RESIDENTIAL FUEL CELL MARKET POTENTIAL AND COST EFFECTIVENESS STUDY

Final Report

Submitted to:
Southern California Gas Company

Prepared by:
Verdant Associates, LLC

Verdant Associates, LLC
Berkeley, CA 94707
www.verdantassoc.com

September 18, 2025

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TABLE OF CONTENTS

VERDANT

VERDANT

LIST OF FIGURES

VERDANT

LIST OF TABLES

VERDANT

GLOSSARY

Term	Definition
Anode	The negative electrode in a fuel cell or battery where oxidation occurs, releasing electrons into the external circuit.
Avoided Costs	The costs that a utility avoids or incurs as a result of the installation of distributed energy resources (DERs), such as reduced energy procurement, transmission, or environmental compliance costs. These are quantified using the California Public Utilities Commission's Avoided Cost Calculator (ACC).
Baseload	A baseload represent the minimum, constant load that a home will see throughout the year. A fuel cell that operates at a constant output will be sized to offset the home's baseload.
BCR (Benefit-Cost Ratio)	A metric used in cost-effectiveness testing that compares the present value of total benefits to total costs. A ratio above 1 indicates net positive value.
Bill Savings	The increase or reduction in a customer's utility bill costs, due to increased or decreased energy usage or energy exports.
Cathode	The positive electrode in a fuel cell or battery where reduction reactions occur, consuming electrons from the external circuit.
Electrolyte	A substance or membrane in a fuel cell or battery that conducts ions between the anode and cathode while preventing electron flow, enabling electrochemical reactions.
Equity Investment	The portion of upfront capital costs for a project that is financed directly by the system owner or investor, rather than through loans or third-party financing.
Load Following	A fuel cell that is load following can quickly increase and decrease the amount of energy it generates to match the home's load.
Load Shape	A profile representing electricity consumption or generation over time, typically shown as hourly data across a full year, used to evaluate demand patterns and resource impacts.
Net Billing Tariff	A utility rate structure where exported energy is compensated at a specified rate, and imported energy is charged separately, aligning compensation more closely with grid value than traditional net metering.
Net Finance Costs	The net cost of financing, including interest paid on loans or leases for energy systems, minus any incentives or tax credits that offset financing expenses.
Net Present Value (NPV)	A financial metric that represents the present value of future cash flows (both costs and benefits), discounted over time to account for the time value of money.
NOx (Nitrogen Oxides)	A group of pollutant gases composed of nitrogen and oxygen, commonly emitted during combustion, and known for contributing to smog and respiratory problems.
O&M Costs (Operations and Maintenance Costs)	Ongoing expenses that are required to operate and maintain energy systems, including equipment servicing, monitoring, and repair. These do not include fuel costs.
PCT (Participant Cost Test)	A cost-effectiveness test that evaluates the economic impacts of a program from the customer's perspective, considering technology acquisition costs and bill impacts.
PEMFC (Polymer Electrolyte Membrane Fuel Cell)	A type of fuel cell that uses a solid polymer electrolyte and operates at low temperatures, commonly used in transportation and residential applications.

Term	Definition
PM (Particulate Matter)	A type of air pollutant consisting of tiny solid or liquid particles, including dust, soot, or smoke, which can harm human health when inhaled.
Renewable Natural Gas (RNG)	Renewable Natural Gas is used to describe biogas that has been upgraded for use in place of fossil natural gas and injected into the pipeline to replace natural gas.
Resiliency Benefits	A metric quantified to represent the monetary amount a customer would pay to ensure reliable power.
SB (Senate Bill)	A legislative measure introduced in the California State Senate; often referenced with a number (e.g., SB 100) to track energy-related policy.
SOFC (Solid Oxide Fuel Cell)	A high-efficiency, high-temperature fuel cell that uses a solid ceramic electrolyte and is suitable for stationary power generation.
SOx (Sulfur Oxides)	Gases composed of sulfur and oxygen, primarily sulfur dioxide (SO_2), produced from burning fossil fuels, contributing to acid rain and health issues.
SPM (Standard Practice Manual)	A key document used by the California Public Utilities Commission to guide the evaluation of energy efficiency and distributed energy resources through standardized cost-effectiveness tests.
Total Resource Cost (TRC) Test	A cost-effectiveness test that evaluates a program's overall economic efficiency by comparing all costs and benefits, regardless of who pays or receives them.
Total System Benefits (TSB)	A metric that summarizes the impact of the fuel cell on the avoided costs, or the marginal cost a utility would avoid in any given hour, if the distributed energy resource provided power instead of the utility
VOCs (Volatile Organic Compounds)	A category of organic chemicals that easily become vapors or gases, contributing to air pollution and smog formation; often emitted during combustion or from solvents.

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1 EXECUTIVE SUMMARY

Residential fuel cells have yet to achieve mainstream adoption in the United States due to several key challenges, including high production costs, constantly evolving energy policies, and a lack of companies producing, marketing, and selling these products. Unlike solar photovoltaic (PV) systems, which have overcome similar barriers decades ago due in part to federal funding and research which raised public awareness, fuel cells must also contend with growing policy momentum toward decarbonization and zero-greenhouse gas emissions targets, particularly in states like California that are exploring strategies to right-size natural gas infrastructure. California's Senate Bill 100 (SB100) further accelerates this shift by mandating 100% clean electricity by 2045, creating additional challenges for gas-dependent technologies like fuel cells.

Despite these challenges, residential fuel cells offer distinct benefits that may make them a compelling option in specific scenarios. Their modular design allows for scalable applications, ranging from medium residential to four-plex and large multifamily properties. Fuel cells provide reliable, continuous power independent of grid fluctuations, operate with low noise due to the absence of moving parts, and achieve electrical conversion efficiencies of up to 60%—which can exceed 90% when integrated with heat recovery. Additionally, they produce no harmful pollutants such as nitrogen oxides (NOx) or particulate matter (PM), making them a cleaner alternative to combustion-based generation.

Widespread adoption, however, remains constrained by high capital costs, with residential system costs as high as $30,000 or more for a 1.5 kW residential unit. Additional expenses include filter replacements, maintenance, and stack replacements (which are estimated at 35% of initial costs), as well as potential financing costs. Limited market awareness and a shortage of trained installers further slow adoption in the U.S.; In Japan and Europe, residential fuel cells have seen greater success, due to government backed subsidies, marketing, and the rising costs of electricity after the Fukushima disaster, combined with higher thermal needs. Japan has also faced electricity resiliency issues resulting from the Fukushima disaster, which lead to an energy shortfall as Japan began shutting down nuclear power plants. This increased the popularity of residential fuel cells as they provided power to residents during outages.

To better understand the potential for residential fuel cells in California, Southern California Gas Company (SoCalGas) and San Diego Gas and Electric (SDG&E) engaged Verdant Associates to research opportunities for residential fuel cells, including understanding current market conditions and trends, quantifying impacts on electrical and gas loads in a home, and analyzing the benefits of recovering heat to be used for domestic hot water heating (DHW) and pool heating. To address these key questions, Verdant performed market research that included literature reviews and in-depth interviews. We then analyzed 73 different scenarios which factored in the following:

- **Home Types:** Smaller single-family homes, larger single-family homes, multifamily 2-4 units, and large multifamily common areas.
- **Climate Zones:** Inland climate zones such as 6 and 13, and coastal climate zones such as 7 and 15.
- **Electrical and Gas Utility Rates:** Using SDG&E, SCE, and SoCalGas residential electric and gas rates.
- **Cost Levels:** Comparing estimates for different equipment costs, along with future cost scenarios under ideal market conditions based on manufacturer estimates and pricing.
- **Fuel Cell Manufacturer Specifications:** Including manufacturer claimed electrical and thermal efficiencies, effective useful life assumptions, estimated operations and maintenance intervals and costs, and whether the fuel cell recovers useful heat for DHW/pool heating.
- **Incentive Levels:** Based on historical incentive levels from the Self Generation Incentive Program (SGIP) for both natural gas and renewable fuel generation technologies, and federal tax credits such as the IRA.
- **Benefits of Resiliency:** The analysis included a resiliency benefit to the customer, which quantified differing values of resiliency for customers.
- **Additional Equipment:** Some scenarios incorporated the effects of solar PV or battery storage equipment, to determine how fuel cells would perform when combined with other generation or storage equipment.

Verdant calculated the fuel cell's cost effectiveness for the 73 different scenarios that were created by combining the variables listed above. We then reviewed the findings to understand the share of the California population that may benefit the most from the installation of residential fuel cells.

This study used Verdant's Distributed Energy Resource Cost-Effectiveness Analysis Tool (DER-CAT) model, to assess cost effectiveness. The model accounts for financial impacts, lifetime bill savings, acquisition costs, generation and consumption load profiles, and cost-benefit calculations using California's Standard Practice Manual tests. While our analysis looked at the Participant Cost Test (PCT), Total Resource Cost Test (TRC), and Total System Benefit (TSB), we highlight the PCT costs and benefits in many situations. To achieve a saturated market, residential fuel cells must receive buy-in from the consumer directly, and without a cost-effective solution these results will be difficult to achieve. Similarly, we calculated a customer payback (in years) to understand how long it would take for a system to pay itself off. Results vary significantly across the 73 different scenarios analyzed, but the most beneficial scenarios, from the participant's perspective, provide PCT results between 1.13 and 1.87 and equipment paybacks between 4.9 and 9.5 years. The results for these most beneficial PCT scenarios are highlighted below in Figure 1-1. While there are many scenarios where the PCT results are well above 1.0, none of the 73 scenarios we received showed TRC results that exceeded 1.0, mostly ranging between 0.20 and 0.35. More about the benefit-cost ratio (BCR) methodology can be found in Section 4.

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FIGURE 1-1: MOST BENEFICIAL SCENARIOS – PCT, PAYBACK, AND TRC RESULTS

Climate	CHP	Home Type	Load Shape	Tech	Inc.	Resiliency Benefit [$]	PCT Ratio	Payback [Yrs]	TRC Ratio	Utility
Inland	Y	SF-Lrg.	LF	FC	Y	$71	1.87	4.9	0.30	SD&GE
Coastal	Y	SF-Lrg.	LF	FC	Y	$71	1.81	5.1	0.31	SD&GE
Inland	Y	SF-Lrg.	LF	FC	N	$1091	1.74	6.9	0.33	SoCalGas/SCE
Coastal	Y	SF-Lrg.	LF	FC	N	$87	1.67	5.8	0.29	SD&GE
Coastal	Y	SF-Lrg.	LF	FC	N	$71	1.66	5.8	0.29	SD&GE
Coastal	Y	SF-Lrg.	LF	FC	N	$1091	1.61	7.8	0.31	SoCalGas/SCE
Inland	Y	SF-Lrg.	LF	FC	Y	$126	1.59	6.0	0.36	SoCalGas/SCE
Coastal	N	MF	LF	FC	N	$141	1.52	6.4	0.28	SD&GE
Coastal	N	MF	Base	FC	N	$0	1.50	6.4	0.25	SD&GE
Inland	Y	SF-Lrg.	LF	FC	N	$87	1.49	6.6	0.28	SD&GE
Inland	N	MF	Base	FC	N	$0	1.48	6.5	0.25	SD&GE
Inland	Y	SF-Lrg.	LF	FC	N	$71	1.48	6.6	0.28	SD&GE
Inland	Y	SF-Lrg.	LF	FC	N	$126	1.46	6.9	0.33	SoCalGas/SCE
Inland	N	MF	LF	FC	N	$141	1.46	6.7	0.27	SD&GE
Coastal	Y	SF-Lrg.	LF	FC	Y	$126	1.45	6.8	0.34	SoCalGas/SCE
Coastal	N	SF-Lrg.	LF	FC	N	$71	1.39	7.3	0.24	SD&GE
Inland	N	MF	LF	FC	N	$252	1.35	7.5	0.32	SoCalGas/SCE
Inland	Y	SF-Sm.	LF	FC	N	$71	1.35	7.5	0.26	SD&GE
Coastal	Y	SF-Lrg.	LF	FC	N	$126	1.33	7.8	0.31	SoCalGas/SCE
Coastal	Y	SF-Sm.	LF	FC	N	$71	1.31	7.8	0.26	SD&GE
Coastal	Y	SF-Lrg.	Base	FC + Strg.	N	$0	1.28	7.9	0.23	SD&GE
Inland	Y	SF-Lrg.	Base	FC + Strg.	N	$0	1.26	8.1	0.23	SD&GE
Inland	N	SF-Lrg.	LF	FC	N	$71	1.24	8.4	0.23	SD&GE
Inland	N	MF	Base	FC	N	$0	1.24	8.3	0.27	SoCalGas/SCE
Coastal	N	MF	Base	FC	N	$0	1.23	8.4	0.27	SoCalGas/SCE
Inland	Y	SF-Sm.	LF	FC	N	$126	1.18	9.2	0.30	SoCalGas/SCE
Inland	N	SF-Lrg.	LF	FC	N	$126	1.17	9.3	0.27	SoCalGas/SCE
Coastal	N	MF	LF	FC	N	$252	1.16	9.3	0.29	SoCalGas/SCE
Inland	N	SF-Sm.	LF	FC	N	$71	1.13	9.5	0.22	SD&GE

SD&GE ■ SoCalGas/SCE

* The figure above shows only the most beneficial scenarios from the perspective of the participant. For a full list of results for all 73 scenarios, see Appendix A.

** CHP Column represents whether the fuel cell recovers heat (Yes or No). Load Shape column represents whether the fuel cell is load following (LF) or baseload (Base). Tech column represents whether the scenario modeled just fuel cells, or fuel cell and battery storage. Inc. column represents whether the scenario considers incentives (Yes or No).

Scenarios with the most favorable PCT ratios generally have the lowest payback (in years) and tend to include homes with the largest energy loads (both electrical and thermal), equipment that recovers heat, equipment with lower upfront costs, and equipment that can follow load. More about this can be found in Section 5 in this report, but several key findings from our analysis include:

- Residential fuel cells installed at larger homes (≥13,000 kWh usage/year) achieve greater cost-effectiveness (especially from a participant's perspective) due to higher baseload energy use,
- Integrating heat recovery improves system economics, especially for properties with pool heating or high domestic hot water (DHW) demand.

- Many residential fuel cells can act as a backup generator to a home, providing power to the home even in the event of a power outage, providing significant benefits for customers that are often affected by outages. There is a range of research highlighting the value of resiliency and what it is worth to a consumer, and customers in high fire threat districts (HFTDs) may often prioritize resiliency, even when fuel cells are not cost-effective solely as backup power.
- Load-following fuel cells provide better financial returns than systems designed for offsetting a home's baseload, as a fuel cell offsetting a homes' baseload will only be sized to a home's minimum load which is often as low as only 500W.
- Retail rates significantly impact viability—customers with the highest electric retail rates, such as those served by SDG&E, see greater bill savings benefits,
- Incentives can also play an important role in reducing payback periods, particularly for low-income households and small multifamily properties.

Verdant also evaluated the impact associated with recovering heat from an existing residential fuel cell through the installation of heat exchangers and storage tanks. The TRC was calculated, representing the cost effectiveness from society's point-of-view, and factors in the avoided cost benefits of the new equipment (due to a reduced gas water heating load at a facility), as well as the upfront cost of the system and the ongoing O&M associated with the new equipment. This option also showed cost-effective potential, with the TRC results ranging from 1.07 - 1.26 as shown below in Table 1-1, depending on the climate zone and the gas utility.

TABLE 1-1: CALCULATED TRC FOR AOE CHP EQUIPMENT

Utility	Climate Zone	Gas Avoided Costs [NPV]	AOE Cost	O&M [NPV]	TRC
SoCalGas	**CZ6**	9,141	$6,249	$1,708	1.15
SoCalGas	**CZ13**	9,994	$6,249	$1,708	1.26
SDG&E	**CZ7**	9,777	$6,249	$1,708	1.23
SDG&E	**CZ15**	8,503	$6,249	$1,708	1.07

More about this can be found in the sidebar in Section 5.2, under the header *Impact of Combined Heat and Power.*

Achieving increased adoption of residential fuel cells will likely require targeting certain residential populations who will receive the most benefit from installing this equipment, such as high-energy-use homes, properties with heat recovery potential such as customers with pool heating or large DHW loads, and outage-prone regions and customers with resiliency needs, such as those in High Fire Threat Districts or on Medical Baseline programs. Finally, policymakers should consider developing incentive programs to mitigate capital costs, particularly for customers in disadvantaged communities and small multifamily units and expanding consumer education and workforce training to increase market awareness and installer availability.

Residential fuel cells have the potential to support California's clean energy goals by improving grid reliability, reducing transmission losses, and providing homeowners with a resilient power source. However, targeted policies, financial incentives, and increased consumer education will be necessary to overcome existing barriers and drive wider adoption.

2 INTRODUCTION

2.1 TECHNOLOGY BACKGROUND

Fuel cells generate electricity through an electrochemical reaction. At the most basic level, the technology consists of two electrodes – an anode (negative electrode) and a cathode (positive electrode) – on either side of an electrolyte. The anode is fed fuel while the cathode is fed oxygen or air. A catalyst separates molecules into protons and electrons. Electrons create the flow of electricity while the protons merge with the oxygen from the air and electrons to produce water and heat. Because fuel cells generate electricity through chemistry rather than through combustion, they can achieve much higher efficiencies than other generation technologies while minimizing emissions resulting from the combustion process.

Many fuel cells in the market today can be operated on different fuels, including natural gas, propane, biogas, syngas, and hydrogen. Fuel cells that are supplied by non-hydrogen fuels require an additional step, utilizing a reformer that extracts the hydrogen molecules from the methane fuel. This study focuses on fuel cells that operate on natural gas.

2.2 SCOPE OF STUDY

This study was prepared by Verdant Associates and commissioned by SoCalGas and SDG&E as part of the SoCalGas 2021 EM&V Roadmap. The study answered the following questions:

Residential Fuel Cell Technology:

- What is the current state of natural gas fuel cell technology for residential stationary systems?

Residential Applications – Benefits and Market Potential:

- What are the benefits from fuel cells, and how do they differ by operating mode?
- What are the energy efficiency benefits from using recovered waste heat to meet domestic hot water (DHW) and pool heating requirements in single family and multi-family situations and what are those quantifiable benefits?
- What is the suitability and market potential for these systems in the residential sector?

System Costs, Market Pricing, and Cost Effectiveness:

- What are the residential fuel cell costs and the projected mature market pricing?
- What is the cost effectiveness of residential fuel cells as measured by the Total Resource Cost (TRC) test, the Participant Cost Test (PCT), and the Total System Benefits (TSB)?

Grid Impacts and System Performance:

- What are the system specifications, including full cycle efficiencies, based on currently available equipment compared with other electric generation sources in the field today?

Technical, Safety, Market Barriers, and Next Steps:

- What are the technical, safety, and perceived market barriers that must be overcome to bring this technology into the mainstream marketplace, and what are the next steps for California?

2.3 STUDY METHODOLOGY

The study focused on four primary activities:

Literature Reviews: The purpose of literature reviews and secondary research was to build on recent analysis that has been conducted in the industry related to the development and market characterization of residential fuel cells, as well as identifying experts, industry professionals, manufacturers, and program administrators that may be willing to share their insights. The outcome of this research gave our team an understanding of system specifications and recent technological advancements, and capital and operational costs (both forecasted and current).

