CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

**FINAL PROJECT REPORT**

# A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California


**Gavin Newsom, Governor**

**March 2019 | CEC-500-2019-030**

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**Contract Number**: PIR-16-008

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ACKNOWLEDGEMENTS

The authors thank Rizaldo Aldas and Kevin Uy at the California Energy Commission for their support and guidance during the entire project. In addition, the authors thank Southern California Gas Company for their guidance, market input, and financial support. The project team also thanks the Technical Advisory Committee members for information provided and specific comments made on draft materials:

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# PREFACE

The California Energy Commission's Energy Research and Development Division manages the Natural Gas Research and Development program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency.
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity.
- Energy-Related Environmental Research
- Natural Gas-Related Transportation.

*Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California* is the final report for the Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California project (grant agreement number PIR-16-008) conducted by the team of ICF, Southern California Gas Company, and DE Solutions. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

# ABSTRACT

This study identifies, characterizes, and assesses combined heat and power (CHP) technologies and applications less than 5 megawatts (MW) for residential, commercial, and light industrial markets in California. Cost, performance, and emissions data are presented for mature CHP technologies, enabling technologies for CHP systems such as absorption chillers and thermal energy storage, and emerging micro-CHP technology options. Potential applications are explored, including buildings with existing CHP installations, types of buildings and loads that are conducive to CHP, and California sites that can support CHP systems.

The market assessment found numerous economically viable applications, with a significant amount of expected adoption. There are 662 MW of CHP systems less than 5 MW currently installed in California, with nearly 1.9 GW of additional CHP capacity less than 5 MW expected to come online over the next 20 years. More than 80 percent of this expected CHP capacity comes from traditional CHP systems between 50 kW and 5 MW in size. However, a large number of sites are expected to install 10-50 kW CHP systems. The future market for 1-2 kW micro-CHP systems for single family homes is uncertain, due to variable residential energy rates and a lack of commercially available equipment, but there could be a large potential market in California for these residential applications.

Natural gas-fueled CHP systems can play an important role in helping California meet greenhouse gas goals. This report also describes opportunities for CHP in microgrid applications and how flexible CHP systems can support the grid while enabling further adoption of renewable energy resources. Also included is a summary of barriers that impede adoption of CHP in California and potential solutions.

**Keywords:** Combined heat and power, cogeneration, micro-CHP, flex CHP, CHP market potential, natural gas, distributed generation, GHG emissions

Please use the following citation for this report:

Jones, David, Keith Davidson, Rod Hite, and Annie Howley. 2019. *A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California*. California Energy Commission. Publication Number: CEC-500-2019-030.

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# EXECUTIVE SUMMARY

## Introduction

Combined heat and power (CHP), also known as cogeneration, produces electricity and useful thermal energy in an integrated system. CHP systems can range in size from a few kilowatts to hundreds of megawatts, and use a variety of different generation technologies such as reciprocating engines, gas turbines, microturbines, and fuel cells. Combining electricity and thermal energy generation into a single process can save up to 35 percent of the energy required to perform these tasks separately.

California accounts for 10 percent of the United States' installed combined heat and power capacity, with 8,500 MW of operational CHP systems. According to the Department of Energy large industrial and institutional CHP installations account for most of this capacity, because of favorable economics and mature product availability, with about 8 percent (663 MW) coming from systems less than 5 megawatts (MW). In a recent California Energy Commission report, the technical potential for CHP in California was estimated at 8,000 MW for new applications between 50 kilowatts (kW) and 5 MW. Additionally, emerging micro-CHP technologies could open the market to thousands of commercial applications and millions of residential applications under 50 kW in size. It is necessary to develop a better understanding of small and micro-scale CHP products and examine their potential to enter the California market.

The project team of ICF, DE Solutions, and Southern California Gas Company (SoCalGas), built on knowledge gained from prior assessments, and extended this knowledge base to small (<5 MW) CHP systems. Methods that have been applied in previous analytical assessments were used for a CHP technical and market assessment grounded in technical data and evaluation.

## Project Purpose

California energy policy, legislation, regulations, and consumer advocacy for sustainable energy practices generally do not encourage natural gas-fueled CHP and do not provide many incentives. This is mainly due to California clean energy goals which mandate 60 percent renewable electricity by 2030 and 100 percent renewable electricity by 2045. While CHP systems can be renewably-fueled, the majority are fueled by natural gas. Additional charges such as standby rates, charged by utilities when CHP systems have scheduled or emergency outages and must draw power from the grid, and load departing fees, charged by utilities when CHP systems are first installed and load has effectively "departed" from the grid, hinder the economics for CHP and discourage new installations. Despite these challenges, the CHP industry continues to advocate for CHP technologies as they can offer a clean, efficient, and economical solution while still contributing to California's ambitious greenhouse gas reduction goals.

This project did a comprehensive assessment of small and micro-scale CHP technical and market potential in California. The assessment focused on residential, commercial, and light industrial markets that can support CHP installations smaller than 5 MW. The project team identified several economic opportunities for small and micro CHP technologies with the associated emission savings. The project team also identified barriers to the increased adoption of small and micro-scale CHP systems and discussed potential solutions to these barriers.

