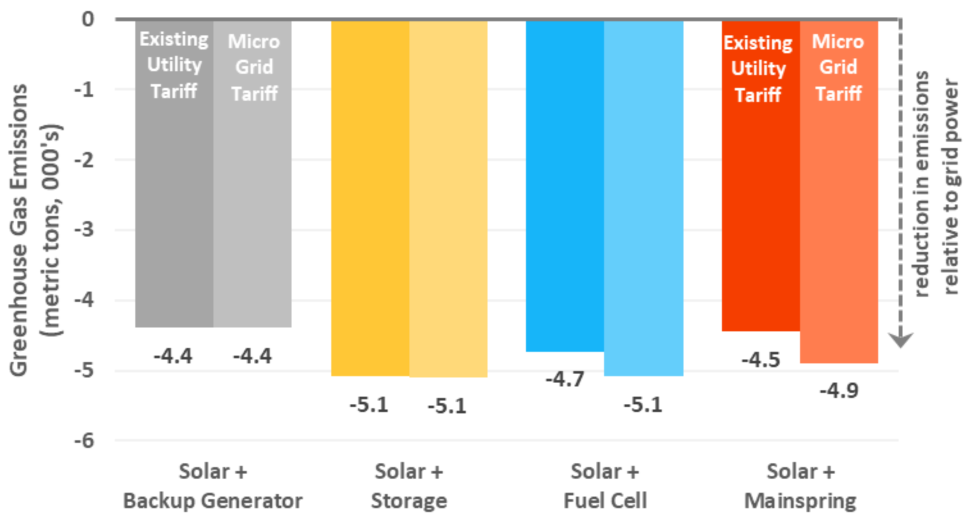
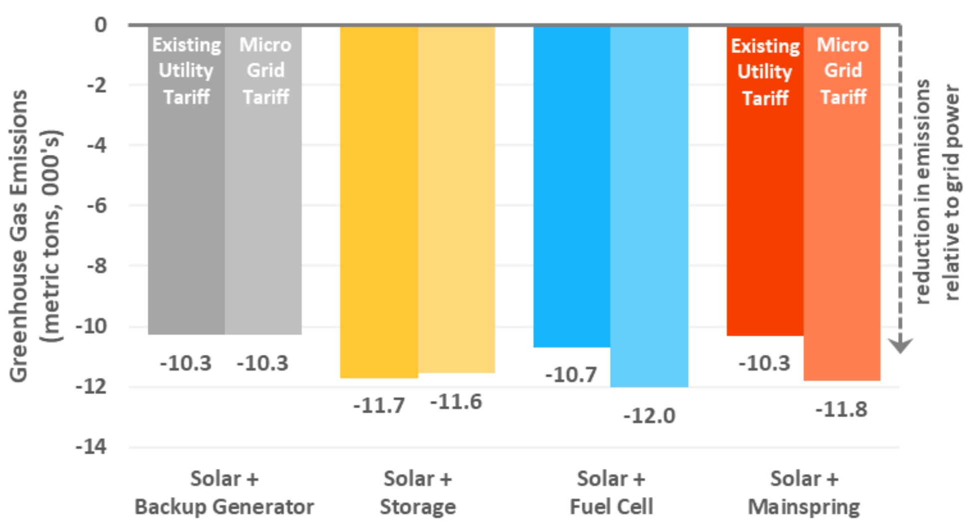


Figure 16: Lifecycle GHG Emissions – School



Both fuel cells and the Mainspring linear generator are unique in that their technology emits near-zero quantities of NO_X and particular matter (PM_{10}), which is not the case for grid scale natural gas generators (peakers and combined cycles). When viewed through this lens, generation from fuel cells or Mainspring reduces NO_X and PM_{10} relative to the grid regardless of the efficiency of the grid generator that is being displaced, as long as these technologies are not offsetting renewable generation. Because all scenarios have the same quantity of solar generation, the Solar + Fuel Cell and Solar + Mainspring configurations are able to generate additional non-solar energy to offset grid generation and provide significantly more NO_X and PM_{10} emission reductions than the Solar + Backup Generator (i.e. "solar only") or the Solar + Storage configurations.