Professional In-Depth Interviews: From the literature reviews, Verdant interviewed four manufacturers that sell residential fuel cells within the US as well as two industry professionals. Interview guides were developed which focused on the state of the industry, potential for the technology, barriers to the market, system costs, impacts, and technology benefits. These interviews were also used to gather information on system and installation costs, as well as system specifications for current units in the market, and help to inform and understand energy efficiency customer advantages and benefits of residential fuel cells.

Cost-Effectiveness Analysis: The cost effectiveness analysis looked at two metrics to measure cost-effectiveness, the PCT which analyzes cost effectiveness from a customer's point of view, and the TRC which analyzes cost effectiveness from society's' point of view. These two tests are based on the foundation of cost-effectiveness analysis for all demand side resources, and are based on the California Standard Practice Manual,[1] which contains the CPUC's method of evaluation energy saving investment using various cost effectiveness tests. An additional analysis looked at the TSB, which represents the net-benefits of the technology.

[1] California Standard Practice Manual. Economic Analysis of Demand Side Programs and Projects. October 2001. https://www.cpuc.ca.gov/-/media/cpuc-website/files/uploadedfiles/cpuc_public_website/content/utilities_and_industries/energy_-_electricity_and_natural_gas/cpuc-standard-practice-manual.pdf. Accessed March 3rd, 2025.

Market Characterization: Once the fuel cell research and cost-effectiveness scenario analyses were performed, the last step was to identify the market that would benefit the most from the installation of residential fuel cells. This analysis relied on data from the Residential Appliance Saturation Survey (RASS) data,[2] electric utility grid reliability reports, local weather data, and census data to identify the number of households across differing climate zones in SoCal Gas and SDG&E territory that meet the specifications in the cost-effective scenarios, from a participant's point of view.

[2] DNV GL Energy Insights USA, Inc. 2020. 2019 California Residential Appliance Saturation Study. California Energy Commission. Publication Number: CEC-200-2021-005-PO.

3 OVERVIEW OF FUEL CELL TECHNOLOGY

3.1 TYPES OF FUEL CELLS

There are several types of fuel cell technologies on the market today, but two technology types are largely used for stationary power: Solid Oxide Fuel Cells (SOFC) and Polymer Electrolyte Membrane Fuel Cells (PEMFC). The characteristics of these two technologies can be found below in Figure 3-1.

FIGURE 3-1: DIFFERENCES BETWEEN SOFC AND PEMFC FUEL CELLS

	Solid Oxide (SOFC)	Polymer Electrolyte Membrane (PEMFC)
Common Electrolyte	Yittria stabilized zirconia	Perfluorosulfonic acid
Operating Temperature	500° - 1,000°C	>120°C
Typical Stack Size	1 kW – 2 MW	<1 kW – 100 kW
Electrical Efficiency (LHV)	60%	60% direct H_2; 40% reformed fuel
Applications	Aux. Power, Electric Utility, Distributed Generation	Backup Power, Portable Power, Distributed Generation, Transportation, Specialty Vehicles
Advantages	High efficiency, fuel flexibility, solid electrolyte, suitable for CHP, hybrid/gas turbine cycle, suitable for continuous / baseline operation. Tubular designs allow for load following operation.	Solid electrolyte reduces corrosion & electrolyte management issues, low temperature, quick start-up and load following / intermittent operation
Challenges	High temperature corrosion and breakdown of cell components. Planar designs have long start up time, limited shutdowns.	Expensive catalysts, sensitive to fuel impurities

Source: U.S. Department of Energy. Office of Energy Efficiency and Renewable Energy. Hydrogen and Fuel Cell Technologies Office. Comparison of Fuel Cell Technologies.

Stationary fuel cells can be designed for baseload or to be load-following. Historically, load-following systems generally utilized PEMFC fuel cells, which have quicker start up abilities and are therefore able to be turned on and off to better align with the heating demand of the building. However, more recently SOFC systems have relied on a tubular stack design. Unlike their planar counterparts, tubular designs allow for better fuel utilization and thermal tolerances, making them better suited for load following applications. Baseload systems tend to use planar SOFC fuel cells which provide constant high electricity production with a much longer start-up time and a limited number of allowable shutdowns. All the fuel cells commercially available that we analyzed for this study were SOFC designs.

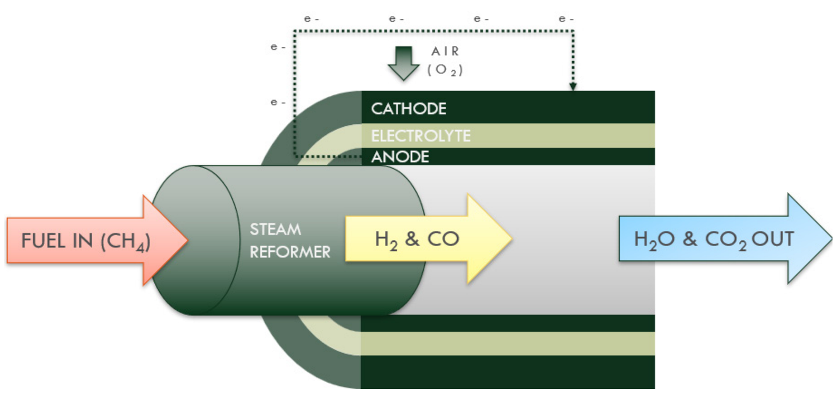
Other fuel cell technologies include direct methanol fuel cells, phosphoric acid fuel cells, alkaline fuel cells, molten carbonate fuel cells, and reversible fuel cells. These fuel cell types are not considered in this study, as they are not generally suited for, nor is anyone manufacturing these for residential applications.

3.2 TECHNOLOGY PRINICPLES

The technology behind fuel cells is based on electrochemical energy conversion, which transforms chemical energy into electrical energy, utilizing an electrochemical reaction between hydrogen and oxygen. This process avoids combusting the fuel and therefore does not release criteria pollutants such as nitrogen oxide (NO_x), sulfur dioxide (SO_x), volatile organic compounds (VOCs) and particulate matter (PM).

The basic structure of the fuel consists of three components; The **anode** which is the negative electrode (or electric conductor) is fed hydrogen and undergoes oxidation producing hydrogen ions and electrons, which are then fed to the external circuit. The ***cathode***, the positive electrode, is fed ambient air and acquires the electrons from the external circuit. The ***electrolyte*** is the medium that allows the ions to pass between the two electrodes, preventing direct electron transfer. Additionally, a steam reformer is required when the input fuel is something other than hydrogen, to separate out the hydrogen and carbon molecules.

FIGURE 3-2: TUBULAR SOFC DESIGN



In the tubular design, as shown in Figure 3-2, each tube is called a cell. Multiple cells are connected in a generator module or stack.

3.2.1 Fuel Cell Benefits

Several key factors set fuel cells apart from other electrical generation equipment requiring combustion technologies:

- **Modular Designs:** The fuel cell stack design allows for scalability, anywhere from small to large scale power applications.
- **Continuous Power Generation:** With a steady source of fuel, fuel cells can provide continuous power independently of grid fluctuations.
- **Low Noise:** Due to the absence of moving parts, the fuel cell operation makes very little noise, making them especially suitable for residential scenarios, or other applications where noise pollution may be a concern.
- **High Efficiencies:** The conversion rate from fuel to electricity can be up to 60%. In comparison, the electrical efficiency is closer to 30-40% for combustion generators. When utilizing heat recovery, these system efficiencies can reach 90% or higher.
- **Minimal Pollutant Emissions:** As there is no fuel being combusted, no criteria pollutants like NO_x, SO_x or PM are being produced.

3.2.2 Fuel Cell Challenges

At the same time, there are a number of challenges that fuel cells currently face:

- **High Costs:** For a residential home, capital costs for this equipment are still quite high. The upfront capital cost can exceed $30,000 for a 1.5 kW system, and the system will not fully offset the home's electrical load. In addition, these systems may require annual maintenance to replace filters, or a full stack replacement at least once during their lifetime. Typical stack costs have been quoted at around 30-35% of the initial capital costs. In some cases, a maintenance plan may be sold along with the fuel cell installation which may cover the cost of a fuel cell stack.
- **Durability and Reliability:** There are very few residential fuel cell manufacturers in the US today. The ones that exist typically have a lifetime between 10-15 years, but often also require a stack replacement at least once during this lifetime. These lifetimes are shorter than technologies like solar PV, although are similar to battery storage. There is one manufacturer that also sells a fuel cell that is designed exclusively for backup power or to minimize high power costs when the grid is expensive or stressed.
- **Regulatory and Policy Hurdles:** California is on a decarbonization pathway that increasingly relies on electrification of buildings and seeks to right-size the gas distribution system. These sort of decarbonization policies may cause difficulties for jurisdictions looking to create programs that aim to increase the use of natural gas appliances such as fuel cells, even if fuel cells may be able to increase grid reliability and avoid many grid-related transmission and distribution losses associated with utility-scale power generation.
- **Market Education:** There is limited awareness and understanding of fuel cells, especially in the residential sectors. Fuel cells could benefit from greater awareness in the United States, as the lack of knowledge surrounding this technology to the typical homeowner is likely a huge barrier to adoption. Additionally, there are limited numbers of organizations who can install and maintain this equipment.

4 METHODOLOGY AND APPROACH

Verdant calculated the cost-effectiveness of residential fuel cells using our DER-CAT model. The model calculates the bill impacts throughout the system lifetime and the associated acquisition costs including equity investments, financing, insurance, and tax costs (or credits). The model quantifies the present value of all cost and benefit streams for the entire life of the system accounting for customer electric and gas loads, retail rates, technology operating costs, and utility marginal costs.

The model's primary purpose is to evaluate the cost-effectiveness of customer-sited technologies using the California Standard Practice Manual (SPM) cost-effectiveness tests. The SPM describes the procedure to determine the cost-effectiveness of utility-sponsored programs. These test results are expressed in terms of a BCR or net benefits, comparing the benefits of installing the equipment to the costs of installing the equipment from various perspectives. From the SPM, the two tests chosen to analyze for this program include the Total Resource Cost (TRC) test and the Participant Cost test (PCT), the former evaluating cost-effectiveness of the technology from the point of view of society, while the latter evaluates cost-effectiveness from the point of view of the participant. As this technology is not yet widely adopted, and there are numerous market barriers associated with a lack of a current market and lack of knowledge about the technology, the PCT is the main focus of the effort, and is the more important test to consider in this case, given that any program geared towards residential fuel cells will have difficulty getting off the ground unless participants can be shown a significant benefit to installing the technology. Figure 4-1 below summarizes the costs and benefits associated with the two tests.

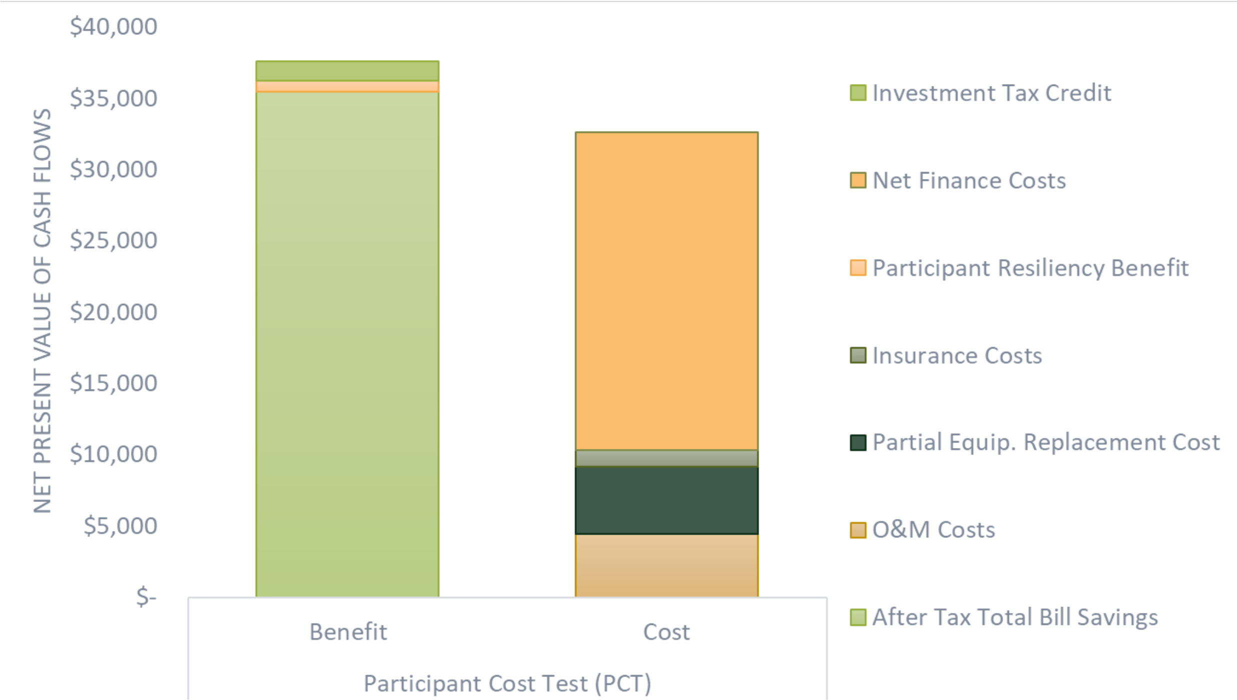
FIGURE 4-1: PCT AND TRC COSTS AND BENEFITS SUMMARY

	Participant Cost Test (PCT)		Total Resource Cost (TRC) Test	
	Benefit	Cost	Benefit	Cost
Avoided Costs				
Electric Avoided Costs			✓	
Gas Avoided (Incurred) Costs				✓
Biogas Avoided Costs			✓	
Bill Savings				
After Tax Total Bill Savings	✓			
Operating Costs				
O&M Costs		✓		✓
Partial Equip. Replacement Cost		✓		✓
Insurance Costs		✓		✓
Participant Resiliency Benefit	✓			
Finance Costs				
Net Finance Costs		✓		✓
Taxes				
Federal Tax Credit (IRA)	✓		✓	
After-Tax Equity Cash Flow				
Equity Investment		✓		✓
Utility Costs				
Total Gas Utility Costs				✓
Total Electric Utility Costs				✓

Participant Cost Test

The PCT is a measure of the quantifiable benefits and costs to the consumer due to their installation of a fuel cell. Participant test benefits include bill savings, state rebates, and any tax refunds or credits that may apply. Participant costs include capital, financing, and other expenditures associated with the installation and operation of the fuel cell. The PCT is primarily sensitive to the cost and the lifetime of the fuel cell, as well as the electric bill savings and gas bill increases associated with operating the equipment. The relationship between the fuel cell equipment cost and the PCT BCR is intuitive – as the system costs increase, the PCT BCR decreases. Figure 4-2 is an illustrative example of the PCT BCR calculation for a residential fuel cell.

FIGURE 4-2: PCT BENEFITS AND COSTS, ILLUSTRATIVE SCENARIO



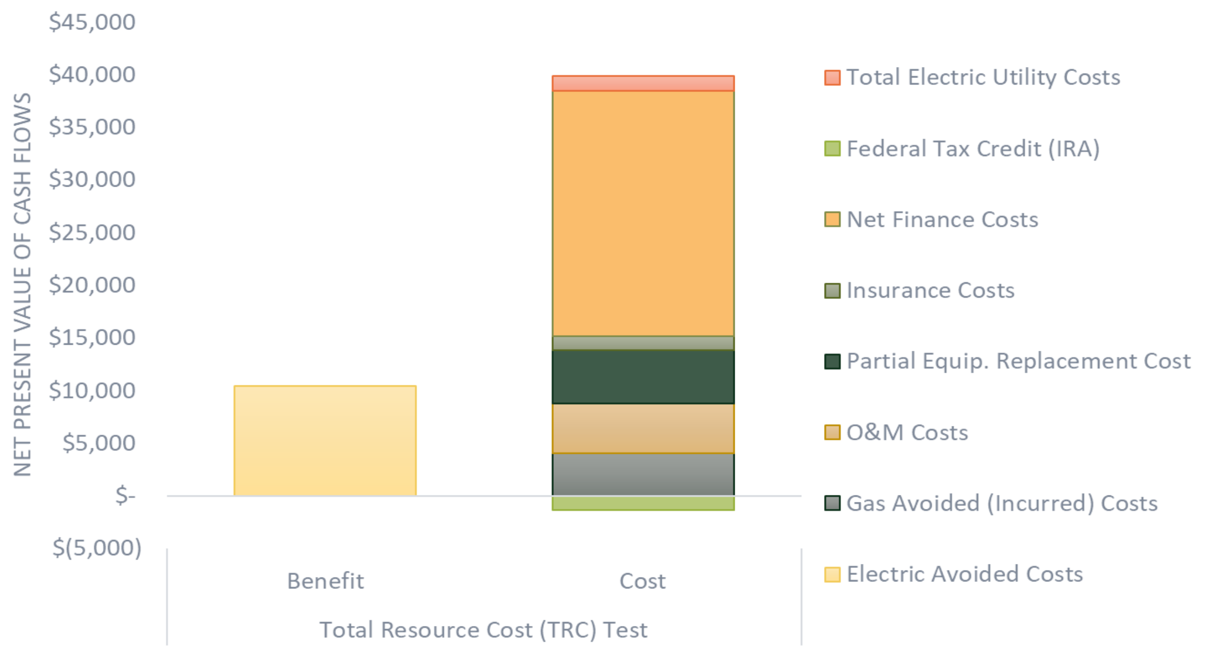
The largest portion of the PCT benefits, the after-tax total bill savings, are calculated as the summation of the electric bill savings and the gas bill increase, based on the difference between the electric bills prior to and after installing the fuel cell, and the difference between the gas bill prior to and after installing the fuel cell. These scenarios assume that there has been no change in electric or gas rates before or after, so the bill savings are a function of the volumetric usage and time-of-use portion of the bills.

The two largest categories of PCT costs include the net finance costs and the equity investment which combined, make up the financed and upfront capital costs related to acquiring the fuel cell.

Total Resource Cost Test

The TRC test measures the net costs of the fuel cell based on the total costs of the program, including both the participants' and the utility's benefits and costs. TRC test benefits include utility avoided costs and the federal income tax refund resulting from the acquisition and financing of the equipment. TRC costs include all expenditures associated with acquiring, installing, and operating the fuel cell (i.e., upfront capital costs, financing costs, ongoing O&M, insurance costs). The federal ITC is treated as a reduction in cost rather than a benefit. Future cash flows are discounted at the utility discount rate. Figure 4-3 displays an illustrative example of the TRC BCR calculation for a residential fuel cell.