By identifying and evaluating CHP opportunities in California, this report may encourage increased adoption of CHP for economic growth and greater system reliability, and may cause policy makers to reconsider the role that CHP can play in California's energy future.

## Project Process

During the 14 months, the project team advanced the knowledge base for small and micro-scale CHP by:

- Evaluated and characterized commercially available and emerging prime mover technologies (for example reciprocating engines, gas turbines, microturbines, fuel cells, and Stirling engines).
- Assessed thermal recovery technologies that can be integrated with prime movers to produce small and micro-scale CHP systems (such as hot water storage, and/or absorption cooling).
- Conducted a market assessment to estimate the market size and potential adoption of small and micro-scale CHP systems in California, including the potential emissions impact.
- Evaluated the impact of different policy scenarios, technology characteristics, and energy rates on the potential market size for CHP.
- Investigated critical integration issues necessary for CHP to dovetail into California's aggressive shift to renewable energy.
- Identified barriers to adopting small and micro-scale CHP systems, and discussed potential solutions to these barriers.
- Held two workshops -presenting the project results to stakeholders and solicited guidance on project progress along the way. The workshops results and stakeholder input received are summarized in APPENDIX E: Workshop Summaries.
- Assembled a Technical Advisory Committee who regularly advised the team, offered input on deliverables, and represented diverse perspectives within the CHP industry. The organizations and individuals represented were:
    - Research Organizations:
        - Electric Power Research Institute – Brittany Westlake
        - Gas Technology Institute – Tim Kingston
    - CHP Technology Manufacturers:

        - Fuel Cell Energy – Paul Fukumoto
        - Regatta Solutions – Steven Acevedo, Mark Gilbreth
        - Solar Turbines Incorporated – Adam Robinson
        - Tecogen – Bill Martini
    - CHP Project Developers and System Operators:
        - NRG Energy – Carol Denning
        - Western Energy (GE Jenbacher) – Steve Hall, Thomas Marihart
    - CHP Technical Assistance Provider:

Expanding on previous California CHP market assessments conducted for the Energy Commission, this assessment evaluated in greater detail the potential markets for CHP systems less than 5 MW in size and for the first time examined the market for micro-CHP systems with a capacity under 50 kW, including future residential markets for single family homes. Overall, the economic and market indicators suggest that California will see a significant increase in the adoption of small CHP systems over the next 20 years. Emerging micro-CHP technologies could open up markets for these smaller applications, providing more societal benefits from CHP's improved efficiency, reduced emissions, energy cost savings, and enhanced resiliency.

The analysis showed that there is close to 12 GW of technical potential for CHP applications smaller than 5 MW in California. 7.4 GW of this potential comes from traditional CHP systems, while more than 4 GW is derived from micro CHP systems smaller than 50 kW in size. Approximately half of the total technical potential is estimated to be economical, with a payback period less than 10 years, and close to 2 GW of new CHP installations are expected to come online over the next 20 years. This represents three times the current installed base of CHP systems less than 5 MW in California.

The results of this analysis will be used by interested stakeholders to make near-term, mid-term, and long-term decisions regarding CHP. For example, facilities interested in installing CHP will use the technology characterization and application analysis to determine which technologies best fit their facility. Technology developers will use the technical and market assessments to determine which applications or which utility territories would have the most market potential for their technology. Research organizations and government agencies will use the issues and barriers assessment to identify the research required to remove barriers for CHP adoption.

The results of this analysis are also summarized in four fact sheets, available in APPENDIX G:
Fact Sheets.

## Sharing Information

The target audience this project are regulators, hardware vendors, project developers, technology RD&D professionals, utility account representatives, and policy analysts. The project team shared results of the project through numerous venues including:

- Two stakeholder workshops.
- Two technical advisory committee meetings.
- Speaking opportunities at outside conferences including presenting at the CHP Association 2017, Cogeneration Day 2017, PowerGen 2017 and the California Clean DG Coalition 2018.

## Benefits to California

Economics and resilience are expected to be the primary drivers for CHP adoption in California, but there will also be societal benefits from CHP installations as higher energy efficiencies and reduced greenhouse gas emissions compared to separate heat and utility power. This project analysis estimates that in 2037, 1.9 GW of small and micro CHP will be adopted, resulting in 39 million MMBtu/year of fuel conserved (primarily natural gas), a savings of 23 percent compared to separate heat and utility power. Additionally, 3,200 tons per year of NOx emissions and more than 1 million tons of carbon dioxide (equivalent) greenhouse gas emissions would be reduced on an annual basis.

By recovering heat normally lost during power generation and avoiding transmission and distribution system losses, CHP reduces overall energy use, lowers GHG and criteria pollutant emissions, increases power reliability, and often provides substantial energy cost savings for end users.

The results from this project are expected to help inform California policymakers on how installing more small CHP systems can contribute to meeting state statutory energy goals including and greenhouse gas emissions reduction by quantifying how much emissions are likely to be reduced. Results from this project are also expected to help the California Energy Commission plan future R&D initiatives that will advance the state of technology of small and micro-scale CHP systems. Finally, this project will benefit facility owners and operators, technology manufacturers and providers, and natural gas IOU ratepayers by quantifying the potential benefits of small CHP systems in California.