Figure 17 and Figure 18 provide NO_X and PM_{10} emissions for the school scenario normalized by on-site generation. For simplicity, the supermarket results are not shown but yield a very similar pattern.

Figure 17: Lifecycle NO_X Emissions – School

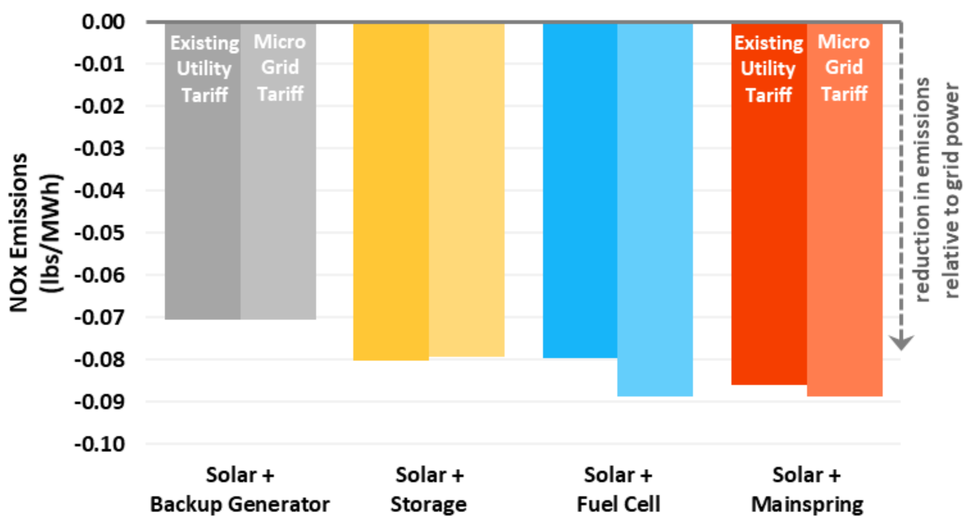
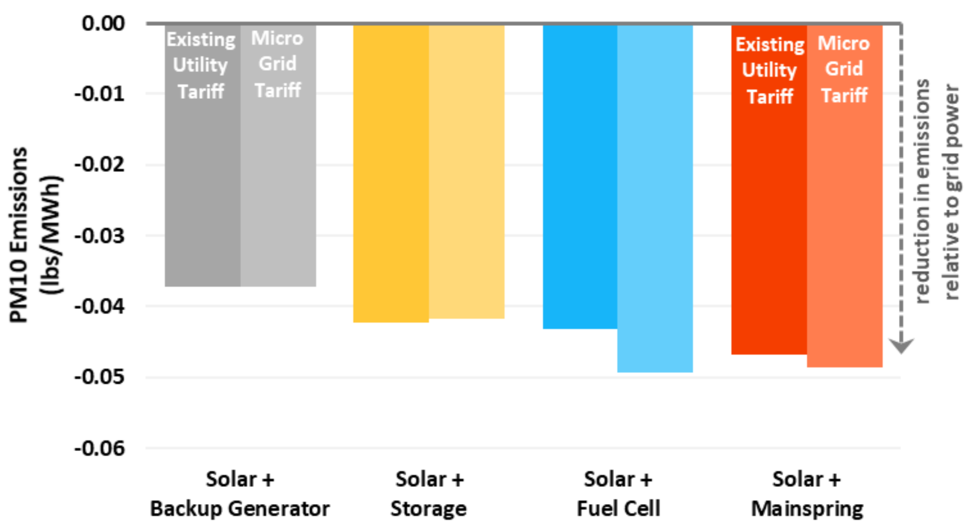


Figure 18: Lifecycle PM10 Emissions – School



It is important to note that while this whitepaper assumes the Mainspring linear generator is powered by natural gas, it should be noted that it can dynamically switch from natural gas or biogas and hydrogen, providing further emission benefits. This is in contrast to commercially available fuel cells, which are designed to only run on one type of fuel and would require retrofit to switch fuels.