FIGURE 4-3: TRC BENEFITS AND COSTS, ILLUSTRATIVE SCENARIO



The SPM calculation of TRC benefits is based solely on avoided costs and the inclusion of the Federal Tax Credit (which is included as a negative cost for modeling purposes), however, fuel cells also have to account for the incurred gas costs which reduce the impact of the electric avoided costs significantly. In this case, gas incurred costs are about 40% of the electric avoided costs, reducing the impact of the electric avoided costs by about 60%. On the Cost calculation, the upfront equipment costs are quite high for residential fuel cells, which, combined with other costs in the SPM calculation, outweigh the TRC calculation benefits of residential fuel cells. Fuel cells also suffer from a mid-life partial replacement cost. Typically, the system stacks need to be replaced once during their lifetime, which can be a significant cost to the customer.

Total System Benefit

As noted above in Figure 4-1, the Total System Benefit (TSB) shows the impact of the fuel cell on the avoided costs, or the marginal cost a utility would avoid in any given hour, if the distributed energy resource provided power instead of the utility. The calculation of the TSB factors in the electric avoided costs as well as the gas incurred costs, based on the 2024 Avoided Cost Calculator.[3] The value, reflected in dollars, is designed to provide a time-varying value of energy savings and greenhouse gas reduction benefits.

4.1 COST-EFFECTIVENESS INPUTS AND ASSUMPTIONS

The following section describes the model inputs and assumptions made when developing the different scenarios to be analyzed.

4.1.1 Fuel Cell Technology Characteristics and Costs

Fuel cells from four different manufacturers were modeled. Due to the small number of manufacturers, specifics for each of the manufacturers are not provided, but the following table highlights the range in characteristics and costs that are modeled.

TABLE 4-1: FUEL CELL TECHNOLOGY CHARACTERISTICS

Characteristic	Range
Electrical Efficiency	30% - 55%
System Efficiency	37.5% - 95%
Nameplate Rating	700W – 1.5 kW
Effective Useful Life (EUL)	10 years – 15 years
Capital Costs	$6,500 - $25,000
Operations and Maintenance (O&M) Costs	$250-$300 / year
Partial Stack Replacement Costs	$6,000 - $9,000

O&M costs were only provided by one manufacturer. No partial stack replacement costs were provided. The O&M costs provided, however, were consistent with alternative research suggesting that O&M costs were around 3 cents/kWh from a study by ICF in 2019,[4] which estimated O&M between 2.6 and 3.2

[3] 2024 Avoided Cost Calculator. https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/der-cost-effectiveness. Accessed 03/17/2024.

[4] ICF. *A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California*. California Energy Commission CEC-500-2019-030. March 2019

cents/kWh. Similarly, none of the manufacturers we spoke with would provide us details on partial or stack replacement costs, so these were assumed to equal 35% of the upfront capital costs.

4.1.2 Avoided Costs

The avoided costs used in this analysis are based on the CPUC 2024 Avoided Cost Calculator (ACC) v1b approved on November 13th, 2024. The analysis includes all components of the avoided costs included in the 2024 ACC:

Electricity

- Cap and Trade
- Greenhouse gas (GHG) Adder
- GHG Rebalancing
- Energy
- Generation Capacity
- Transmission Capacity
- Distribution Capacity
- Ancillary Services
- Losses
- Methane Leakage

Gas

- Market (Commodity)
- Transmission and Distribution
- Environment (CO_2-only, no NO_x)
- Upstream Methane Leakage
- Behind the Meter Methane Leakage
- Air Quality

For simplicity, we depict total electric avoided costs as a single sum of all electric avoided cost components for each utility and climate zone. Customer bills are calculated based on utility baseline territories, which do not always have the same boundary definitions as the California Energy Commission (CEC) building climate zones.[5] Table 4-2 shows our mapping of utility baseline territories to climate zones used for cost-effectiveness simulations.

TABLE 4-2: UTILITY BASELINE TERRITORY TO AVOIDED COST CALCULATOR CLIMATE MAPPING

Electric Utility	Utility Baseline Territory	Avoided Cost Calculator Climate Zone
SCE	6	CZ6
	13	CZ13
SDG&E	Coastal	CZ7
	Desert	CZ15

[5] California Building Climate Zones. https://www.buildingincalifornia.com/wp-content/uploads/2014/02/Building_Climate_Zones.pdf. Accessed 03/17/2024.

4.1.3 Baseline Load Shapes

Several different home types were modeled, each one requiring four different load shapes (one for each climate zone modeled). The load shapes were based on a small single-family home, a large single-family home, a multifamily fourplex, and a large multifamily common area. The load shapes were based on NREL's ResStock data (2022.1 Release),[6] which is a bottom-up model using multiple data sources, statistical sampling methods, and building energy simulations to develop load shapes for different residential homes across the US. The data were based on typical meteorological year (TMY3)[7] weather file data, and based on the following criteria:

Single-Family (Small)	**Single Family (Large)**	**Multifamily Fourplex**
Climate Zones: 6, 7, 13, 15 **Sq. Ft.:** 1,138 to 1,220 & 2,631 to 3,301 **Geometry:** Single-Family Detached	Climate Zones: 6, 7, 13, 15 **Sq. Ft.:** 5,587 to 6,348 **Geometry:** Single-Family Detached	Climate Zones: 6, 7, 13, 15 **Sq. Ft.:** All **Geometry:** Multifamily with 2-4 Units

The approach to developing the load shape for multifamily common areas was slightly different. There was not a good source of common area load shapes available, so we developed a common area load shape using the following sources and assumptions:

- RASS data from the latest (2019) study was used to develop annual loads for pool/spa heating and pool/spa pump, outdoor lighting, and clothes washers and dryers, and miscellaneous plug loads. Where available, the multifamily data were used, but where there was no data available, single-family data were substituted.
- End-use annual shapes came from the same NREL ResStock data described above for single family detached housing, for pool heating and pool pump loads, clothes washer and dryer loads, and miscellaneous plug loads.
- The end-use shapes from NREL were then adjusted by the overall annual load data from RASS, to come up with a multifamily calibrated end use load shape. The outdoor lighting load shape was

[6] National Renewable Energy Laboratory. ResStock. 2022.1 Release. https://resstock.nrel.gov/datasets#end-use-savings-shapes. Accessed March 17th, 2025.

The 2024.2 Release was also used to pull loadshapes for the larger sized single family homes.

[7] TMY data set provides designers and other users with a reasonably sized annual data set that holds hourly meteorological values that typify conditions at a specific location over a longer period of time, such as 30 years. More information can be found in the NREL User Manual.

S. Wilcox and W. Marion. *User Manual for TMY3 Data Sets.* NREL. May 2008. https://www.nrel.gov/docs/fy08osti/43156.pdf. Accessed 04/17/2025.

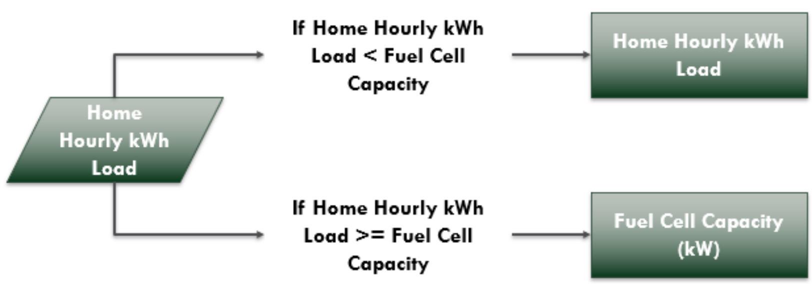
multiplied by 75 to represent 75 apartment units. The washer and dryer annual loads were multiplied by 15 to represent 15 separate washer and dryers at a multifamily complex.

- All of these end use load shapes were combined to represent a multifamily common area load shape.

4.1.4 Fuel Cell Generation, Heat Recovery, and Battery Storage Load Shapes

Fuel cell generation was modeled differently for baseload scenarios versus load following scenarios. For baseload scenarios, the fuel cell generation load shape was simulated as a constant output throughout the entire year, representing the home's minimum load, rounded to the nearest 0.5kW. For small single-family homes, 0.5 kW was used. For large multifamily homes, 1.0 kW was used.

Load-following fuel cell generation was based on the hourly load of the home and followed the logic on the right. When the total hourly electrical load of the home was less than the maximum fuel cell capacity, then the fuel cell output was equal to the home hourly kWh load, but when it was greater than the fuel cell capacity, then that hourly load was equal to the maximum fuel cell capacity.



The heat recovery model took a simplified approach, factoring in the electrical efficiency and total system efficiency of the fuel cell to calculate a total heat output. It also accounted for a heat recovery efficiency of 90% to account for the transfer of the heat from the fuel cell output to the water itself. The model assumed that when there was natural gas usage for DHW and pool heating, it was being offset by the heat output of the fuel cell. For multifamily common area scenarios, the waste heat was constantly being used by the pool to offset the pool heating. While this doesn't account for the fact that additional heat can be recovered and stored in a storage tank, the scenarios also did not account for the additional costs associated with any hot water storage tanks.

Finally, several fuel cell manufacturers design their systems with the ability to integrate with battery storage or solar PV. We ran several scenarios with battery storage as well as with both battery storage and PV. The battery storage load shapes assumed self-consumption mode, and charging from fuel cell outputs, so the battery would charge from any excess fuel cell output and then discharge to meet additional load that could not be met by the fuel cell and therefore minimize grid-provided electricity.

4.1.5 Retail Rates and Renewable Natural Gas Additional Costs

Each fuel cell technology was modeled in the electrical IOU service territories as producing electricity that would replace electricity valued at an IOU specific residential TOU rate. The rates chosen were based on the size of the customer typically owning a given technology and technology size. The electricity rates used to value electricity production are shown below but were also set to increase each year. The retail rate escalator was set at 4% per year.

TABLE 4-3: ELECTRIC AND GAS RATES USED TO VALUE ENERGY PRODUCTION

Load Shape	SCE - Electric	SoCal Gas – Gas	SDG&E - Electric	SDG&E – Gas
MF Common Area	TOU-GS1-E	GR	AL-TOU < 500kW	GR
All Others	TOU-D-4-9	GR	TOU-DR2	GR

A fuel cell operating on renewable natural gas (RNG) would be the most applicable and appropriate scenario in California's current regulatory landscape. However, unfortunately there is not currently an RNG rate that residential customers can apply for. Nonetheless, we modeled a potential future rate, assuming that soon residential customers in California will be able to purchase RNG on the wholesale market. These customers would pay the utilities a transportation cost, presumably based on the volume of gas that they would use. We assumed that an 80% RNG and 20% natural gas mixture would be available in the future, and that the added cost would be $1/therm. This RNG rate was modeled for two scenarios, one with an incentive and one without.

4.1.6 Incentives and Tax Credits

Two scenarios were modeled with a program incentive. The standard incentive was modeled at $2/W, which is equivalent to what Self Generation Incentive Program (SGIP) used to pay for non-renewable fuel cells. This resulted in an upfront $3,000 incentive for the 1.5 kW system modeled. There was an additional scenario analyzed which utilized renewable natural gas. In this scenario, an additional $2/W adder was included, to bring the total to $4/W, consistent with the SGIP when a renewable fuel was used.

While the Residential Clean Energy Credit equals 30% of the new, qualified clean energy property, fuel cells are specifically called out at being limited to $500 for each half kilowatt of capacity, and if multiple people live at the home, the combined credit for all residents can't exceed $1,667 for each half kilowatt of fuel cell capacity, therefore the fuel cell was capped at $1,667 for each half kilowatt of capacity.[8]

[8] IRS Residential Clean Energy Credit. https://www.irs.gov/credits-deductions/residential-clean-energy-credit. Accessed March 17th, 2025.

4.1.7 Financing and Insurance

Fuel cells can be financed using debt. In our model, fuel cells are assumed to be financed with equity and debt. As a simplifying assumption, we modeled with 30 percent equity upfront payment and 70 percent debt financing. We estimate a 5 percent cost of debt with a loan term equal to the EUL for use in the model. Loan interest payments are assumed to be not tax deductible.

4.1.8 Resiliency Benefit

A resiliency benefit was added for certain scenarios. This was based on a willingness to pay survey that Verdant performed as part of the 2021 SGIP Market Assessment[9] which developed a discrete choice model, presenting SGIP respondents with a series of questions to investigate their willingness to pay for battery storage. A statewide willingness to pay $/kWh value was calculated for residential customers who would be willing to pay both for whole house backup and a partial home backup system to support 30% of the home's electrical needs. The study suggested that customers are willing to pay between $8.81 - $24.96/kWh to ensure that they would have partial home resiliency in cases of outages. On average, this comes out to approximately $17/kWh that a customer would pay for resiliency, which we used for our model.

To support the willingness to pay analysis, we also looked at the average and maximum outages that have occurred over the last four years in the SCE and SDG&E service territories. The latest (2023) electric utility annual reliability reports include System Average Interruption Duration Index (SAIDI) calculations which measure the amount of time the average SCE customer experienced an outage or an interruption for more than 5 minutes. These reliability reports tabulate the SAIDI across each district in each IOU's service territory, over the last decade. In our case we looked at both the planned and the unplanned outages.

In addition to this, the reports also provide the district-level SAIDI for each year. To represent the highest potential resiliency benefit, we took the average maximum SAIDI across districts over the last four years.

[9] Verdant Associates. *2021 SGIP Energy Storage Market Assessment Study.* November 10th, 2022. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/self-generation-incentive-program/sgip-2021-market-assessment-study.pdf. Accessed March 17th. 2025.

TABLE 4-4: SCE & SDG&E AVERAGE SAIDI (LAST FOUR YEARS) AND WPC SAIDI

Utility	Average SAIDI	Maximum District SAIDI per Year
SCE[10]	297	2,566
SDG&E[11]	166	205

Finally, the average and maximum SAIDI (converted to hours) was multiplied by the average willingness to pay value listed above, of $17/kWh, and the multiplied by the kWh capacity of the fuel cell, shown in the algorithm below:

$$Resiliency\ Benefit = Willingness\ to\ Pay\ [\$] \times FC_{Capacity}\ [kW] \times \frac{SAIDI}{60}[Hours]$$

The result showed a range in resiliency benefits shown in Table 4-5 below. The standard resiliency is used for most scenarios. The range in values reflect the fuel cell capacity used in the different scenarios. The high resiliency value represents a single scenario.

TABLE 4-5: SCE & SDG&E RESILIENCY BENEFIT RANGE

Utility	Standard Resiliency	High Resiliency
SCE/SoCal Gas	$58 - $252	$1,091
SDG&E	$31 - $141	$87*

*SDG&E's high resiliency value is lower than the maximum standard resiliency value due to the assumptions on fuel cell capacity based on the different scenarios analyzed.

[10] SCE. *Annual Reliability Report. Calendar Year 2023.* July 15th, 2024. https://www.sce.com/sites/default/files/AboutUs/Reliability/Annual%20Reliability%20Report%202023.pdf. Accessed March 17th, 2025.

[11] SDGE. *Electric System Reliability Annual Report 2023.* July 15th, 2024. https://www.sdge.com/sites/default/files/SDG%26E%20Annual%20Electric%20System%20Reliability%20Report%20202407%20FINAL%20%282023%29.pdf. Accessed March 17th, 2025.

5 COST-EFFECTIVENESS ANALYSIS

The results from the 73 cost-effectiveness scenario analyses performed are presented throughout Section 5. The scenarios were designed to determine under what conditions a residential fuel cell would make the most sense, both from society's perspective and from the participant's perspective, as well as determine in which conditions a residential fuel cell does not make sense.

Table 5-1 shows the details of each scenario, organized by "group number." Each group number represents a specific scenario applied across all four climate zones.

TABLE 5-1: SCENARIO DESCRIPTIONS

Group #	Home Type	CHP	RNG & Export	Operation Type	Mfr. #	Incentive	Cost	Annual Resiliency	Tech.
1	MF2-4	No	No	Baseload	1	No	Actual	None	FC
2	MF2-4	No	No	Load Follow	3	No	Actual	Std.	FC
3	Common Area	Yes	No	Baseload	3	No	Actual	Std.	FC
4	SF-Small	No	No	Backup	2	No	Actual	Std.	FC
5	SF-Small	Yes	No	Baseload	3	No	Actual	None	FC+Storage
6	SF-Large	Yes	No	Baseload	3	No	Actual	None	FC+Storage
7	SF-Small	No	Yes	Baseload	1	No	Actual	None	FC
8	SF-Small	No	No	Load Follow	1	No	Actual	None	FC+Storage+PV
9	SF-Small	Yes	No	Load Follow	3	No	Actual	Std.	FC
10	SF-Large	Yes	No	Load Follow	3	No	Actual	Std.	FC
11	SF-Small	No	No	Load Follow	3	No	Actual	Std.	FC
12	SF-Large	No	No	Load Follow	3	No	Actual	Std.	FC
13	SF-Small	No	No	Baseload	3	No	Actual	Std.	FC+Storage
14	SF-Large	No	No	Baseload	3	No	Actual	None	FC+Storage
15	SF-Small	Yes	No	Load Follow	4	No	Actual	Std.	FC
16	SF-Large	Yes	No	Load Follow	3	Yes	Actual	Std.	FC
17	SF-Large	Yes	No	Load Follow	3	No	Future	Std.	FC
18	SF-Large	Yes	No	Load Follow	3	No	Actual	High	FC
19	SF-Small	No	Yes	Baseload	1	Yes	Actual	None	FC

5.1 COST-EFFECTIVENESS BENEFIT COST RATIO RESULTS

Figure 5-1 below highlights the average cost-test results, across all climate zones for each utility, ordered from best-case to worst-case PCT scenarios. The large range in PCT results indicate that there are certain scenarios where installing a fuel cell could be beneficial to residential customers. However, on the other hand, there are also scenarios with very low PCT results, indicating there are scenarios that would not be good fit for a customer. In general, from the TRC standpoint, none of the scenarios were found to be cost-effective.

The best-case scenario, which showed PCT results about two times higher than the next best scenario was the result that took into account a growth rate of fuel cells. In a saturated market, one manufacturer noted that bulk purchasing would significantly reduce freight costs. By also sourcing additional components locally, they aim to offer a residential fuel cell for $10,000. At this projected upfront cost, the technology is expected to achieve a rapid payback period.