# CHAPTER 1: Introduction

This project completed a combined heat and power (CHP) technical and market assessment for small (less than 5 Megawatt [MW]) CHP systems applicable to residential, commercial, and light industrial markets in California. Previous California Energy Commission assessments profiled CHP technologies greater than 50 kilowatt (kW). This study updates the product performance and cost characteristics in the 50 kW – 5 MW size range and provides a look at smaller CHP technologies down to 1 kW in size to serve residential, small commercial, and light industrial applications.

Combined heat and power, also known as cogeneration, produces electricity and useful thermal energy in an integrated system. CHP systems can range in size from a few kilowatts to hundreds of megawatts, and can use a variety of different generation technologies such as reciprocating engines, gas turbines, microturbines, and fuel cells. Combining electricity and thermal energy generation into a single process can save up to 35 percent of the energy required to perform these tasks separately.

Currently there is 663 MW of operational CHP capacity in California for systems sized 5 MW or smaller.[1] An earlier study for the California Energy Commission estimates that 8,000 MW of untapped CHP potential exists in California for systems in the 50 kW – 5 MW size class.[2] Considering the additional potential for <50 kW systems that has yet to be quantified, it is clear that the residential, small commercial and light industrial markets have been underserved by CHP thus far.

CHAPTER 2 of this report provides a summary of representative prime movers in the <5 MW size class, along with key enabling technologies. The prime mover technologies covered in this report are reciprocating engines, gas turbines, microturbines, fuel cells, and Stirling engines. The enabling technologies include absorption cooling, ultra-low emission control systems, and thermal energy storage. CHP applications less than 5 MW are analyzed for the California market. First, current CHP installations are reviewed, providing insight on the markets for which CHP systems are currently being deployed. Next, potential CHP applications and opportunities specific for California are identified. Finally, California energy prices are explored.

In CHAPTER 3 the technical, economic, and market adoption potential is assessed for CHP applications in California. First, existing CHP installations are considered, and the

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[1] U.S. DOE Combined Heat and Power Installation Data Base. Available online: https://doe.icfwebservices.com/chpdb/

[2] Hedman, Bruce, Ken Darrow, Eric Wong, and Anne Hampson. ICF International, INc. 2012. Combined Heat and Power: 2011-2030 Market Assessment, California Energy Commission, CEC-200-2012-002.

technical potential for new CHP systems under 5 MW in size is quantified.[3] Following the technical potential analysis, economics are evaluated for potential CHP installations in California, for both traditional (50 kW – 5 MW) and micro (<50 kW) CHP markets, using the prime mover technologies characterized in CHAPTER 2. CHAPTER 3 concludes with a 20-year forecast for CHP adoption in California, the estimated emissions impacts compared to utility electricity purchases, and the results for alternative scenarios that include capital incentives and electricity rate reform.

CHAPTER 4 of this report highlights a range of CHP integration issues in California. These issues include the impact of policies and regulations on the potential for CHP adoption in California, opportunities for CHP to participate in a renewable energy future, and the value of CHP to different stakeholders. This chapter also summarizes key potential barriers that impede the adoption of CHP, followed by a list of recommendations that could address these barriers.

Finally, CHAPTER 5 summarizes the efforts and results of this Energy Commission technical and market assessment for small CHP applications in California.

[3] Facilities with technical potential include all buildings and campuses that can effectively use the electric and thermal output from CHP systems.

# CHAPTER 2: Identification and Characterization of Technologies and Applications

## Technology Identification and Characterization

This chapter identifies CHP technologies under 5 MW currently in use in California and describes their performance, cost, and emissions characteristics. Mature CHP technologies, enabling technologies, and emerging micro-CHP options are assessed for potential <5 MW CHP applications in the California market.

### Mature CHP Technologies

#### Reciprocating Engines

Reciprocating internal combustion engines (ICE) are a mature technology used for power generation, transportation, and many other purposes. Worldwide production of reciprocating internal combustion engines exceeds 200 million units per year.[4] For CHP installations, reciprocating engines have capacities that cover the range of this assessment from 1 kW to 5 MW (Figure 1). Several manufacturers offer reciprocating engines for distributed power generation, and these engines, which are most often fueled with natural gas, are well suited for CHP service.

**Figure 1: Reciprocating Engines**

Credit: Photo Courtesy of Western Energy Systems

[4] Power Systems Research. EnginLink™. 2013.

Table 1 provides a summary of attributes of reciprocating engines.