Benefits of Firm Generation

The economic results of this whitepaper clearly demonstrate the economic infeasibility of providing reliable microgrid power for a multi-day (72-hr) period using only solar + battery storage. Instead, some type of firm generation is needed that can dispatch for prolonged periods of time without running out of charge. A backup generator, fuel cell, or the Mainspring linear generator are all capable of providing this firm generation. The need for firm generation is not unique to this whitepaper and these findings are consistent with other studies analyzing the larger California grid.[7]

While the Solar + Storage configuration does provide approximately 15% more greenhouse gas emission savings compared to the Solar + Backup Generator scenario, these savings come at great expense. For the school microgrid configuration, the Solar + Storage scenario results in $6.2 million in incremental net cost to the customer relative to the Solar + Backup Generator scenario while resulting in only 1,300 tons of incremental greenhouse gas reductions. From the customer's perspective, the cost of these emission reductions is $4,800/ton, over 200x higher than the current California cap and trade price on greenhouse gas emissions.

In practice, it may be beneficial to construct a microgrid using combinations of multiple technologies from this analysis. In any case, this whitepaper highlights the important role that firm generation will play in any reliable microgrid configuration. The Mainspring linear generator is one such option that can provide reliability and economic benefits while still providing net environmental benefits relative to California.

[7] https://www.ethree.com/wp-content/uploads/2019/06/E3_Long_Run_Resource_Adequacy_CA_Deep-Decarbonization_Final.pdf

5. Appendix

Financial Assumptions

Table 2: Key Financial and Operating Assumptions

Item	Solar	Battery	Fuel Cell	Backup Gen	Mainspring
Heat Rate Higher Heating Value	N/A	N/A	6.745 MMBtu/MWh	N/A[8]	8.416 MMBtu/MWh
Installed Cost Capital + Installation	$1,667/kW	$177/kW + $324/kWh[9]	$6,550/kW	$676/kW	$2,800/kW
Fixed O&M	$11/kW-yr	$20/kW-yr	$0/kW-yr	$10/kW-yr	$0/kW-yr
Variable O&M	$0	$0	$40/MWh	$10/MWh	$2.50/run-hr
Lifetime	30 yrs	10 yrs	20 yrs	20 yrs	20 yrs
Federal Investment Tax Credit (2022)	26%	26%	26%	N/A	N/A

Solar and fuel cell costs are based on the Lazard Levelized Cost of Energy Analysis (version 11.0) while the cost of battery storage is based on the Lazard Levelized Cost of Storage Analysis (version 6.0). All costs have been adjusted downward by to account for expected cost declines through 2022 (the year of the microgrid installation) using cost forecast trajectories from the National Renewable Energy Laboratory Annual Technology Baseline (ATB) 2020 report.

Battery Cost Sensitivity

While this report uses best-available publicly-available data to characterize the cost of battery energy storage, there is significant uncertainty about how these costs will evolve over time. To that end, E3 evaluated a sensitivity case to assess the economics of solar + storage if battery pack costs were to decline to $100/kWh, a long-hailed landmark number within the industry. It

[8] Operation of backup diesel generator for customer economics is assumed to be incompatible with local air quality restrictions, so diesel generator does not run outside of grid outage events.