FIGURE 5-1: AVERAGE COST EFFECTIVENESS BCR RESULTS AVERAGED ACROSS CLIMATE ZONES

Grp. #	Home Type	CHP	Export	Load Shape	Mfr. #	Incentive	Cost	Resiliency Value [$]	Avg. PCT Ratio	Avg. TRC Ratio
#17	SF-Large	Yes	No	Load Follow	Mfr. 3	No	Future	$71	3.82	0.54
								$126	3.39	0.61
#16	SF-Large	Yes	No	Load Follow	Mfr. 3	Yes	Current	$71	1.84	0.31
								$126	1.52	0.35
#18	SF-Large	Yes	No	Load Follow	Mfr. 3	No	Current	$87	1.58	0.29
								$1091	1.68	0.32
#10	SF-Large	Yes	No	Load Follow	Mfr. 3	No	Current	$71	1.57	0.29
								$126	1.40	0.32
#1	MF	No	No	Baseload	Mfr. 1	No	Current	$0	1.49	0.25
									1.23	0.27
#2	MF	No	No	Load Follow	Mfr. 3	No	Current	$141	1.49	0.28
								$252	1.26	0.30
#9	SF-Small	Yes	No	Load Follow	Mfr. 3	No	Current	$71	1.33	0.26
								$126	1.03	0.28
#12	SF-Large	No	No	Load Follow	Mfr. 3	No	Current	$71	1.31	0.23
								$126	1.12	0.26
#6	SF-Large	Yes	No	Baseload	Mfr. 3	No	Current	$0	1.27	0.23
									1.07	0.25
#11	SF-Small	No	No	Load Follow	Mfr. 3	No	Current	$71	1.11	0.22
								$126	0.82	0.23
#14	SF-Large	No	No	Baseload	Mfr. 3	No	Current	$0	1.05	0.19
									0.85	0.21
#19	SF-Small	No	No	Baseload	Mfr. 1	Yes	Current	$0	1.03	0.37
									0.65	0.38
#15	SF-Small	Yes	No	Load Follow	Mfr. 4	No	Current	$33	0.99	0.18
								$59	0.79	0.19
#7	SF-Small	No	Yes	Baseload	Mfr. 1	No	Current	$0	0.83	0.33
									0.53	0.34
#5	SF-Small	Yes	No	Baseload	Mfr. 3	No	Current	$0	0.67	0.13
									0.55	0.14
#13	SF-Small	No	No	Baseload	Mfr. 3	No	Current	$0	0.56	0.12
									0.45	0.13
#8	SF-Small	No	No	Load Follow	Mfr. 1	No	Current	$0	0.50	0.22
									0.46	0.21
#3	CA	Yes	No	Baseload	Mfr. 3	No	Current	$71	0.49	0.31
								$126	0.58	0.34
#4	SF-Small	No	No	Backup	Mfr. 2	No	Current	$105	0.23	0.01

SDG&E (first row of each group) — SoCalGas/SCE (second row of each group)

* The final results for all scenarios, across all climate zones, can be found in Appendix A.

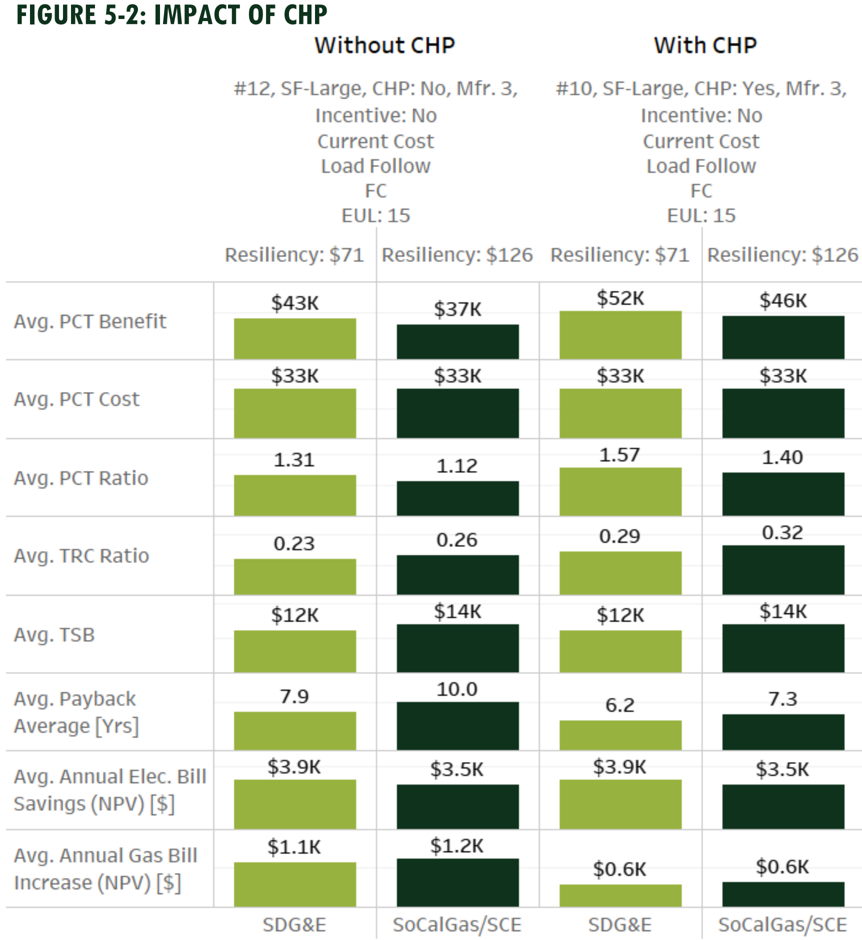
5.2 COMPARING RESULTS

Two of the important questions to be answered through this analysis include: What is the impact of recovered heat for domestic hot water, and what is the market potential for residential fuel cells? We answer these questions by comparing different scenarios against each other to quantify the impact, both to the customer, as well as to society, along with other key metrics including things like bill savings, years of payback, and TSB.

Impact of Combined Heat and Power

The first comparison shows the average impacts, across all climate zones in each IOU territory, of the impact of combined heat and power (CHP). The results in Figure 5-2 compare the PCT benefits and costs over the lifetime of the system, along with the overall PCT BCR, the average payback, and the net present value (NPV) of the electric bill savings and gas bill increases. The **light green** colors represent results for SDG&E territory while the **dark green** colors represent results for SCE/SoCal Gas territory. The columns on the left show the impact of a system that does not recover heat, while the columns on the right show the impact of the same system that does recover heat, using that heat to offset the gas usage for DHW and pool heating loads. Utilizing CHP increases the overall PCT BCR about 20% in this scenario. As shown, the costs to a customer do not change, but the overall benefits are increased. The TSB also shows an increase, as the CHP offsets some of the utility incurred costs of the additional natural gas usage, and without utilizing CHP the TSB is found to increase or incur utility-related costs rather than avoiding them. This

FIGURE 5-2: IMPACT OF CHP



affects the average payback of a system which sees a reduction of about 25% in the length of payback. There are no changes to the average electric bill savings, however, the average gas bill increase that a customer would see from installing this system drops quite substantially, by about 50%, as the fuel cell's constant operation can offset some of the DHW and pool heating costs.

A fuel cell that is able to recover heat, with a high enough water heating load such as DHW and pool heating, achieves benefits above one that does not recover heat, to both the participant and to society.

Additionally, if heat recovery equipment were installed onto an existing residential fuel cell that did not recover heat, the AOE has the potential for cost-effective TRC values above 1.0.

Combined Heat and Power Add-On Equipment

Our team also evaluated the impact of recovering heat on an existing residential fuel cell at a home. While we recognize there are currently no commercially available add-on equipment (AOE) kits that are built to recover heat from residential fuel cells, this is something that could feasibly be designed. This alternative calculation took the difference of the two runs identified in Figure 5-2. The change in electric avoided costs is negligible, while the change in gas avoided costs is positive given that the CHP AOE would reduce the total fuel load of a home, by reducing the gas water heating load. The system costs were assumed to be 25% greater than the difference between Manufacturer #3, whose system recovers heat, and Manufacturer #1 whose system does not. The additional 25% assumes that a non-standard stand-alone part will cost more as it will be sourced from different sources (separate heat exchanger, piping, pump, and storage tank sources) and will require separate and additional installation costs.

We also included an O&M cost for the additional equipment, which is in the range of our O&M assumptions for the entire fuel cell system of about 2% per year which would account for pump failures, storage tank failures, piping leaks, and any other issues that may arise. Similar O&M assumptions are baked into the original calculation as well.

Table 5-2 below shows the potential TRC related to installing AOE CHP onto an existing installed residential fuel cell system.

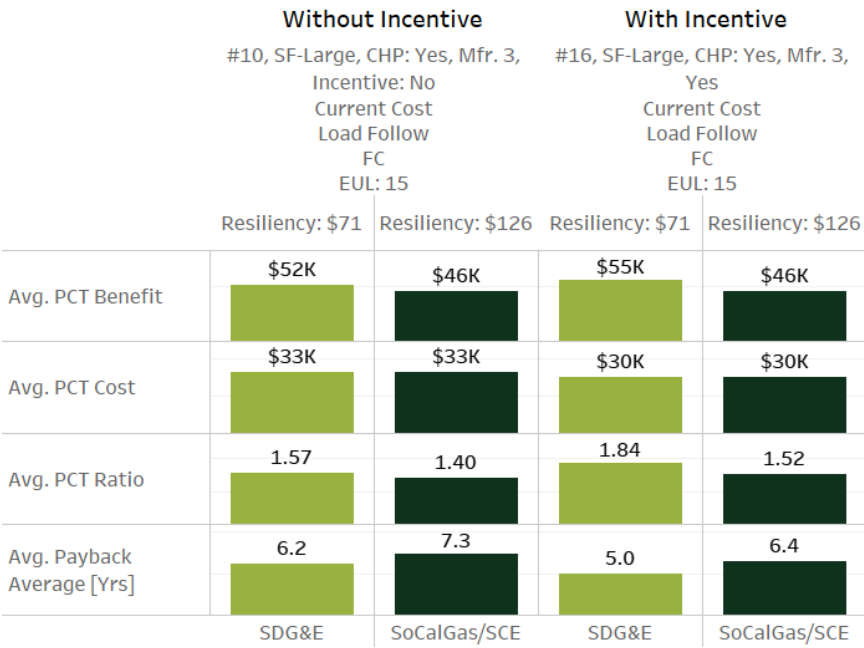
TABLE 5-2: CALCULATED TRC FOR AOE CHP EQUIPMENT

Utility	Climate Zone	Gas Avoided Costs [NPV]	AOE Cost	O&M [NPV]	TRC
SoCalGas	CZ6	9,141	$6,249	$1,708	1.15
SoCalGas	CZ13	9,994	$6,249	$1,708	1.26
SDG&E	CZ7	9,777	$6,249	$1,708	1.23
SDG&E	CZ15	8,503	$6,249	$1,708	1.07

Impact of a Program Incentive

The analysis also looked at whether a program incentive would provide significant benefits to a customer. An incentive of $2/W was considered, which is the same as the incentive that was once provided to fuel cell customers in the SGIP. Figure 5-3 provides this comparison, again showing results for both SDG&E territory and the SCE/SoCal Gas territory. The columns on the left reflect the impact on the cost effectiveness test outputs without a program incentive, while the columns on the right show the results incorporating an SGIP-equivalent incentive. With upfront capital costs around $25,000 for a 1.5 kW fuel cell, the upfront incentive modeled comes out to 12% of the total capital costs of the unit. This upfront incentive is modeled as a reduction in the costs to a customer, which calculates out to an overall increase in the PCT BCR of about 8-10%. Additionally, this scenario shows a reduction of about 13%, or just under one year to the average payback.

FIGURE 5-3: IMPACT OF AN INCENTIVE

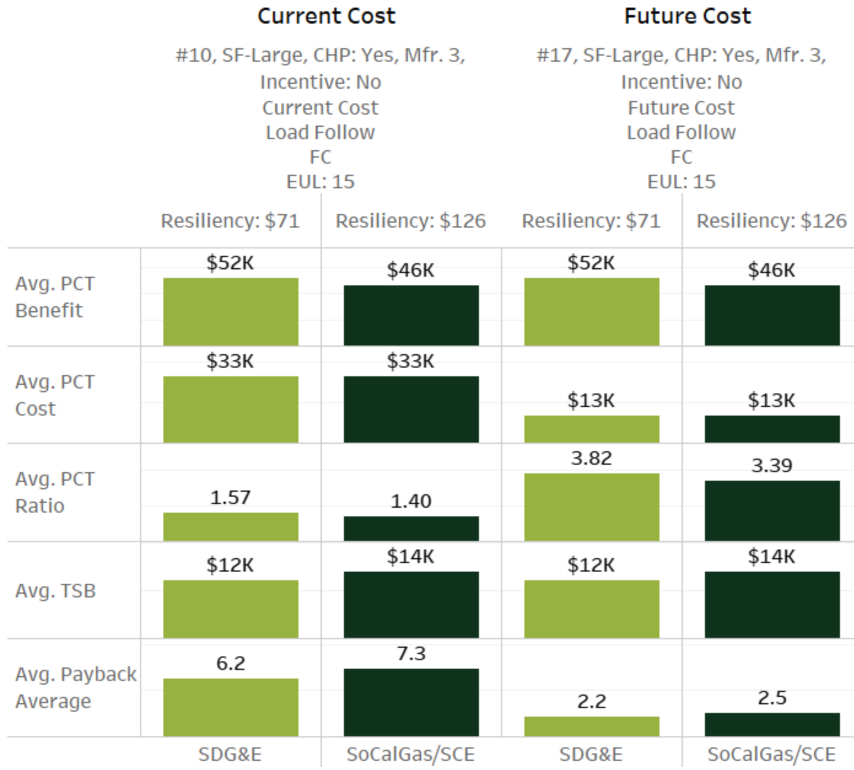


Including a program incentive may not necessarily be a deciding factor for many customers, but it might help to entice customers that are on the fence, and may be better geared towards customers in high fire threat districts or low-income neighborhoods.

Impact of Forecasted Upfront Cost Reductions

Estimating what a future market would look like relies heavily on estimating what a fuel cell may cost in a saturated market, when parts are ordered at scale, and some local sources can be utilized. The main benefit here being that cost reductions related to the cost of producing the fuel cell can be passed down to consumers. One manufacturer has a future goal of selling their system for $10,000, rather than their current $25,000 price tag. The same scenario was analyzed using this new cost, as an indicator of the impacts that the system cost has on the overall PCT and TRC results. The results are shown in Figure 5-4, with the results on the left showing the cost-effectiveness results using the current pricing and the results on the right showing the results for the same system under forecasted future upfront pricing. As the systems are assumed to be financed over the lifetime of the unit, a $15k reduction in upfront costs would have a $20k reduction in costs over the system's life, resulting in a PCT ratio that is over two times higher than the actual cost scenario. The TRC BCR results show an increase of almost 2x as well. Finally, the average customer payback under this future cost scenario drops to about a third of what it was under the "current cost" scenario, at just over two years.

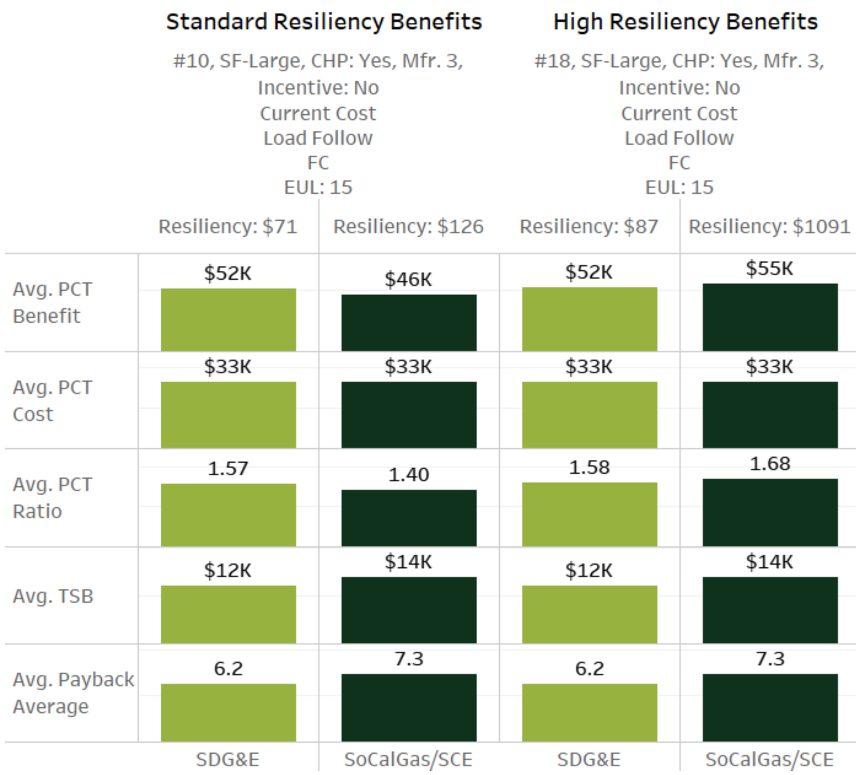
FIGURE 5-4: COMPARISON OF CURRENT VS FUTURE COSTS



Upfront capital costs play an important role in the overall cost effectiveness BCR results. Reducing the overall cost of a system improves results not just from a participant point of view but also from a societal point of view.

Impact of Resiliency Benefits

FIGURE 5-5: IMPACT OF RESILIENCY BENEFITS



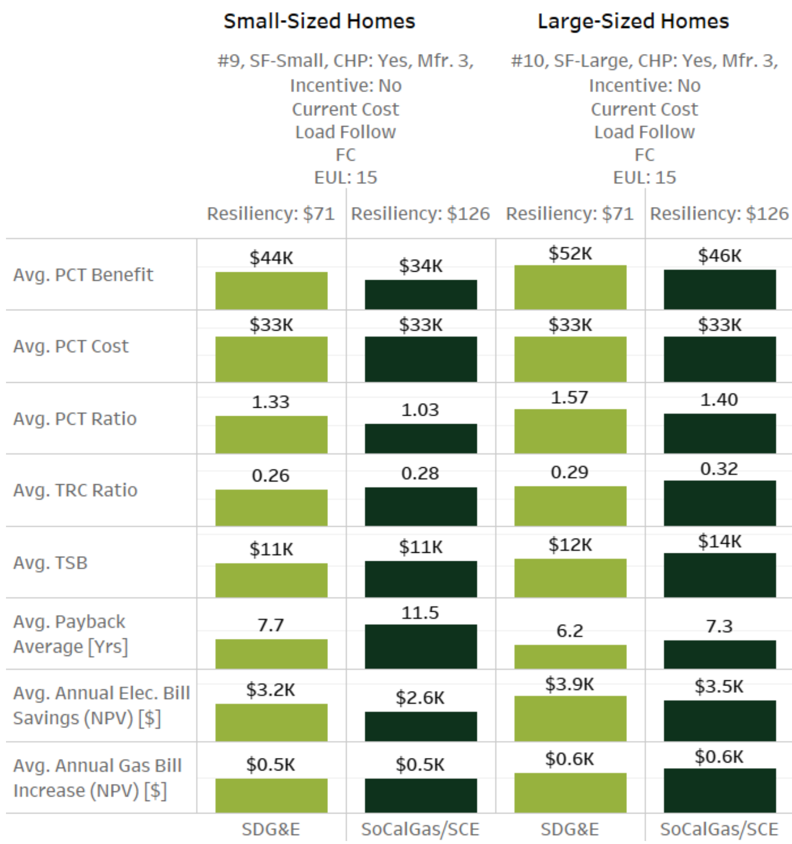
A customer resiliency benefit was included as a participant benefit in certain scenarios. The modeled resiliency benefit is estimated using analysis performed for the SGIP Market Assessment study in 2021. More about this study, and the methodology used to quantify resiliency benefits is described above in Section 4.1.8. but the benefit is expressed in dollars per year and represents the amount of money a residential customer would be willing to pay for resiliency to maintain power during periods of significant outages such as a Public Safety Power Shutoff (PSPS) event. Different values were provided by customers in SDG&E and SCE/SoCal Gas territory, as each territory has had varying degrees of power shutoffs and outages over the last few years. The value of the resiliency benefit is based on the number of hours of grid power outages a typical customer may experience across a year. We performed a comparison of two different scenarios, one with a standard resiliency benefit, and another with a high resiliency benefit reserved for those customers who may live in high fire thread districts, or who may have experienced multiple or extended outages over the last few years, and would be willing to pay even higher amounts for additional resiliency benefits as could be obtained from a fuel cell. As shown in Figure 5-5, resiliency benefits are modeled as a PCT benefit and affect the PCT rather than the TRC test. The impact of resiliency was found to affect residential customers in the SoCal Gas/SCE territory more than those in the SDG&E territory. This is because SDG&E customers have seen, on average, far fewer hours of outages over the last few years than SoCal Gas/SCE customers, so while the high resiliency scenario had very little impact on the BCR results for SDG&E, they did increase the results for SoCal Gas/SCE customers by about 13%. It is important to note that resiliency benefits do not provide a quantifiable financial benefit to the customer, which is why the average payback does not change, yet they do provide the customer peace of mind as well as benefits against extended outages including heating and cooling and safeguarding perishables from spoiling.