**Table 1: Summary of Reciprocating Engine Attributes**

| Attribute | Description |
|---|---|
| **Size Range** | Reciprocating engines for CHP are available in sizes from 1 kW to 10 MW.<br>The majority of CHP installations with reciprocating engine are below 5 MW.[2] |
| **Thermal Output** | Thermal energy can be recovered from the engine exhaust, cooling water, lubricating oil and intercooler, and then used to produce hot water, low pressure steam, or chilled water (with an absorption chiller). |
| **Part-load Operation** | Reciprocating engines perform well at part-load and are well suited for both baseload and load following applications. |
| **Fuel** | Reciprocating engines can be operated with a wide range of fuels. For CHP in California, natural gas is the most common fuel but biogas is also commonly used when available. |
| **Reliability** | Reciprocating engines are a mature technology with high reliability. |
| **Other** | Reciprocating engines have relatively low installed costs and are widely used in CHP applications. Reciprocating engines start quickly and operate on typical natural gas delivery pressures with no additional gas compression required. California emission regulations have challenged reciprocating engine technology but emissions control solutions have been developed. |

Source: Adapted from U.S. DOE. Reciprocating Engines CHP Technology Fact Sheet. July 2016

*Applications*

There are more than 700 reciprocating engine CHP installations in California, representing 68% of the entire population of installed CHP systems in this size class (1 kW - 5 MW).[5] These reciprocating engines have a combined capacity of nearly 381 MW, with the vast majority fueled by natural gas and other gaseous fuels. Common applications for reciprocating engine CHP systems include universities, hospitals, water treatment facilities, industrial facilities, and commercial buildings.

*Technology Description*

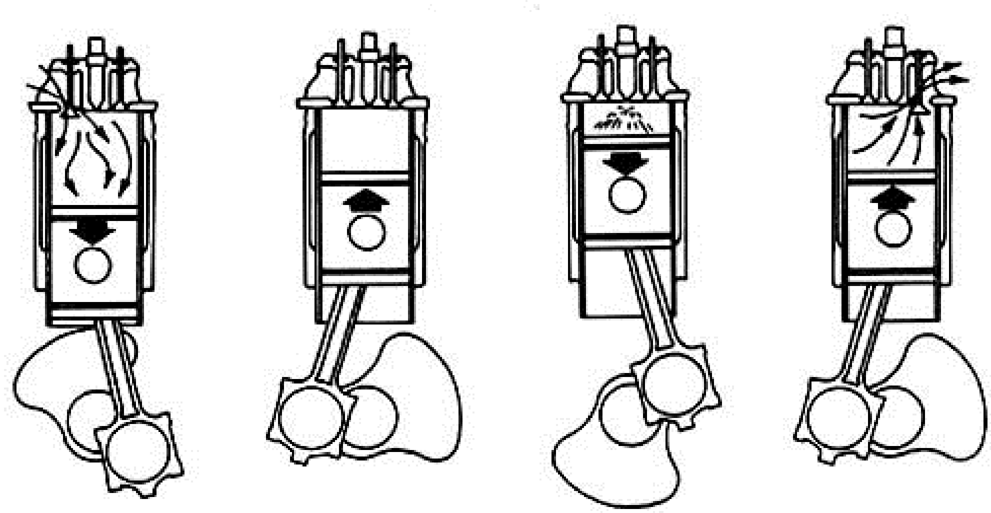
The spark ignition Otto-cycle engine is the reciprocating engine design prevalent in CHP applications. These engines use a cylindrical combustion chamber in which a close fitting piston travels the length of the cylinder. The piston connects to a crankshaft that

[5] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Data compiled through December 31, 2015. https://doe.icfwebservices.com/chpdb/

transforms the linear motion of the piston into the rotary motion of the crankshaft. Most engines have multiple cylinders that power a single crankshaft.

Otto-cycle engines use a spark plug to ignite a pre-mixed air/fuel mixture introduced into the cylinder. For CHP, most installations utilize four-stroke spark ignition engines, as shown in Figure 2.

**Figure 2: Four-Stroke Spark Ignition Reciprocating Engine**




Source: IHS Engineering

Reciprocating engines are characterized as either rich-burn or lean-burn. Rich-burn engines are operated near the stoichiometric air/fuel ratio, which means the air and fuel quantities are matched for complete combustion, with no excess air. In contrast, lean-burn engines are operated at air levels significantly higher than the stoichiometric ratio. Because of lower combustion temperatures in lean-burn engines, engine-out NOx emissions are reduced compared to rich-burn engines.

*Performance Characteristics*

Performance characteristics for five representative natural gas reciprocating engines used in CHP applications are summarized in Table 2. Rich-burn and lean-burn engines are represented along with three types of generators:

- An *induction* generator relies on power from the grid for field excitation and shuts down during a grid outage;
- A *synchronous* generator can run independent from the grid and must be in synch with the grid AC when operating in parallel; and
- Permanent magnet generators can produce power with waveforms incompatible with the power grid. The power is first rectified to DC power and then

conditioned by an *inverter* to parallel the grid. Inverter based systems can run isolated from the grid.

- Induction and synchronous generators are most commonly used for CHP installations. Inverter-based generators carry a cost premium, but they have some operational advantages over traditional generators and they are becoming more common, especially for smaller CHP systems.