[9] Energy storage capital costs are based on both the power capacity (kW) and energy capacity (kWh) of the battery. See Table 1 for details on the energy and power capacity configuration for both the supermarket and school batteries. Total capital costs are calculated using the following formula (kW power capacity * $/kW capital cost + kWh energy capacity * $/kWh capital cost).

is important to note that cost declines to this level represent only the costs of the battery packs themselves, not other costs such as inverters, balance of system costs (BOS), and engineering, procurement, and construction (EPC). These costs would also likely only be achievable in utility-scale battery installations that can take advantage of significant economies of scale not available to the commercial school and supermarket analyzed in this study. To that end, E3 represented a "$100/kWh" battery pack cost scenario with a $177/kW power capacity cost + $150/kWh energy capacity cost, justified with the following rationale:

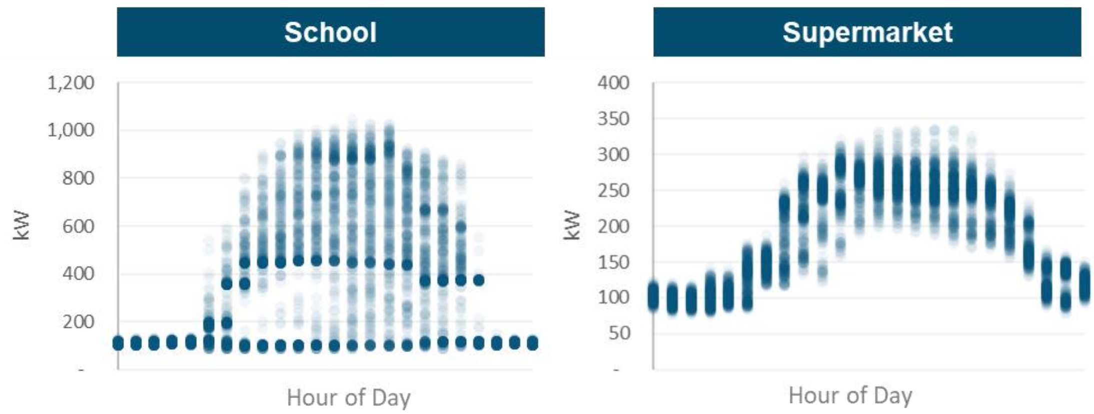
+ $177/kW power capacity: inverter costs, balance of system costs, and engineering, procurement, and construction costs are not likely to be affected by a reduction in battery pack costs
+ $150/kWh energy capacity: smaller economies of scale for commercial customers account for approximately a 50% premium over utility-scale installations which is consistent with the latest publicly-available data from Lazard

Even with this lower battery cost sensitivity, solar + storage was still significantly uneconomic with the NPV values ranging from -$740,000 to -$784,000 for the supermarket and -$707,000 to -$980,000 for the school. This shows that the general conclusions of this paper hold even if battery costs were to decline significantly more than currently projected.

Key Assumptions

Hourly 8,760 electricity load profiles were gathered from the U.S. Department of Energy OpenEI database for both the secondary school and supermarket customer types for Napa, California. Figure 19 shows the distribution of hourly electricity loads for each customer type across the year.

Figure 19: Distribution of Electricity Loads by Hour

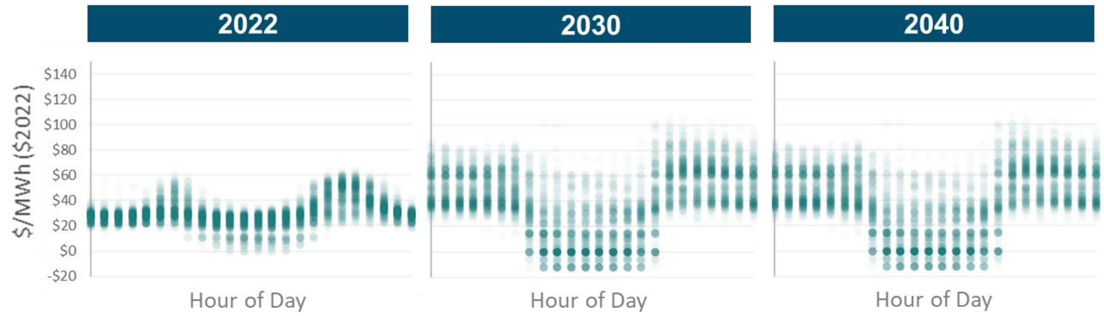


Hourly 8,760 solar profiles were gathered from the National Renewable Energy Laboratory System Advisor Model (SAM) for Napa, California. The analysis assumes a fixed-tilt racking system, 20° tilt, 1.2 inverter loading ratio, and 96% inverter efficiency which yields an 18% capacity factor. Figure 20 shows the distribution of hourly solar generation across the year.