Customers in SoCal Gas/SCE territory have experienced a larger average quantity of hours of outages across all circuits and districts in recent history than customers in SDG&E territory. Customers in High Fire Threat Districts may be especially interested in resiliency, and more willing to pay for the added peace-of-mind and non-energy benefits that they would see from a fuel cell.

Impact of Residential Home Size

Residential home size and the electrical consumption of a home plays an important role in whether the investment in a fuel cell is worth it to a customer. A fuel cell will output continuous power. Some systems can ramp-up and ramp-down the power output to meet load, but they cannot easily and quickly shut off, meaning that a premise with a higher baseload at all hours will be able to offset more of that load than a smaller home. Smaller homes may have hours where the system is still operating and using natural gas, but the load of the home is lower than the minimum load the fuel cell can operate at. In these scenarios, the fuel cell may have to shed the excess generated load. In most of the scenarios we have analyzed, the fuel cell cannot export to the grid, due to California laws allowing exports only for those generation systems operating on renewable fuel. In most scenarios, fuel cells operating in larger homes were found to show better cost effectiveness results than those operating in smaller sized homes. The PCT benefits increased between 15-35%, as did the PCT BCR. The average number of years of payback decreased also by around 20%.

FIGURE 5-6: IMPACT OF RESIDENTIAL HOME SIZE

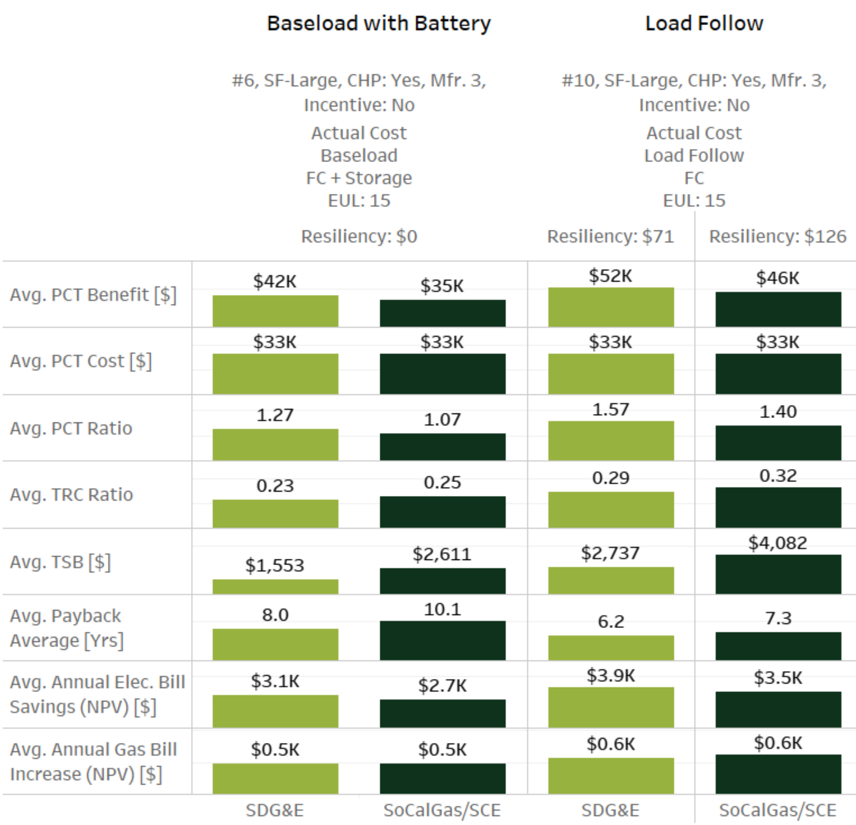


Homes with larger electrical loads (approximately 13 thousand kWh/year) see more benefits and a shortened payback period from the installation of fuel cells than smaller homes (those closer to 7 thousand kWh/year), as larger homes will have a higher baseload, and offset more grid-purchased electrical usage than smaller homes.

Impact of Baseload vs Load Following

Traditionally, stationary power fuel cells provide a constant output, offsetting a customer's baseload electricity usage rather than varying output to follow a load. However, in residential settings especially, the baseloads are quite low, and the ability to follow load provides an advantage. Historically, PEM fuel cells were better at providing load following flexibility, but more recent technological advances have enabled SOFC systems to also follow load. Additionally, combining a continuous output fuel cell with battery storage helps to cushion some of the load variation in a home, and allows the fuel cell to send some of the energy generated to the battery in times of low home load. Figure 5-7 displays the results of a fuel cell to offset a homes' baseload combined with a battery to help offset a home's peak loads compared to just a fuel cell that follows a home's load. When a fuel cell offsets the baseload, it should be sized to the minimum load that a facility will see. For a residential facility, this lowest load may be less than 0.5 kW, less than a third of the 1.5 kW fuel cell that is modeled in several cases. When combined with a battery, the assumption is that the fuel cell can operated up to 1 kW continuously. The load following scenarios however, produce more electricity throughout the year, offsetting a higher percentage of grid-purchased electricity. The results show an increase in the PCT benefits and PCT ratios by over 20% for load following systems compared to those only offsetting a baseload. The TSB is also over 50% higher for load following systems, and the payback is shortened by a few years.

FIGURE 5-7: IMPACT BASELOAD VS LOAD FOLLOWING LOADSHAPES

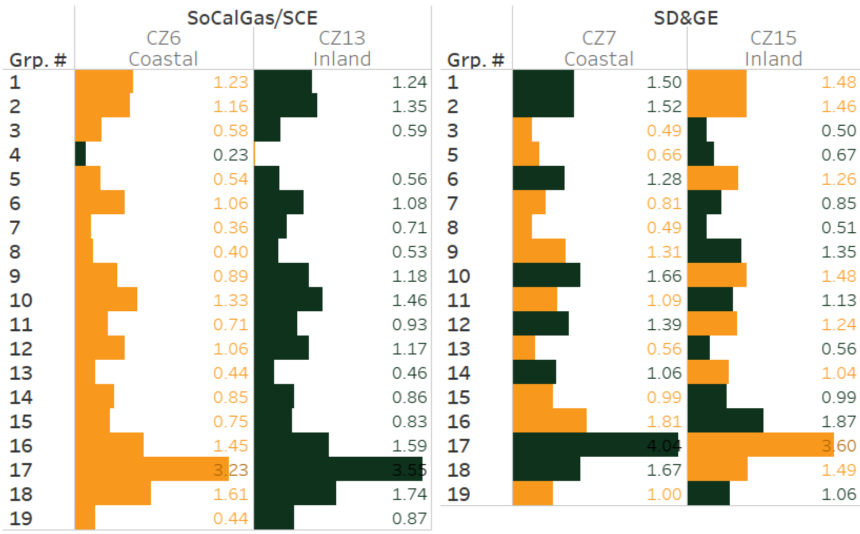


Fuel cells that can follow load perform much better than those that are designed to solely offset a baseload. Base loaded systems would be more appropriate for larger commercial facilities with very high baseloads. However, for residential scenarios, a fuel cell that follows load will provide greater benefits.

Impact of Climate Zones

Comparing PCT results across the different climate zones for each scenario also shows some interesting results. Figure 5-8 below shows the comparison of results for each simulation across climate zones. The ***dark green*** bars represent the higher of the two PCT ratios for the coastal vs inland climate in each utility service territory, while the ***orange*** shows the lower of the two. In the SoCal Gas/SCE territory, the scenarios analyzed in the inland CZ, CZ13 always shows a higher PCT benefit than the results for the coastal climate zone, CZ6. This is due to the year-round higher home loads in the inland climate zones, with higher heating loads in the winter and higher cooling loads in the summer. SDG&E climate zones show different results. The inland climate zone 15 has higher cooling loads in the summer, but lower heating loads in the winter. In some scenarios, the coastal climate zone showed higher benefits while other scenarios these higher benefits were seen in the inland climate zone. The real driver behind the benefits though has less to do with climate zone and more to do with how much the fuel cell is being utilized.

FIGURE 5-8: IMPACT OF CLIMATE ZONE



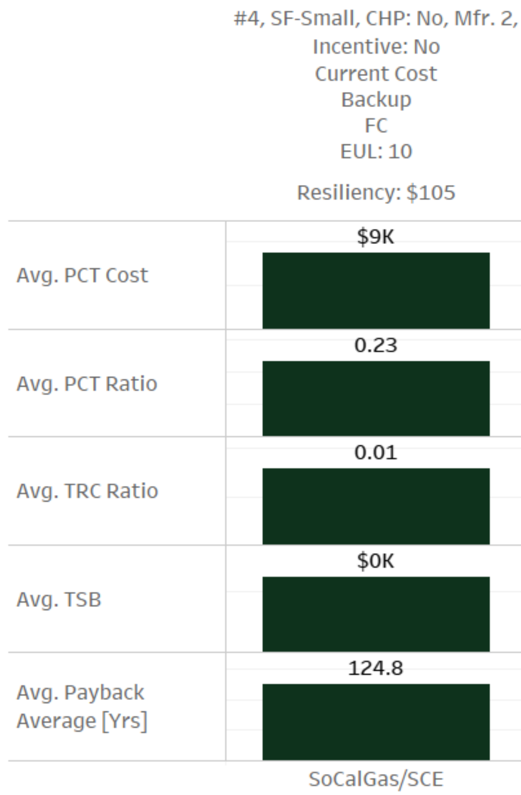
While the scenarios across the SoCal Gas/SCE climate zones analyzed showed the inland climate zones showing higher participant benefits, and the SDG&E results showed a mixture, the real driver behind the participant benefits have to do with how much the fuel cell is being utilized. A participant will see the most benefits when they are able to maximize the energy generated from their fuel cell.

VERDANT

Fuel Cells as Backup Only Power

There is a fuel cell on the market that is designed to be utilized exclusively for backup power or to minimize high power costs when the grid is expensive or stressed.. The cost of the fuel cell is much lower, but it is also only utilized for a handful of hours each year. Our analysis took the list of PSPS events over the last few years, looking only for residential customers, and selected a single circuit to analyze, which represented one of the circuits with the higher number total hours of PSPS outages during 2022 and 2023. This would represent the higher end of what a customer may experience in PSPS events, because not every customer on a circuit is always going to experience that many outages, or the entire duration of outages that a circuit may see.

FIGURE 5-9: BACKUP POWER SCENARIOS



The results for the backup power scenario are displayed on the right in Figure 5-9. Only one scenario for SoCal Gas/SCE was simulated as the PSPS events were modeled on a SCE circuit. Our analysis found that from a participant perspective, the fuel cell does not provide cost effective benefits for a participant. Assuming only these PSPS events (which estimated 82 hours of outages across the year across three separate events), the fuel cell does not generate enough electricity to pay itself back, as shown from the years of payback on the right, shown to be 125 years. However, other than the resiliency benefits that the model accounts for, there are other benefits that customers may see in having a backup power generator, including surge protection, enhanced home security and safety to power things like alarms and cameras during outages, potential increases in property value and insurance benefits, and business continuity for remote workers. In colder climates, backup power can also help to protect against pipes freezing and bursting.

While there is certainly a market for backup power generation, from a PCT and TRC cost-effectiveness and payback standpoint, these systems do not pencil out. Other non-energy benefits that may relate to peace of mind, insurance, and home protection are a driver of backup power generation. These are not accounted for in our analysis, but may play an important role as a driver of residential fuel cell adoption, especially for emergency and backup power scenarios.

Renewable Natural Gas and Export

Verdant also analyzed two different scenarios where the modeled fuel cell operated on an 80% RNG / 20% natural gas mixture. While there is not currently a renewable natural gas tariff available for residential customers, the analysis models the BCR based on a future potential scenario. SoCal Gas expects to launch their Voluntary RNG Tariff (VRNGT) in 2025, and while they do not currently plan on offering it to residential customers, there may eventually be opportunities for residential customers to procure RNG. The model factors in an added cost for the voluntary RNG tariff, which is assumed to be $1/therm, which can represent a significant increase to the customer throughout the year.[12]

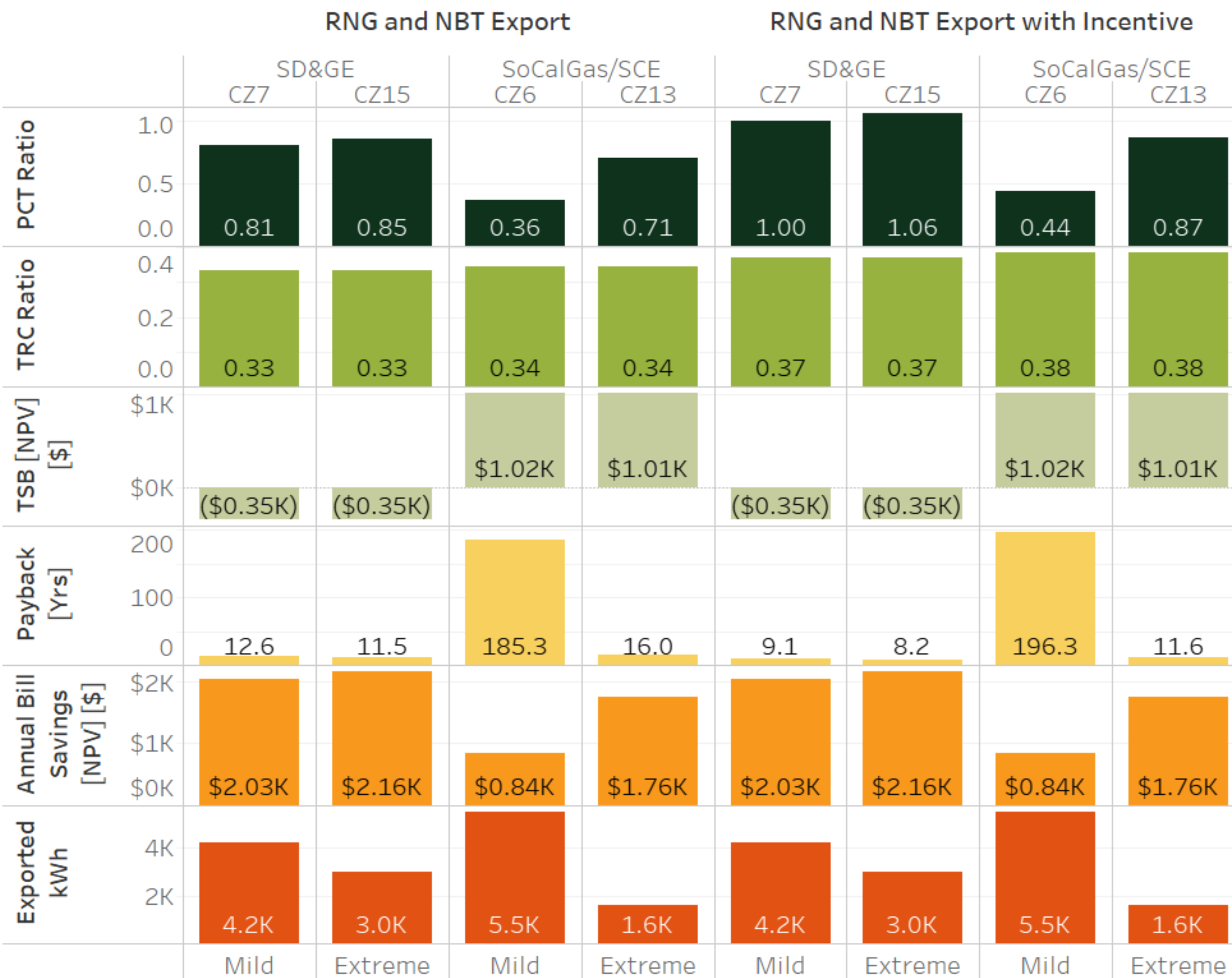
The use of RNG allows a customer to be able to export power back to the grid, a feature not allowed for natural gas fueled generators. The assumption is that the customer's credit would be calculated based on the Net Billing Tariff (NBT) guidelines which are based on avoided cost values. The two scenarios analyzed, shown below in Figure 5-10, compare the RNG and export scenarios across all the climate zones with and without providing an incentive. The incentive scenario provided matches what the SGIP used to provide, which included an additional $2/W renewable fuel adder, bringing the total incentive to $4/W.

Overall, most scenarios utilizing RNG and exporting their excess electricity are not found to be cost effective from a participant's perspective. The cost of the fuel cell, combined with the cost of the fuel to operate the fuel cell and the added cost of the renewable fuel makes this scenario generally not cost effective. However, the added benefit of an incentive does increase the PCT BCR around 20%, suggesting that if equipment customer costs could be reduced, this scenario shows promise. For simplicity, the RNG and export scenarios below do not include the benefits of heat recovery.

The scenario that results in the worst results is the model from SoCal Gas/SCE in the coastal climate, CZ6. This scenario has total bill savings of only about $800/year and exports the highest amount of electricity due to the home's lower baseline electrical load. This suggests that the value of exported electricity relative to the cost of the gas used to generate the electricity may not be worthwhile. The scenarios modeled here are all based on smaller homes.

[12] As of March 18th, 2025, SoCal Gas announced the first renewable natural gas procurement contract with Organic Energy Solutions. https://www.socalgas.com/newsroom/press-release/socalgas-announces-first-renewable-natural-gas-contract. Accessed March 19th, 2025.

FIGURE 5-10: RNG AND EXPORT SCENARIOS



As discussed previously, larger homes generally see increased benefits, because they have larger electrical loads, as do fuel cell systems that recover heat. These scenarios make greater use of the fuel cell generation. Therefore, it is safe to presume that a home with larger electrical loads utilizing RNG may see greater benefits to the point that it would be cost effective for the customer. Additionally, with the cost of an RNG tariff that increases the cost of the RNG by $1/therm, it does not make sense to export excess generation, so following a home's load makes more sense than exporting the excess generation.

6 MARKET ASSESSMENT

A key element of this research was to understand segments of the Southern California residential market would most benefit from the installation of residential fuel cells. Once we understood which scenarios showed the most benefits, the next step was to apply these scenarios to the southern California population. Figure 6-1 displays the best scenarios for SoCal Gas/SCE and SDG&E territories. These scenarios that showed the highest benefits for participants (greater than 1.10 PCT Ratio) were mostly SF-large sized homes, with CHP, and fuel cells that followed load.