**Table 2: Reciprocating Engine Performance Characteristics**

| Description | Rich-burn Induction | Rich-burn Inverter | Lean-burn Synchronous | Lean-burn Synchronous | Lean-burn Synchronous |
|---|---|---|---|---|---|
| Net Electric Power (kW) | 75 | 100 | 820 | 1,390 | 4,280 |
| Fuel Input (MMBtu/hr, HHV) | 0.896 | 1.175 | 8.05 | 13.41 | 36.51 |
| Useful Thermal (MMBtu/hr) [6] | 0.450 | 0.61 | 3.46 | 5.76 | 13.39 |
| Electric Heat Rate (MMBtu/hr) | 11,971 | 11,750 | 9,730 | 9,630 | 8,520 |
| Electric Efficiency (%, HHV) | 28.5% | 29.0% | 35.1% | 35.4% | 40.0% |
| Thermal Efficiency (%, HHV) | 50.3% | 52.2% | 43.0% | 38.6% | 35.0% |
| Overall Efficiency (%, HHV) | 78.8% | 81.2% | 78.1% | 74.0% | 75.0% |

**Performance characteristics are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

[6] Maximum hot water supply and return temperatures on the rich-burn engines is 230°F and 180°F respectively. For the lean-burn engines, maximum supply and return temperatures is 194°F and 158°F respectively. Additional lower grade heat (120 – 127°F) is available off the power electronics and the intercoolers, but was not included in the table.

The five systems shown range from 75 kW to 4.3 MW, which covers most CHP installations that use reciprocating engines in California. Electric efficiencies generally increase with size, and the electric efficiencies for the five systems range from approximately 28% to 40%. Overall, CHP efficiencies are close to 80%. As electrical efficiency increases, the quantity of thermal energy available to produce useful heat decreases per unit of power output, increasing the power to heat ratio.

*Capital and Operation and Maintenance (O&M) Costs*

Table 3 shows representative capital costs for natural gas reciprocating engines used in California CHP applications. The costs are average values based on data collected from multiple manufacturers. Installed costs can vary significantly depending on the scope of the plant equipment, geographical area, competitive market conditions, special site requirements, emission control hardware (South Coast Air Quality Management District [SCAQMD] Regulations), and prevailing labor rates.

**Table 3: Reciprocating Engine Capital and O&M Costs**

| Description | Rich-burn | Rich-burn | Lean-burn | Lean-burn | Lean-burn |
|---|---|---|---|---|---|
| Net Electric Power (kW) | 75 | 100 | 820 | 1,390 | 4,280 |
| **Capital Cost** | | | | | |
| Engine/Generator Package ($/kW) | $1,350 | $1,750 | $1,310 | $1,100 | $630 |
| Exhaust HR and Emission Equip. ($/kW) | Incl. | Incl. | $240 | $170 | $100 |
| Balance of Plant and Installation ($/kW) | $2,000 | $2,000 | $1,300 | $1,300 | $1,400 |
| Total Installed Cost | $3,350 | $3,750 | $2,850 | $2,570 | $2,130 |
| **Maintenance Cost** | | | | | |
| O&M – Engine/ Generator Pkg. (¢/kWh) | 2.4 | 2.4 | 1.6 | 1.2 | 1.0 |
| O&M – Balance of Plant (¢/kWh) | Incl. | Incl. | 0.3 | 0.3 | 0.3 |
| Total O&M Cost (¢/kWh) | 2.4 | 2.4 | 1.9 | 1.5 | 1.3 |

**Costs are average values and are not intended to represent specific products.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

Capital costs for generator set packages shown in Table 3 include all expenses for a complete CHP system, including heat recovery hardware and emission control equipment necessary to comply with SCAQMD Rule 1110.2.

The CHP systems shown in Table 3 are for hot water production, although reciprocating engines are also capable of producing low pressure steam. With construction and installation included, installed costs range from $3,700 to $2,130 per kW. As indicated, capital costs decline on a per kW basis as size increases. Non-fuel O&M costs are also shown in Table 3. As indicated, these costs range from 2.4 to 1.3 ¢/kWh. Like capital costs, O&M costs decline as capacity increases.

*Emissions*

Table 4 shows the various air criteria regulations applicable to reciprocating engine CHP operating on natural gas in California. Emissions can vary significantly between different engine models and manufacturers, and can also vary significantly with small changes in operating conditions (such as air/fuel ratio). Rich-burn engines have higher uncontrolled NOx emissions compared to lean-burn engines and are supplied with a three-way catalyst to control NOx, CO, and VOC emissions. For lean-burn engines, selective catalytic reduction (SCR) is used to reduce NOx emissions, and an oxidation catalyst is used to reduce CO and VOC emissions.

SCAQMD, whose territory is home to approximately 50% of California's population, is a serious non-attainment area that modified its reciprocating engine emission rule (1110.2) for Distributed Generation (DG) in 2008. The updated Rule 1110.2 required frequent testing using portable emission analyzers to ensure ongoing compliance. As of July 2017, several engine CHP projects have been permitted in SCAQMD since the rule was modified. In February 2018, the SCAQMD Board approved a Best Available Control Technology (BACT) determination update to reference Rule 1110.2 for non-emergency engine generators. This determination will be considered by other U.S. air districts when permitting reciprocating engine generators in the future.