Figure 20: Distribution of Solar Generation by Hour

This whitepaper uses a projection of California Independent System Operator (CAISO) hourly energy prices as an input into the Microgrid tariff compensation structure. These prices were developed by E3 using the AURORA production simulation model and reflect expected future market dynamics including increasing renewable and storage resources that are consistent with California's aggressive greenhouse gas reduction targets. While hourly energy prices were developed for each year of the analysis period (2022-2041), Figure 21 shows a distribution of these values for three snapshot years.

Figure 21: Distribution of Hourly CAISO Day-Ahead Energy Market Prices for Snapshot Years



These hourly market price forecasts were in part based on a forecast of natural gas prices and California cap and trade greenhouse gas emission prices. E3 used a natural gas price forecasted based on the latest natural gas price forward curve (pulled from SNL) transitioning to a long-term price forecasted from the U.S. Energy Information Agency by 2040. These prices rise from approximately $3.00/MMBtu ($2022) in 2022 to $4.00/MMBtu ($2022) by 2040. E3 assumed California cap and trade prices would trade at the floor price through 2040, in large part due to the large emission reductions pursued outside of this program. Carbon prices rise from approximately $20/metric ton ($2022) in 2022 to $46/metric ton ($2022) in 2040.

E3 assumed that both the secondary school and supermarket customer would take service from Pacific Gas & Electric on the medium general demand-metered time-of-use electricity tariff. The current B-19 tariff is provided in Table 3 and is assumed to escalate at 3%/yr nominal (1%/yr real) which is consistent with long-term California electricity retail rate forecasts.[10]

Table 3: B-19 Pacific Gas & Electric Tariff

Tariff Component	Charge
Customer Charge	$4.77/meter-day
Demand Charges	
Summer Peak	$25.79/kW-month
Summer Part-Peak	$5.30/kW-month
Summer	$21.44/kW-month
Winter Peak	$1.77/kW-month
Winter	$21.44/kW-month

[10] https://www.ethree.com/wp-content/uploads/2019/06/E3_Long_Run_Resource_Adequacy_CA_Deep-Decarbonization_Final.pdf

Energy Charges	
Summer Peak	$0.16520/kWh
Summer Part-Peak	$0.13541/kWh
Summer Off-Peak	$0.11434/kWh
Winter Peak	$0.14628/kWh
Winter Off-Peak	$0.11426/kWh
Winter Super Off-Peak	$0.07130/kWh

Additionally, the Mainspring linear generator configurations were subject to a standby reservation charge of $8.45/kW-month applied to 85% of reservation capacity, consistent with the PG&E SB tariff. This charge was also escalated at 3%/yr nominal.

Data Sources

- Bloom Energy. (2019). *Energy Server 5 Product Datasheet*.
- EIA (U.S. Energy Information Administration). (2020). *Annual Energy Outlook 2020 National Energy Modeling System*.
- Lazard. (2020). *Lazard's Levelized Cost of Storage Analysis – Version 6.0*.
- Lazard. (2017). *Lazard's Levelized Cost of Energy Analysis – Version 11.0*.
- NREL (National Renewable Energy Laboratory). (2020). *2020 Annual Technology Baseline*. Golden, CO: National Renewable Energy Laboratory.
- NREL System Advisor Model (SAM) Solar Profile Simulator
- Department of Energy OpenEI database of commercial and residential hourly load profiles for all TMY3 locations in the United States