FIGURE 6-1: SCENARIOS WITH THE HIGHEST POTENTIAL BENEFITS FOR MARKET ASSESSMENT

SoCalGas / SCE

Grp. #	Climate	CHP	Home Ty..	Load Shape	Tech	Incentive	Resiliency Benefit [$]	
18	Inland	Y	SF-Large	Load Follow	FC	N	$1091	1.74
18	Coastal	Y	SF-Large	Load Follow	FC	N	$1091	1.61
16	Inland	Y	SF-Large	Load Follow	FC	Y	$126	1.59
10	Inland	Y	SF-Large	Load Follow	FC	N	$126	1.46
16	Coastal	Y	SF-Large	Load Follow	FC	Y	$126	1.45
2	Inland	N	MF	Load Follow	FC	N	$252	1.35
10	Coastal	Y	SF-Large	Load Follow	FC	N	$126	1.33
1	Inland	N	MF	Base Load	FC	N	$0	1.24
1	Coastal	N	MF	Base Load	FC	N	$0	1.23
9	Inland	Y	SF-Small	Load Follow	FC	N	$126	1.18
12	Inland	N	SF-Large	Load Follow	FC	N	$126	1.17
2	Coastal	N	MF	Load Follow	FC	N	$252	1.16

SDG&E

Grp. #	Climate	CHP	Home Ty..	Load Shape	Tech	Incentive	Resiliency Benefit [$]	
16	Inland	Y	SF-Large	Load Follow	FC	Y	$71	1.87
16	Coastal	Y	SF-Large	Load Follow	FC	Y	$71	1.81
18	Coastal	Y	SF-Large	Load Follow	FC	N	$87	1.67
10	Coastal	Y	SF-Large	Load Follow	FC	N	$71	1.66
2	Coastal	N	MF	Load Follow	FC	N	$141	1.52
1	Coastal	N	MF	Base Load	FC	N	$0	1.50
18	Inland	Y	SF-Large	Load Follow	FC	N	$87	1.49
1	Inland	N	MF	Base Load	FC	N	$0	1.48
10	Inland	Y	SF-Large	Load Follow	FC	N	$71	1.48
2	Inland	N	MF	Load Follow	FC	N	$141	1.46
12	Coastal	N	SF-Large	Load Follow	FC	N	$71	1.39
9	Inland	Y	SF-Small	Load Follow	FC	N	$71	1.35
9	Coastal	Y	SF-Small	Load Follow	FC	N	$71	1.31
6	Coastal	Y	SF-Large	Base Load	FC + Storage	N	$0	1.28
6	Inland	Y	SF-Large	Base Load	FC + Storage	N	$0	1.26
12	Inland	N	SF-Large	Load Follow	FC	N	$71	1.24
11	Inland	N	SF-Small	Load Follow	FC	N	$71	1.13

The following subsections present several important conclusions based on the cost effectiveness analysis and results.

6.1 IMPORTANCE OF RESILIENCY

Customers willing to pay for resiliency see larger benefits, especially in SoCal Gas/SCE territory where there are districts that have seen quite a significant number of outages over the last few years. The SoCal Gas/SCE territory showed significant resiliency benefits for those customers that might be willing to pay for the added resiliency. To identify those customers who might be most willing to pay for resiliency, we looked back at the Resiliency Reports from SCE and SDG&E. The reports highlight the top 1% Worst Performing Circuits (WPC) in each utility's service territory. The WPCs are identified using three years of system outages history, although these numbers exclude Major Event Days (MED) and planned outages.

For SCE, there were 72 WPC representing 127,802 customers. While the WPC are identified using three years of system outage history, SCE also notes if a circuit was also on the prior report's list of WPC. There were an additional 38 circuits noted on the same list in the prior report, representing 53,514 customers. Customers in these WPC have experienced average annual total outages between 142 minutes (2.4 hours) and 52,206 minutes (807 hours / 36 days). For SDG&E, there were 10 circuits on the WPC list, representing 10,245 customers. None of these circuits were on the prior report's WPC list. However, the customers in these WPC experienced average annual total outages between 607 minutes (10 hours) and 2,298 minutes (38 hours).

6.2 CATEGORIES OF CUSTOMERS NEEDING INCENTIVES

Paying incentives can increase participant benefits and shorten the payback period. The two scenarios analyzed that paid incentives ($2/W and $4/W) were both found to increase participant benefits, by reducing the cost of financing and therefore shortening the customer's payback period. Incentives in the RNG scenario would also help to offset the additional costs of an RNG tariff. These may be especially useful to customers that would classify for the Equity Resiliency Budget Program under the SGIP. These are customers who live in Tier 2 or Tier 3 High Fire Threat Districts or who have medical conditions requiring the use of additional electricity or gas to power medical devices or to keep consistent home temperatures. Customers may also be eligible for the Equity Resiliency program if they meet certain conditions related to PSPS events.

As of the end of January 2025, there were 9,536 customers applying to the SGIP through SCE, SoCal Gas, or SDG&E that had qualified for the Equity Resiliency Budget Program. This represents almost 30% of the entire SGIP population in those territories.

The medical baseline (MBL) population is less well known currently. The CPUC required the IOUs to file Tier 3 Advice letters[13] establishing numeric goals for their new signups and retention rates within the

[13] CPUC Decision (D.)20-06-003 (June 20, 2020)

MBL. However, the IOUs proposed an MBL eligible population study to better understand the success of their current marketing efforts and to advise their process of setting future enrollment goals. The study is currently waiting for CPUC authorization to move ahead based on the research plan, and therefore results are not expected until 2026, but the Medical Baseline Study Research Plan provides a list of Conditions, Devices, and Condition-Device Combinations that would make a customer eligible for the MBL.[14] Once these study is approved and the results have been finalized, there will be greater insight into the number of potential MBL customers in each IOU's service territory. Records from SoCal Gas[15] and SDG&E[16] disconnect reports show there were 35,916 SoCal Gas customers enrolled in the MBL, and 61,730 SDG&E MBL customers, as of January 2025, but this doesn't tell us what the eligible population might be.

The CPUC High Fire Threat Districts are separated into three fire-threat areas. Tier 1 are High-Hazard Zones designated by the United States Forest Service (USFS) and California Department of Forestry and Fire Protection (CAL FIRE). Tier 2 consists of areas on the CPUC Fire-Threat Map where there is an elevated risk from wildfires associated with overhead utility power lines. Tier 3 areas are where there is an extreme risk of wildfires associated with overhead utility power lines.[17] Figure 6-2 below shows the intersection of the Tier 2 and Tier 3 HFTDs and the California Building Climate Zones.

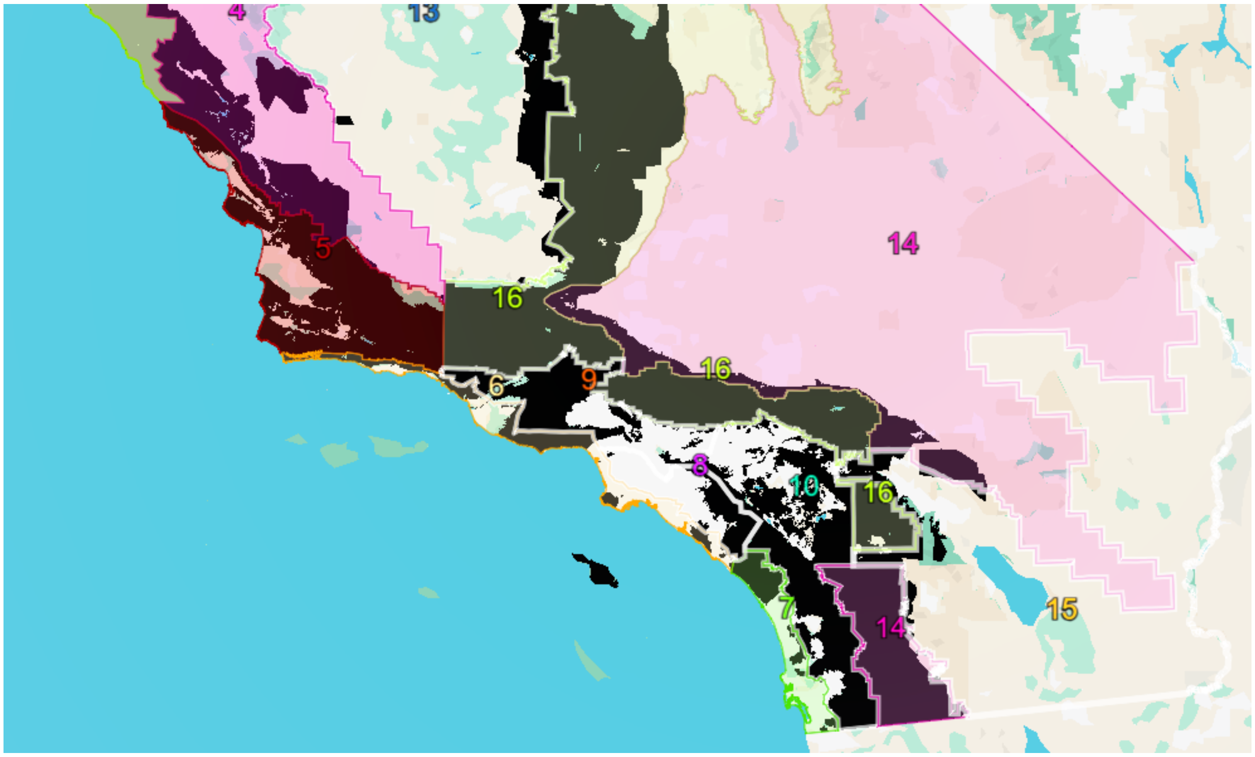
[14] Verdant Associates. Medical Baseline Study Research Plan. Appendix A. September 10th, 2024. https://pda.energydataweb.com/api/view/4067/Final_MedicalBaselineStudy_ResearchPlan_20240930_.pdf. Accessed March 21st, 2025.

[15] Disconnection Settlement Monthly Report of Southern California Gas Company (U 902 M). Section 7 – Basic Information. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M556/K897/556897431.PDF. Accessed March 19th, 2025.

[16] Disconnection Settlement Monthly Report of San Diego Gas & Electric Company (U 902 M). Section 7 – Basic Information. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M556/K897/556897431.PDF. Accessed March 19th, 2025.

[17] CPUC Fire-Threat Maps and Fire-Safety Rulemaking. https://www.cpuc.ca.gov/industries-and-topics/wildfires/fire-threat-maps-and-fire-safety-rulemaking. Accessed March 19th. 2025.

FIGURE 6-2: HIGH FIRE THREAD DISTRICTS AND CLIMATE ZONES



* The darkened areas of the map represent Tier 2 or Tier 3 HFTDs.

About two thirds of CZ10 in SDG&E's territory is listed as a Tier 2 or Tier 3 HFTD, as is much of North County CZ7. In SoCal Gas territory, about a third of the CZ4 territory, and most of CZ5, CZ9 are listed as HFTDs. Based on the RASS data[18] there are approximately 360,000 SDG&E customers in CZ7 and 175,000 SDG&E customers in CZ10. For SoCal Gas, there are approximately 4,000 customers each in CZ4 and CZ5, and 880,000 customers in CZ9.

[18] 2019 Residential Appliance Saturation Study. https://www.energy.ca.gov/data-reports/surveys/2019-residential-appliance-saturation-study. Accessed March 19th, 2025.

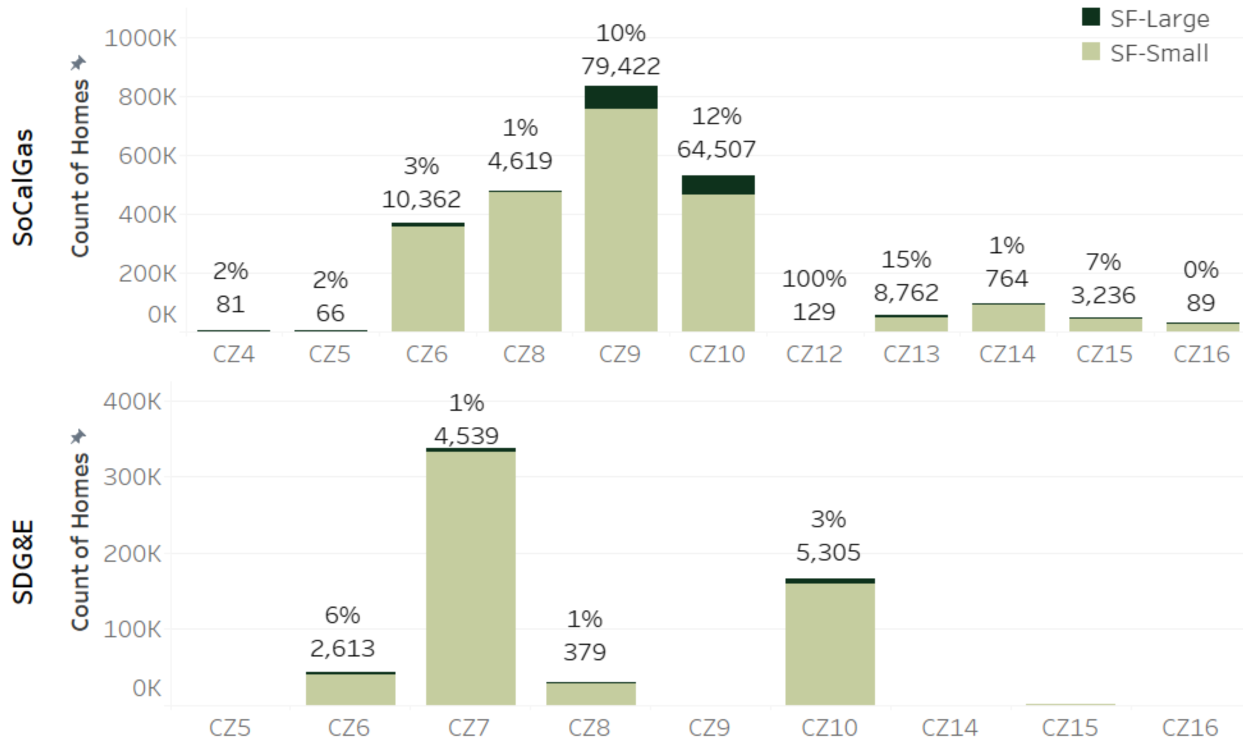
TABLE 6-1: APPROXIMATE CUSTOMERS IN HFTD TIER 2 AND 3 DISTRICTS

Utility	Climate Zone	Approximate Total Customers	% in HFTD	Customers in HFTD
SoCal Gas	CZ4	4,000	25%	1,000
	CZ5	4,000	75%	3,000
	CZ9	880,000	33%	290,000
SDG&E	CZ7	360,000	33%	120,000
	CZ10	175,000	66%	116,000

* Based on 2019 RASS data, with Natural Gas Utility of either SDG&E or SoCalGas, SF homes, and listed by climate zone. These counts are based on homes that are owner occupied and are the respondent's primary residence.

Larger homes, or those with larger electrical loads, are more likely to see greater benefits and quicker payback. Homes with higher electrical loads that can utilize more of the generation from the fuel cell and offset more of the grid-purchased electricity year-round will benefit more from the use of a fuel cell. In the scenarios simulated, large-sized homes were around 6,000 $ft^{2,}$ and typically had an electrical baseline load greater than 12,000 kWh for coastal climate zones, and greater than 13,000 kWh for inland climate zones. The RASS data gives us an idea of how many large homes are represented in each climate zone, and by each gas utility. These are found below in Figure 6-3, where the ***dark green*** bars represent the large homes, and the ***light green*** bars represent standard smaller homes. Understandably, very few of the residential houses meet or exceed the high electrical energy usage classified to make them a "large" home. However, the two areas with the largest number of 'large sized' homes are CZ9 and CZ10 in SoCal Gas territory. Ten percent of homes in CZ9 and twelve percent of homes in CZ10 were considered large homes, representing almost 80,000 and 65,000 homes, respectively. In SDG&E territory, a total of approximately 12,500 customers across climate zones 6, 7, and 10 were designated as 'large' customers.

FIGURE 6-3: COUNT OF LARGE-SIZED HOMES ACROSS CLIMATE ZONE

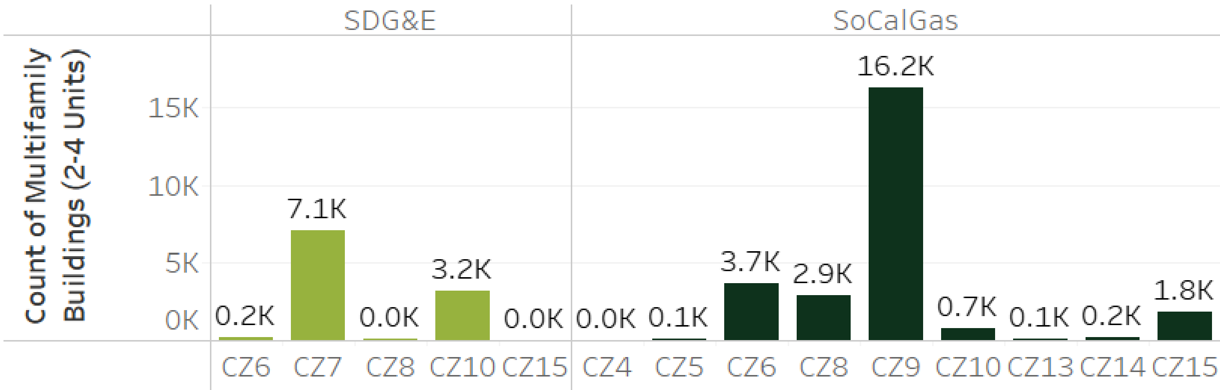


* Based on 2019 RASS data, with Natural Gas Utility of either SDG&E or SoCal Gas, SF homes, and listed by climate zone. These counts are based on homes that are owner occupied and are the respondent's primary residence.

6.3 POTENTIAL FOR MULTIFAMILY PROGRAMS

Small multifamily (2-4 units) buildings could benefit from fuel cells. Scenarios simulated for small multifamily facilities (2-4 units) suggest that these buildings may be good candidates for fuel cells. These scenarios resulted in PCT BCRs that were well above 1.0. These scenarios were analyzed at the whole building level, so all tenants would typically see benefits. However, it's not entirely clear how many of these facilities are master metered, and how benefits may be split between tenants. The 2019 RASS report notes that out of almost 40 thousand households surveyed, 303 of them were master-metered, but it doesn't specify if these were electric or gas master metered, or the size of the apartment building facility. Figure 6-4 below shows the breakout of Multifamily 2-4 units across ***SDG&E*** and ***SoCal Gas*** climate zones.

FIGURE 6-4: COUNT OF MULTIFAMILY BUILDINGS (2-4 UNITS)



* Based on 2019 RASS data, with Natural Gas Utility of either SDG&E or SoCal Gas and listed by climate zone. These counts are based on homes that are owner occupied and are the respondent's primary residence. Because the RASS data actually represents households, we divided the total number by three to get an assumed number of multifamily building.