The California Air Resources Board (CARB) has a DG Certification requirement for non-permitted natural gas DG that applies to DG engines less than 50 hp in size. CARB DG technologies are exempt from local air district permitting which can simplify planning, lowering costs, and potentially increase adoption CARB emission levels are also expressed in pounds (lbs) per MWh and provide an emission credit for recovered heat. The CARB DG levels shown in Table 4 contain CO and VOC requirements that are more stringent than SCAQMD.

**Table 4: Reciprocating Engine Emission Regulations**

| Constituent | NOx[7] | CO[8] | VOC[9] |
|---|---|---|---|
| BACT (ppm at 15% O2)<br>(lbs/MWh)[10] | 11.0<br>0.10 – 0.12 | 70.0<br>0.66 – 0.72 | N/A<br>N/A |
| SCAQMD Rule 1110.2 (lbs/MWh)[11] | 0.07 | 0.20 | 0.10 |
| CARB DG (lbs/MWh) | 0.07 | 0.10 | 0.02 |

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

Table 5 shows $CO_2$ emissions for engine CHP systems based solely on the power output. For the complete CHP system, $CO_2$ emissions are calculated with a thermal credit for natural gas fuel that would otherwise be used by an on-site boiler. With this credit, $CO_2$ emissions range from 478 - 540 lbs/MWh. For comparison, a typical natural gas combined cycle power plant will have emissions of 800 - 900 lbs/MWh.[12]

**Table 5: Reciprocating Engine CHP $CO_2$ Emissions**

| Description | Rich-burn | Rich-burn | Lean-burn | Lean-burn | Lean-burn |
|---|---|---|---|---|---|
| Net Electric Power (kW) | 75 | 100 | 820 | 1,390 | 4,280 |
| Electricity Only (lbs/MWh) | 1,475 | 1,375 | 1,139 | 1,127 | 997 |
| CHP (lbs/MWh) | 521 | 478 | 528 | 523 | 540 |

**Emissions are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

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[7] NOx conversion: NOx [lbs/MWh] = NOx [ppm at 15% $O_2$] / 271 / electrical efficiency [%, HHV] X 3.412.

[8] CO conversion: CO [lbs/MWh] = CO [ppm at 15% $O_2$] / 446 / electrical efficiency [%, HHV] X 3.412.

[9] VOC conversion: VOC [lbs/MWh] = VOC [ppm at 15% $O_2$] / 779 / electrical efficiency [%, HHV] X 3.412.

[10] For CHP systems with efficiencies of 60% or greater, a heat recovery credit is applicable at the rate of one MWh for each 3.4 MMBtu of heat recovered. The range is dependent on the performance characteristics and representative values are based on complete heat utilization.

[11] For CHP systems with efficiencies of 60% or greater, a heat recovery credit is applicable at the rate of one MWh for each 3.4 MMBtu of heat recovered.

[12] United States Department of Energy. Combined Heat and Power Fact Sheets – Reciprocating Engines. July 2016. Retrieved from: https://www.energy.gov/sites/prod/files/2016/09/f33/CHP-Recip%20Engines.pdf

### Gas Turbines

Gas turbines are available in sizes ranging from approximately one to more than 300 MW and are used to meet diverse power needs, including propulsion (for example aircraft, ships, and trains), direct drive (such as pumps and compressors) and stationary electricity generation (Figure 3). Gas turbines are well suited for industrial and institutional CHP applications because the high temperature gas turbine exhaust can either be used to generate high pressure steam or used directly for heating or drying. For CHP applications, gas turbines are more common in sizes greater than 5 MW.

**Figure 3: Example of a Gas Turbine**

Source: Solar Turbines

Table 6 provides a summary of gas turbine attributes. Gas turbines are used extensively for CHP, particularly at industrial and large institutional sites.

**Table 6: Summary of Gas Turbine Attributes in Applications**

| Attribute | Description |
|---|---|
| Size Range | For sizes less than 5 MW, the subject of this report, there are a limited number of products available. The smallest gas turbine size considered in this analysis is 3 MW. |
| Thermal Output | Gas turbines produce high temperature exhaust, and thermal energy can be recovered from this exhaust to produce steam, hot water, or chilled water (with an absorption chiller). The exhaust can also be used directly for industrial process drying or heating. Oxygen in the exhaust allows exhaust re-heating for additional useful thermal energy potentially adding dynamic flexibility to the gas turbine application. |
| Part-load Operation | The electrical generation efficiency of gas turbines declines significantly as the load is decreased. Therefore, gas turbines provide the most efficient performance in base load applications where the system operates at, or near, full load. |
| Fuel | In California, natural gas is the most common fuel. Biogas can also be used if properly treated. |
| Reliability | Gas turbines are a mature technology with high reliability. |
| Other | Gas turbines have relatively low emissions and are widely used in industrial CHP applications. Installed costs are on the high side for the smaller (less than 5 MW) machines. |