E3's Renewable Energy Storage (RESTORE) Model

RESTORE is a sophisticated energy dispatch optimization tool that calculates hourly market revenues for various dispatchable energy assets, including traditional resources, energy storage, and more. RESTORE maximizes revenues across multiple potential value streams including customer energy charges, customer demand charges, and utility values (energy, carbon, distribution capacity, generation capacity, transmission capacity) as applicable in the Microgrid tariff. RESTORE's revenue maximization is constrained by co-optimizing the potentially competing performance requirements for monetizing the various potential value streams. A set of sample RESTORE dispatch plots from this analysis for the school customer is provided in Figure 22 and Figure 23.

Figure 22: Sample RESTORE Dispatch – 2030 – School – Existing Utility Tariff

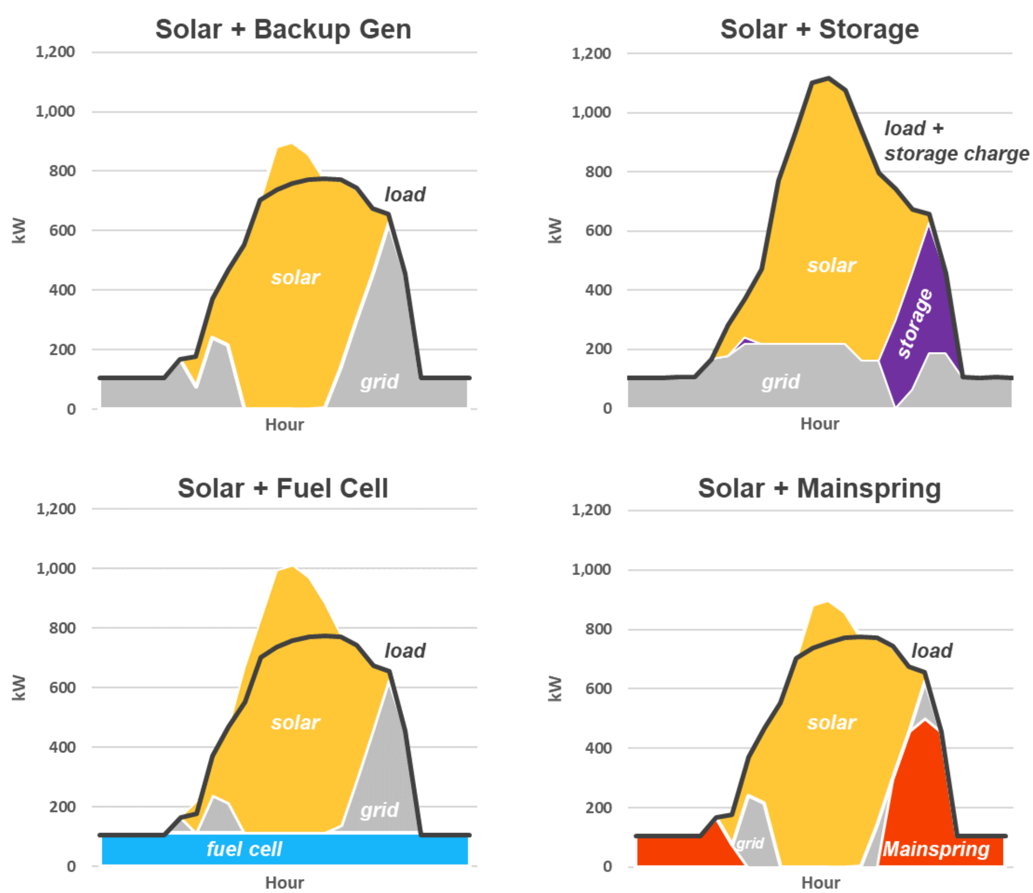


Figure 23: Sample RESTORE Dispatch – 2030 – School – Microgrid Tariff