The Solar on Multifamily Affordable Housing (SOMAH) Program focuses on installing solar PV on multifamily housing. The program provides significant subsidies for the installation of Solar PV systems on qualifying multifamily affordable housing properties. The evaluation of the SOMAH program focused part of its effort on property owner process improvements and identified barriers that the program faced with property owners, including:[19]

1. Not their top priority
2. Lack of staff to manage a solar installation project
3. Property owner organizational structure
4. Project financing
5. Distrust in the solar contractors market the program
6. Property physical site issues
7. Application burden and property ownership structure

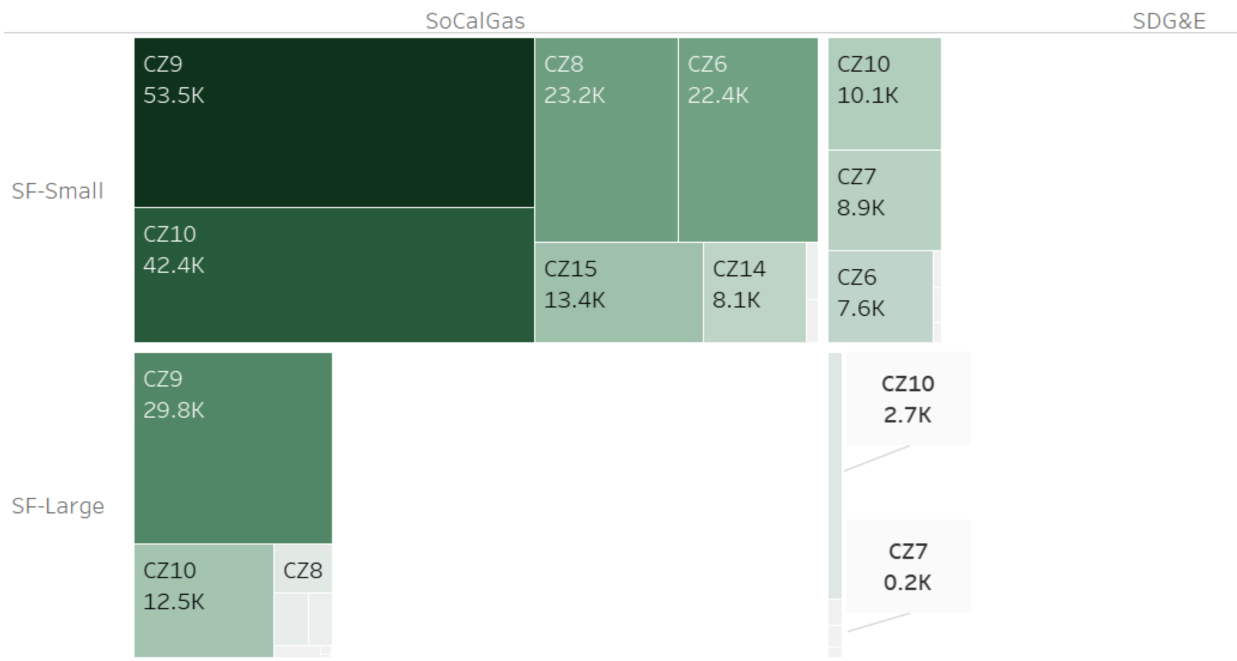
We would expect that the barriers to installing solar on multifamily facilities would be similar to the barriers to the installation of fuel cells. The SOMAH program shares the benefits from the installation of the PV system between the tenants and the owner, with the tenants receiving a share of the energy generated and the owner receiving a share of the energy for the common areas, as well as the incentives. A similar approach may need to be taken to incentivize multifamily property owners to install residential fuel cells.

[19] Verdant Associates. Solar on Multifamily Affordable Housing Second Triennial Report. Table 5-8. July 14th, 2023. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/somah/2023-somah_second_triennial_report.pdf. Accessed March 19th, 2025.

6.4 MAXIMIZING BENEFITS WITH POOL HEATING

Homes with pool heating loads provide an additional opportunity for residential fuel cells with heat recovery to maximize their benefits. Throughout both SoCal Gas and SDG&E territory, just over a quarter of large-sized homes have natural gas heated pools, and about 5% of small-sized homes have natural gas heated pools. These homes represent an additional opportunity for residential fuel cells to utilize the waste heat and reduce customer bills. Figure 6-5 summarizes the estimates from the 2019 RASS of the number of natural gas heated pools by home size, gas utility, and climate zone. The largest share of homes with pools are in SoCal Gas's territory in small-sized homes, CZ9, with just over 50,000 pools and an additional 40,000 in CZ10.

FIGURE 6-5: NUMBER OF SWIMMING POOLS HEATED WITH NATURAL GAS



* Based on 2019 RASS data, with Natural Gas Utility of either SDG&E or SoCal Gas, single family, and listed by climate zone. These counts are based on homes that are owner occupied and are the respondent's primary residence, and reflect homes with pools with natural gas heating.

6.5 EFFECTS OF ELECTRIC AND GAS RATE STRUCTURES

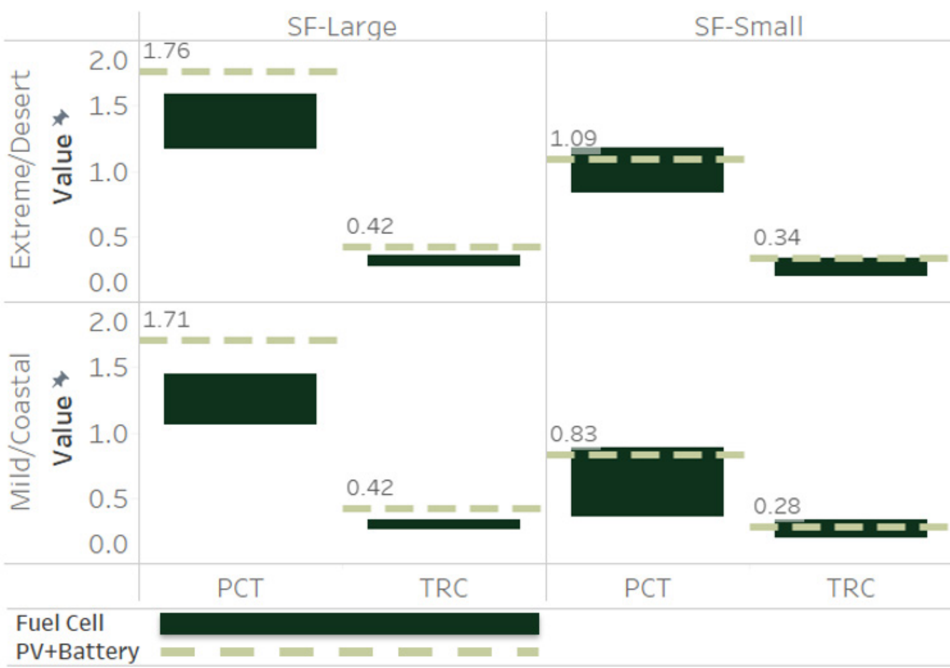
In the scenarios and rates analyzed, SDG&E has higher electrical rates and lower gas rates than SoCal Gas/SCE territory, which result in increased participant benefits related to fuel cell installation. Avoiding higher electricity rates is a benefit to customers, as is increasing gas purchases at a lower rate.

6.6 COMPARISONS OF FUEL CELL TO PV & BATTERY BENEFIT COST RATIOS

Solar PV and battery storage combinations have become increasingly mainstream, providing resiliency benefits to residential customers, reducing the need for grid-purchased electricity, and providing customers with bill savings. Understanding how fuel cell cost effectiveness compares to PV and battery storage results may help understand the possibility of fuel cells capturing some of the market potential that is currently being held by PV and battery storage.

Verdant performed cost-effectiveness simulations on PV and battery storage as a comparison to the fuel cell results. While the PV and battery storage simulations cannot be directly compared to fuel cells, they are presented here to provide a range in potential BCRs, and to provide some context between the differences in results. Four simulations, performed for an alternate study, were reviewed, comparing a large and small home in SCE's service territory, one in a coastal climate zone and the other in a desert climate zone. The results for these four scenarios are highlighted below in Figure 6-6, compared to the fuel cell results for similar scenarios. The ***dark green*** bars represent the range in fuel cell results from the scenarios that we analyzed, whereas the PV + Battery results, shown in ***light green*** represent a single run that was performed.

FIGURE 6-6: COMPARISON OF PV + BATTERY AND FUEL CELL BCR RESULTS



In the scenarios analyzed, PV + Battery modeling showed greater PCT and TRC results for SF-Large facilities than the range in fuel cell results. For SF-Small facilities, the results were towards the top of the fuel cell results range. However, as these PV + Battery simulations were performed for a separate, unrelated study, there are several caveats to make in this analysis before trying to compare the results directly:

- The size of the home (the home's electrical loads) are not identical in the PV + Battery and the Fuel Cell scenarios. The PV + Battery scenario for SF-Small home has a load that is about two-thirds of the Fuel Cell home load, and for the SF-Large home, the PV + Battery home load is about 1.5x that of the Fuel Cell scenario.
- The climate zones do not line up perfectly. The PV + Battery inland climate zone represents CZ14, whereas the Fuel Cell inland climate zones are simulated based on CZ13.

In general, fuel cell BCR results are similar, but slightly lower, than PV + Battery results. There are several reasons why fuel cell results may be lower than the PV + Battery results:

- The PV system does not have the additional cost of fuel associated with it, which affects both the participant's bill savings, as well as the avoided costs (incurred costs) related to gas transportation.
- The PV + Battery system (depending on the PV system size) has the potential to provide higher energy offset during peak hours of the day, meaning that it offsets more of the grid hours with the highest grid-related costs.
- The effective useful life of a PV system is longer than that of the fuel cell, which means PV has additional years of benefits accruing to the customer and contributing to the present value, while the capital costs can also be spread over more years.

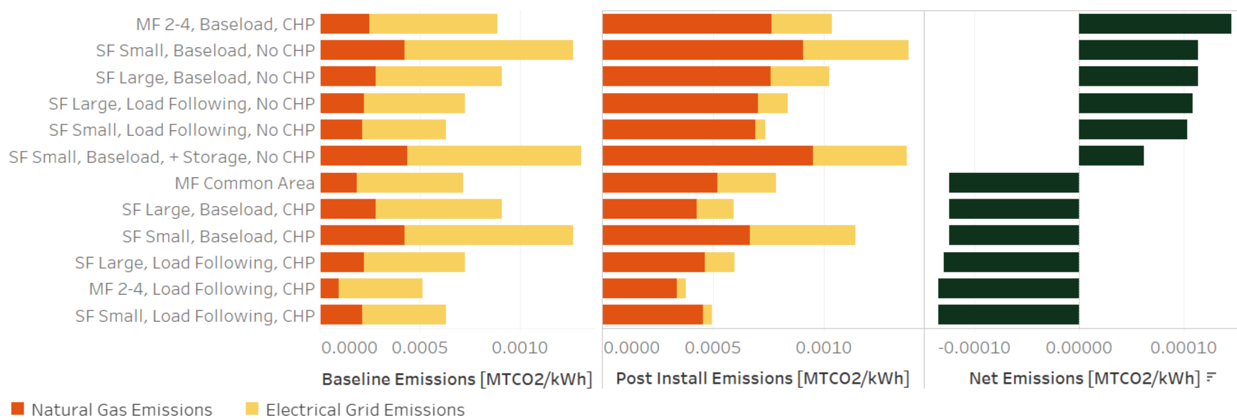
There are also several additional benefits to fuel cells that are not captured by PV + Battery systems:

- The fuel cell recovers heat that can be used to offset the DHW and pool heating.
- The fuel cell provides 24-hour benefits, meaning it will offset the home's baseload, not just when the sun is shining, although this can also be accomplished through the right sizing of the PV + Battery system.

6.7 GREENHOUSE GAS EMISSIONS

Installing a residential fuel cell can produce a range in emissions outcomes depending on the different scenarios in which the system is installed. Net emissions are based on two factors; the increased natural gas emissions from the residential fuel cell, and the decreased grid emissions resulting from the decreased electricity needs. The net emissions are calculated by load shape and shown below in Figure 6-7. A positive net emission value indicates an increase in emissions from installing a residential fuel cell, while a decrease in net emissions indicates a reduction in emissions resulting from installing a residential fuel cell.

FIGURE 6-7: EMISSIONS [MTCO2/KWH]



Systems designed to recover heat all achieve a reduction in emissions, as they can offset some of their natural gas usage used for domestic hot water heating and pool heating. However, systems that do not recover heat all create increased emissions.

Emissions of the grid are calculated based on the SGIP signal[20] developed by WattTime, which represents a real-time indicator of greenhouse gas emissions. This signal is based on the Marginal Operating Emissions Rate from the marginal generator on the grid at any given moment.

[20] The SGIP GHG signal is provided by WattTime under a contract with the California Energy Commission and CPUC to support emissions-aligned operation of distributed energy resources. https://content.sgipsignal.com/.

6.8 CALIFORNIA POLICY CONTEXT

California has ambitious decarbonization and electrification policies. California Senate Bill (SB) 100 requires that 60% of California's electricity must be generated from renewable resources by 2030 and requires 100% carbon free electricity by 2045.[21] Therefore, finding a place for fuel cells in California's future may be a difficult task. However, fuel cells operating on RNG can provide benefits to customers, offsetting grid-purchased power, avoiding electrical grid-related costs, and reducing emissions. As discussed in the sections above, RNG scenarios for homes that maximize the use of the fuel cell capacity see the greatest benefits. However, there are currently no RNG tariffs available to residential customers, so while this may be a feasible option in the future, it may be useful to explore how fuel cells might play a role in other scenarios below:

Medical Baseline Customers: The medical baseline program provides several benefits to customers with life-threatening medical conditions with the need of electrical devices or consistent heating and cooling needs. The program also provides their residential customers with extra notifications in advance of PSPS events and other planned outages. However, it does nothing for customers in the event of unplanned outages, some of which can last for quite a while as seen from the annual reliability reports described in Section 6.1. Customers who rely on powered medical devices to keep them alive, or may already have back-up generators for this purpose, may benefit from a fuel cell, which could help them survive through a multi-day outage. This option will also be cleaner and provide less emissions and greenhouse gases than a fossil fueled emergency generator.

As discussed previously in Section 6.1, the Medical Baseline Study Research Plan provides a list of Conditions, Devices, and Condition-Device Combinations that would make a customer eligible for the MBL[22] and may be useful to help target MBL customers who would most benefit from the added resiliency a fuel cell can provide.

Home Electrical Service Upgrades: Older homes may have costly electrical upgrades related to electrification, including whole home electrical wiring requirements, panel upgrades, and utility service upgrades. While the electrical wiring and panel upgrades may need to be done regardless, it is possible that utility service upgrades can be postponed if a customer is able to serve part of their electrical load with a fuel cell.

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[21] California Energy Commission. SB100 Joint Agency Report. https://www.energy.ca.gov/sb100. Accessed 03/14/2025.

[22] Verdant Associates. Medical Baseline Study Research Plan. Appendix A. September 10th, 2024. https://pda.energydataweb.com/api/view/4067/Final_MedicalBaselineStudy_ResearchPlan_20240930_.pdf. Accessed March 21st, 2025.

The cost-of-service upgrades can vary widely, but a report by SPUR[23] cites that in scenarios where the home has underground service lines, 5% of projects can cost upwards of $31,000 to modify the service. In overhead service line scenarios, 5% of projects can cost upwards of $40,000. These numbers are based on PG&E estimates, and may involve right of way or easements, additional and/or upgrades to infrastructure, and difficult conditions or long trenching required. Installing a fuel cell may alleviate the need for cost-of-service upgrades.

GHG Emissions and Avoided Costs: While SB 100 is targeting 100% clean energy by 2045, it also targets grid reliability and environmental, social, and economic cost benefits. Fuel cells, in many scenarios under current grid conditions, can provide cleaner energy generation than is produced from the grid. At the very least, this can make it a transitionary resource that can be relied on to help balance grid stability with the increase in intermittent renewable energy. Additionally, distributed resources like fuel cells can reduce transmission losses as well as avoid costly grid upgrades and repairs that may be needed as more homes turn toward electrification.

[23] SPUR. *Solving the Panel Puzzle. Avoiding and streamlining electric panel and service upsizing to accelerate building decarbonization.* May 2024. https://www.spur.org/sites/default/files/2024-05/SPUR_Solving_the_Panel_Puzzle.pdf. Accessed March 21st, 2025.

7 CONCLUSIONS

Residential fuel cells can offer promising solutions under specific scenarios for providing reliable, efficient, and resilient energy, particularly in regions with high electricity costs, frequent power outages, and high fire threat risks. Verdant analyzed multiple scenarios to demonstrate situations in which consumer benefits exceed the costs, providing cost-effective solutions to reduce customer bills and grid costs. The analysis highlights key factors influencing the feasibility and cost-effectiveness of residential fuel cells:

- **Heat Recovery Enhances System Benefits:** Fuel cells with heat recovery capabilities provide greater economic and environmental benefits, particularly in homes with significant domestic hot water (DHW) or pool heating needs. These systems improve overall efficiency and deliver added value to both participants and society.
- **Customer Characteristics Influence Cost-Effectiveness:** Larger homes with higher annual electricity consumption (closer to 13,000 kWh/year) experience improved payback periods and greater cost savings compared to smaller homes (~7,000 kWh/year). Homes in inland climate zones also see higher participant benefits due to increased year-round utilization of the fuel cell system.
- **Resiliency as a Driver of Adoption:** Customers in Southern California Edison (SCE) service territory have historically experienced a higher frequency of power outages compared to those in San Diego Gas & Electric (SDG&E) territory. In High Fire Threat Districts, customers may prioritize resiliency benefits despite backup-only fuel cell systems not achieving favorable cost-effectiveness under traditional metrics. The added peace of mind, potential insurance discounts, and home protection associated with fuel cells as a backup power source may also influence the adoption decisions of a consumer.
- **Load-Following Fuel Cells Provide Greater Value:** Fuel cells designed to follow a home's energy load perform better in residential applications than those designed to offset a constant baseload. Load-following systems maximize generation and minimize exported electricity, resulting in improved participant benefits and cost-effectiveness.
- **Incentives Can Support Market Growth:** While incentives may not be the primary deciding factor for many customers, they can enhance cost-effectiveness by shortening payback periods. Targeted incentive programs may be particularly effective in encouraging adoption among low-income customers.
- **Fuel Source Considerations Impact Economic Viability:** Renewable Natural Gas (RNG) can provide additional environmental benefits when used with fuel cells; however, the higher cost of RNG and the lower value of exports under the net billing tariff (NBT) reduces the financial appeal of excess electricity exports. As a result, fuel cells should prioritize utilizing the energy generated to maximize offsetting the grid-purchased electricity over exporting surplus energy.

- **Regional Rate Differences Affect Benefits:** SDG&E customers experience higher participant benefits due to the combination of elevated electricity rates and lower gas costs, making fuel cell adoption more attractive in this region compared to SoCal Gas/SCE territories.