Source: Adapted from U.S. DOE Gas Engine CHP Technology Fact Sheet. July 2016

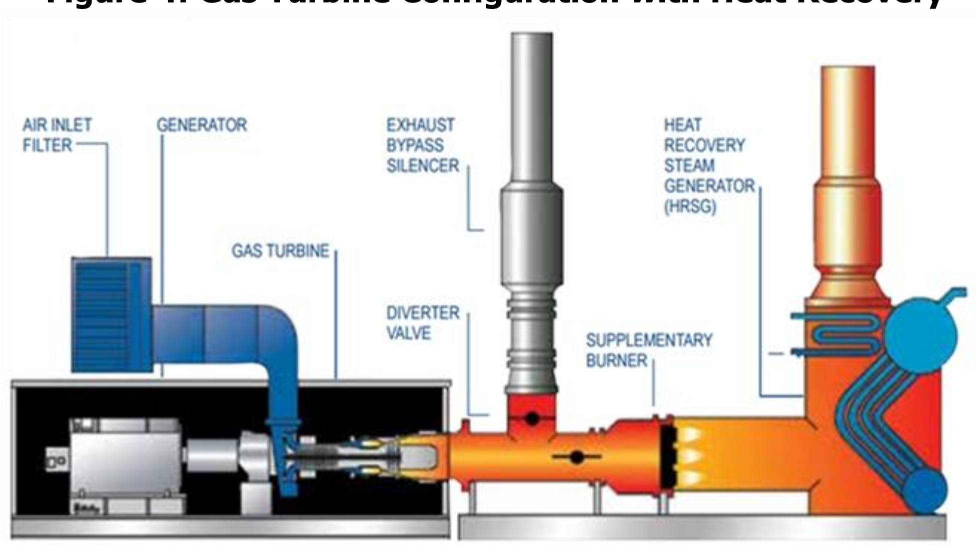
*Technology Description*

Gas turbines are constant pressure open cycle heat engines that are characterized by the Brayton Thermodynamic Cycle. Primary gas turbine hardware subsystems include a compressor, a combustion chamber, and an expansion turbine. Figure 5 highlights the key components of a simple cycle gas turbine. The compressor elevates the pressure and heats the inlet air which is then further heated by the addition of fuel in the combustion chamber. The hot air and combustion gas mixture drive an expansion turbine, producing enough energy to provide shaft power to the generator or mechanical process and to drive the compressor. The power produced by an expansion turbine and consumed by a compressor is proportional to the absolute temperature of the gas passing through the system. Consequently, it is advantageous to operate the expansion turbine at the highest practical temperature consistent with economic materials and internal blade cooling technology and to operate the compressor with an inlet air flow temperature as low as possible. Most turbines are equipped with supplemental burners that can inherently produce incremental steam more efficiently than a separate boiler, boosting overall efficiency of the system.

Figure 4 shows an industrial gas turbine configured for CHP. The CHP arrangement includes a gas turbine that drives an electric generator with exhaust heat used to produce steam in a heat recovery team generator (HRSG).

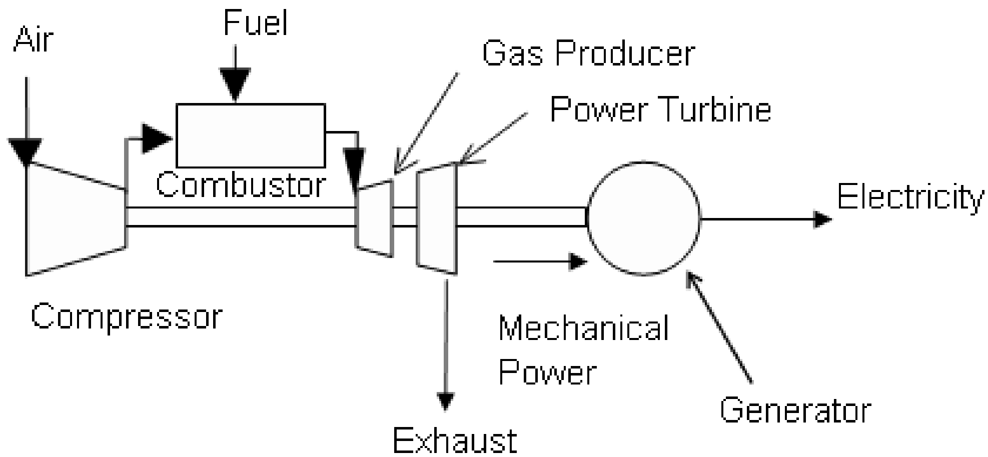
Figure 5 highlights the key components of a simple cycle gas turbine. The compressor elevates the pressure and heats the inlet air which is then further heated by the addition of fuel in the combustion chamber. The hot air and combustion gas mixture drive an expansion turbine, producing enough energy to provide shaft power to the generator or mechanical process and to drive the compressor. The power produced by an expansion turbine and consumed by a compressor is proportional to the absolute temperature of the gas passing through the system. Consequently, it is advantageous to operate the expansion turbine at the highest practical temperature consistent with economic materials and internal blade cooling technology and to operate the compressor with an inlet air flow temperature as low as possible. Most turbines are equipped with supplemental burners that can inherently produce incremental steam more efficiently than a separate boiler, boosting overall efficiency of the system.