There are also many challenges that residential fuel cells still face, including significant regulatory hurdles and a growing push towards decarbonization. California's Senate Bill 100 mandates that 100% of the state's electricity must be carbon-free by 2045, emphasizing the transition away from fossil fuels. This shift poses challenges for fuel cells that rely on non-renewable fuels such as natural gas. Nonetheless, fuel cells that operate on Renewable Natural Gas (RNG) could align with California's clean energy goals while providing essential resiliency benefits. Additionally, this study does not address the potential for fuel cells operating on hydrogen, or a blend of hydrogen and natural gas. This could be an area of future study, as hydrogen fuel cells could be a resource to support California's decarbonization policies.

Fuel cells may also play a role in specific applications where resiliency is critical. Medical Baseline customers who depend on powered medical devices could benefit from fuel cells as a reliable backup power source during outages. Additionally, fuel cells may help homeowners avoid costly utility service upgrades that are sometimes required for full electrification. Furthermore, with the push to an electrified California, a growing electricity grid may face reliability challenges, and fuel cells could serve as a transitional technology, reducing grid strain and providing decentralized generation to complement intermittent renewables.

While regulatory challenges remain, fuel cells have the potential to support California's clean energy future by providing localized, resilient, and lower-emission energy solutions. Strategic deployment, supportive policies, and technological advancements will be key to their long-term viability.

APPENDIX A MODEL RESULTS

A.1 GROUP #1

This scenario represents a multifamily facility with 2-4 units, where the fuel cell offsets the facility's baseload. The system does not recover heat, and there are no resiliency benefits for this scenario, as the manufacturer can only operate in a power outage when installed in conjunction with a battery. No incentives have been included as part of this scenario.

FIGURE A-1: RESULTS FOR GROUP #1

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
1	Base Load	MF	N	Mfr. #1	N	SD&GE	$0	FC
						SoCalGas/SCE	$0	FC

A.2 GROUP #2

This scenario represents a multifamily facility with 2-4 units, where the fuel cell offsets follow the load of the facility. The system does not recover heat, but resiliency benefits are being accounted for. No incentives have been included as part of this scenario.

FIGURE A-2: RESULTS FOR GROUP #2

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
2	Load Follow	MF	N	Mfr. #3	N	SD&GE	$141	FC
						SoCalGas/SCE	$252	FC

A.3 GROUP #3

This scenario represents a multifamily facility's common area with over 50 units, where the fuel cell offsets the baseload of the facility's common area, including pool area, outside lighting, and laundry facilities. The system recovers heat that is used to offset pool heating. The calculations account for resiliency benefits that the participant may see. No incentives have been included as part of this scenario.

FIGURE A-3: RESULTS FOR GROUP #3

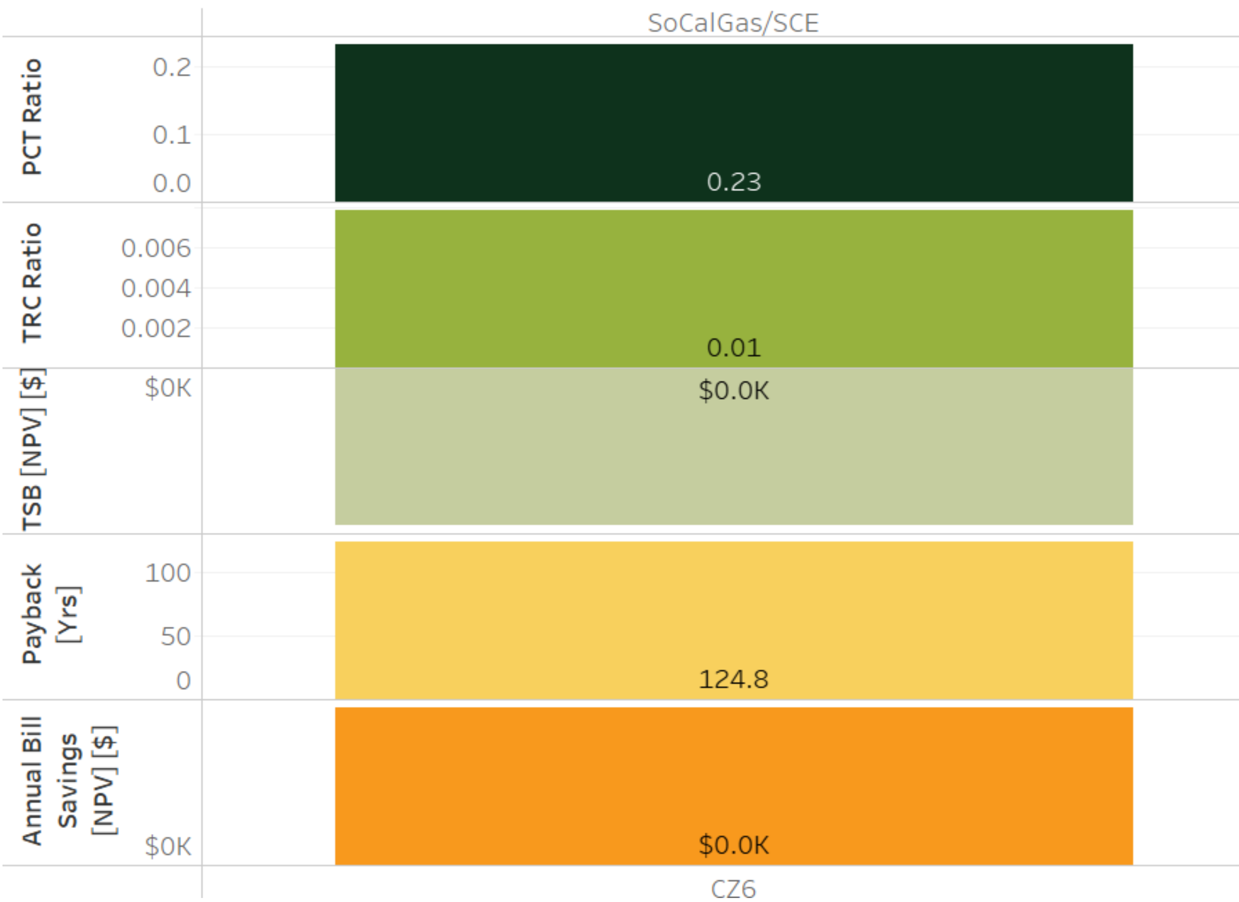
Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
3	Base Load	CA	N	Mfr. #3	Y	SD&GE	$71	FC
						SoCalGas/SCE	$126	FC

A.4 GROUP #4

This scenario represents a small single-family home where the fuel cell is only used as a backup generator in the event of power outages. No incentives have been included as part of this scenario. Only single run for one climate zone simulated.

FIGURE A-4: RESULTS FOR GROUP #4

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
4	Backup	SF-Small	N	Mfr. #2	N	SoCalGas/SCE	$105	FC



A.5 GROUP #5

This scenario represents a small single-family home where the fuel cell offsets the home's baseload. No incentives have been included as part of this scenario, but the fuel cell does recover heat that is used to offset natural gas DHW and pool heating usage. The fuel cell operates in conjunction with a battery that is already installed at the home, where the fuel cell charges the battery, and the battery is used to help reduce the facility's grid-purchased electricity when the home's load is greater than the capacity of the fuel cell. No resiliency benefits are included, because they are assumed to be accounted for with the battery already. No battery installation or capital costs are considered.

FIGURE A-5: RESULTS FOR GROUP #5

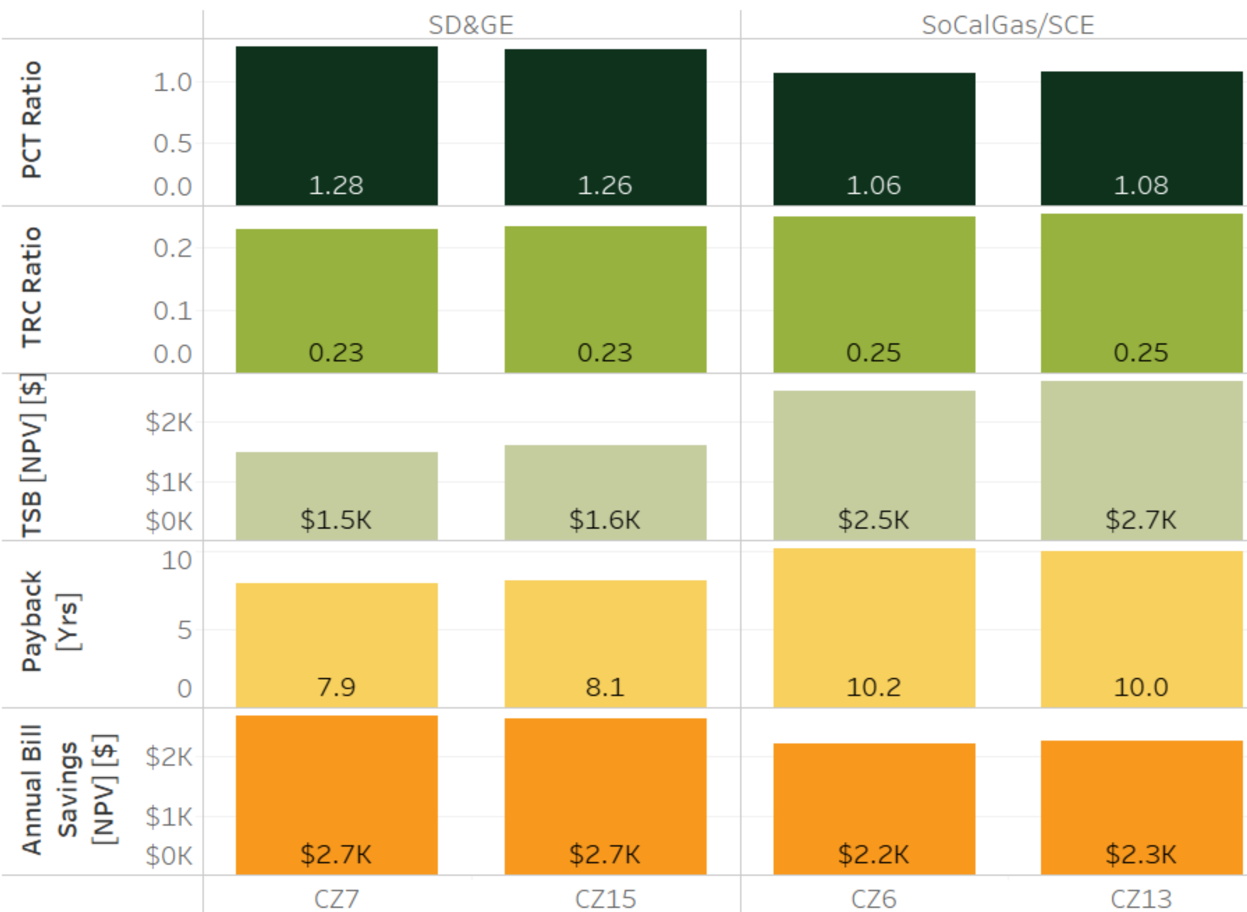
Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
5	Base Load	SF-Small	N	Mfr. #3	Y	SD&GE	$0	FC + Storage
						SoCalGas/SCE	$0	FC + Storage

A.6 GROUP #6

This scenario represents a large single-family home where the fuel cell offsets the home's baseload. No incentives have been included as part of this scenario, but the fuel cell does recover heat that is used to offset natural gas DHW and pool heating usage. The fuel cell operates in conjunction with a battery that is already installed at the home, where the fuel cell charges the battery, and the battery is used to help reduce the facility's grid-purchased electricity when the home's load is greater than the capacity of the fuel cell. No resiliency benefits are included, because they are assumed to be accounted for with the battery already. No battery installation or capital costs are considered.

FIGURE A-6: RESULTS FOR GROUP #6

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
6	Base Load	SF-Large	N	Mfr. #3	Y	SD&GE	$0	FC + Storage
						SoCalGas/SCE	$0	FC + Storage



A.7 GROUP #7

This scenario represents a small single-family home where the fuel cell offsets the home's baseload. No incentives have been included as part of this scenario, and the fuel cell does not recover heat. There are no resiliency benefits for this scenario, as the manufacturer can only operate in a power outage when installed in conjunction with a battery. This scenario operates on Renewable Natural Gas and exports any generated power that cannot be used back to the grid. The mild-climate SoCalGas/SCE scenario performs so much more poorly than the others, because the milder climate and the small sized home provides less of an opportunity for the fuel cell to offset grid-load in this specific scenario.

FIGURE A-7: RESULTS FOR GROUP #7

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
7	Base Load	SF-Small	N	Mfr. #1	N	SD&GE	$0	FC
						SoCalGas/SCE	$0	FC

A.8 GROUP #8

This scenario represents a small single-family home where the fuel cell follows the home's load. No incentives have been included as part of this scenario, and the fuel cell does not recover heat. There are no resiliency benefits for this scenario, as the scenario involves the installation of the fuel cell that operates in conjunction with existing battery storage and solar PV. The fuel cell provides power during times when the solar PV is not generating, and when the battery is fully discharged.

FIGURE A-8: RESULTS FOR GROUP #8

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
8	Load Follow	SF-Small	N	Mfr. #1	N	SD&GE	$0	FC + Storage + PV
						SoCalGas/SCE	$0	FC + Storage + PV

A.9 GROUP #9

This scenario represents a small single-family home where the fuel cell follows the home's load. The fuel cell recovers heat to be used to offset DHW and pool heating. Resiliency benefits are considered as a benefit to the customer. No incentives are provided.

FIGURE A-9: RESULTS FOR GROUP #9

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
9	Load Follow	SF-Small	N	Mfr. #3	Y	SD&GE	$71	FC
						SoCalGas/SCE	$126	FC

A.10 GROUP #10

This scenario represents a large single-family home where the fuel cell follows the home's load. The fuel cell recovers heat to be used to offset DHW and pool heating. Resiliency benefits are considered as a benefit to the customer. No incentives are provided.

FIGURE A-10: RESULTS FOR GROUP #10

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
10	Load Follow	SF-Large	N	Mfr. #3	Y	SD&GE	$71	FC
						SoCalGas/SCE	$126	FC

A.11 GROUP #11

This scenario represents a small single-family home where the fuel cell follows the home's load. The fuel cell does not recover any heat. Resiliency benefits are considered as a benefit to the customer. No incentives are provided. This scenario should be compared to Group #9 to quantify the impact of CHP.

FIGURE A-11: RESULTS FOR GROUP #11

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
11	Load Follow	SF-Small	N	Mfr. #3	N	SD&GE	$71	FC
						SoCalGas/SCE	$126	FC

A.12 GROUP #12

This scenario represents a large single-family home where the fuel cell follows the home's load. The fuel cell does not recover any heat. Resiliency benefits are considered as a benefit to the customer. No incentives are provided. This scenario should be compared to Group #10 to quantify the impact of CHP.

FIGURE A-12: RESULTS FOR GROUP #12

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
12	Load Follow	SF-Large	N	Mfr. #3	N	SD&GE	$71	FC
						SoCalGas/SCE	$126	FC

A.13 GROUP #13

This scenario represents a small single-family home where the fuel cell offsets the home's baseload. No incentives have been included as part of this scenario, and the fuel cell does not recover heat. The fuel cell operates in conjunction with a battery that is already installed at the home, where the fuel cell charges the battery, and the battery is used to help reduce the facility's grid-purchased electricity when the home's load is greater than the capacity of the fuel cell. No resiliency benefits are included, because they are assumed to be accounted for with the battery already. No battery installation or capital costs are considered. This scenario should be compared to Group #5 to quantify the impact of CHP.

FIGURE A-13: RESULTS FOR GROUP #13

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
13	Base Load	SF-Small	N	Mfr. #3	N	SD&GE	$0	FC + Storage
						SoCalGas/SCE	$0	FC + Storage

A.14 GROUP #14

This scenario represents a large single-family home where the fuel cell offsets the home's baseload. No incentives have been included as part of this scenario, and the fuel cell does not recover heat. The fuel cell operates in conjunction with a battery that is already installed at the home, where the fuel cell charges the battery, and the battery is used to help reduce the facility's grid-purchased electricity when the home's load is greater than the capacity of the fuel cell. No resiliency benefits are included, because they are assumed to be accounted for with the battery already. No battery installation or capital costs are considered. This scenario should be compared to Group #6 to quantify the impact of CHP.

FIGURE A-14: RESULTS FOR GROUP #14

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
14	Base Load	SF-Large	N	Mfr. #3	N	SD&GE	$0	FC + Storage
						SoCalGas/SCE	$0	FC + Storage

A.15 GROUP #15

This scenario represents a small single-family home where the fuel cell follows the home's load. No incentives have been included as part of this scenario, but the fuel cell does recover heat. This is the only scenario run for manufacturer #4, which offers a much smaller, 700W fuel cell.

FIGURE A-15: RESULTS FOR GROUP #15

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
15	Load Follow	SF-Small	N	Mfr. #4	Y	SD&GE	$33	FC
						SoCalGas/SCE	$59	FC

A.16 GROUP #16

This scenario represents a large single-family home where the fuel cell follows the home's load. This does follow load, recovers heat to offset pool heating and DHW, and includes resiliency benefits. This scenario also includes a $2/W incentive. Compare this to Group #10 to quantify the effect of the incentive.

FIGURE A-16: RESULTS FOR GROUP #16

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
16	Load Follow	SF-Large	Y	Mfr. #3	Y	SD&GE	$71	FC
						SoCalGas/SCE	$126	FC

A.17 GROUP #17

This scenario represents a large single-family home where the fuel cell follows the home's load. This does follow load, recovers heat to offset pool heating and DHW, and includes resiliency benefits. This scenario also represents the fuel cell scenario incorporating potential future costs of a fuel cell. Compare this to Group #10 to quantify the effect the costs have on the results.

FIGURE A-17: RESULTS FOR GROUP #17

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
17	Load Follow	SF-Large	N	Mfr. #3	Y	SD&GE	$71	FC
						SoCalGas/SCE	$126	FC

A.18 GROUP #18

This scenario represents a large single-family home where the fuel cell follows the home's load. This does follow load, recovers heat to offset pool heating and DHW. It also factors in a maximum resiliency benefit for a home that sees significant outages throughout the year. Compare this to Group #10 to quantify the effect the resiliency benefit has on the results.

FIGURE A-18: RESULTS FOR GROUP #18

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
18	Load Follow	SF-Large	N	Mfr. #3	Y	SD&GE	$87	FC
						SoCalGas/SCE	$1091	FC

A.19 GROUP #19

This scenario represents a small single-family home where the fuel cell offsets the home's baseload. No incentives have been included as part of this scenario, and the fuel cell does not recover heat. There are no resiliency benefits for this scenario, as the manufacturer can only operate in a power outage when installed in conjunction with a battery. This scenario operates on Renewable Natural Gas and exports any generated power that cannot be used back to the grid. The mild-climate SoCalGas/SCE scenario performs so much more poorly than the others, because the milder climate and the small sized home provides less of an opportunity for the fuel cell to offset grid-load in this specific scenario. This also includes an incentive of $4/W. Compare this to Group #7 to quantify the effect of the incentive.

FIGURE A-19: RESULTS FOR GROUP #19

Grp. #	Load Shape	Home Type	Incentive	Mfr. #	CHP	Utility	Resiliency Benefit [$]	Tech. Type
19	Base Load	SF-Small	Y	Mfr. #1	N	SD&GE	$0	FC
						SoCalGas/SCE	$0	FC