**Figure 4: Gas Turbine Configuration with Heat Recovery**




Source: Energy Solutions Center

**Figure 5: Components in Simple Cycle Gas Turbine**




Source: US DOE. Fact Sheets. July 2016

There is one combustion turbine less than 5 MW in size that is recuperated. A recuperated turbine includes a heat exchanger that preheats combustor air with heat from the exhaust, reducing fuel consumption and increasing electric efficiency at the expense of heat output. This turbine is best suited for applications with high power-to-heat ratios, such as, institutional buildings, hospitals, and data centers.

*Performance Characteristics*

As mentioned previously, gas turbine CHP performance improves with larger sizes. Table 7 indicates overall CHP efficiencies for gas turbines 5 MW and smaller are typically in the range of 65% to 75%, although higher efficiencies can be achieved depending on site specific conditions and engineering design configurations. Supplemental firing of the exhaust, for example, can produce incremental steam at higher efficiencies than a boiler, boosting overall CHP efficiency.

**Table 7: Gas Turbine Performance Characteristics**

| Description | Simple Cycle | Simple Cycle | Recuperated | Simple Cycle |
|---|---|---|---|---|
| Net Electric Power (kW)[13] | 3,300 | 4,300 | 4,300 | 5,300 |
| Fuel Input (MMBtu/hr, HHV)[14] | 46.1 | 57.5 | 43.8 | 66.0 |
| Useful Thermal (MMBtu/hr) | 21.3 | 27.6 | 13.4 | 31.6 |
| Electric Heat Rate (MMBtu/hr) | 13,967 | 13,267 | 10,115 | 12,354 |
| Electric Efficiency (%, HHV) | 24.4% | 25.7% | 33.7% | 27.6% |
| Thermal Efficiency (%, HHV)[15] | 46.1% | 47.9% | 30.5% | 47.7% |
| Overall Efficiency (%, HHV) | 70.5% | 73.6% | 64.2% | 75.3% |
| Supplemental Firing to 1600°F | | | | |
| Supplemental Fuel (MMBtu/hr) | 35.3 | 29.9 | NA | 34.1 |
| Supplemental Heat | 36.1 | 31.0 | NA | 35.4 |
| Overall Efficiency (%, HHV) | 84.2% | 83.8% | NA | 84.9% |

**Performance characteristics are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

### *Capital and O&M Costs*

A gas turbine CHP plant has many interrelated subsystems. The basic package includes a gas turbine, low-NOx combustor, gearbox, electric generator, inlet air and exhaust ducting, inlet air filtration, starting system, an exhaust silencer, and a container. The Balance-of-Plant (BOP) includes the HRSG, water treatment system, and an emission control system (e.g., selective catalytic reduction and an oxidation catalyst). A fuel gas compressor is often required, but the size and cost varies depending on the pipeline gas pressure in proximity to the site. Except for special circumstances, the recuperated

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[13] Fuel compressor not included – actual compressor power requirements dependent on service gas pressure which is site specific.

[14] Fuel input to gas turbine only – does not include fuel for supplemental firing if so equipped. All quantities in this factsheet are based on the higher heating value (HHV) of the fuel unless noted otherwise. The ratio of HHV to LHV is assumed to be 1.105 for natural gas.

[15] Thermal energy is based on generating 150 psig saturated steam, with 7% of steam production bypassed to deaerator (i.e., 93% of total steam available for process).

turbine does not require Selective Catalytic Reduction (SCR) or an Oxidation Catalyst, due to its inherently low turbine outlet emissions. Installed capital costs vary significantly depending on the scope of the plant equipment, geographical area, competitive market conditions, special site requirements, emissions control requirements, and prevailing labor rates.

Table 8 shows estimated capital costs for four representative gas turbine CHP systems used in typical applications. As indicated, there are economies of scale with installed costs declining from $3,580/kW for a 3.3 MW system to $2,430/kW for a 5 MW system.

**Table 8: Gas Turbine Capital and O&M Costs**

| Description | Simple Cycle | Simple Cycle | Recuperated | Simple Cycle |
|---|---|---|---|---|
| Net Electric Power (kW)[16] | 3,300 | 4,300 | 4,300 | 5,300 |
| Capital Cost | | | | |
| Turbine/Generator ($/kW) | $860 | $770 | $970 | $630 |
| Emissions Control ($/kW) | $430 | $330 | N/A | $270 |
| Balance of Plant & Installation ($/kW) | $2,290 | $1,770 | $1,890 | $1,530 |
| Total Installed Cost ($/kW) | $3,580 | $2,870 | $2,860 | $2,430 |
| Supplemental Firing Adder ($/kW) | $505 | $311 | N/A | $253 |
| Maintenance Cost | | | | |
| O&M - Turbine/Generator (¢/kWh) | 0.90 | 1.05 | 1.60 | 1.03 |
| O&M - Balance of Plant (¢/kWh) | 0.45 | 0.45 | 0.30 | 0.45 |
| Full Service O&M (¢/kWh) | 1.35 | 1.50 | 1.90 | 1.48 |

**Costs are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

*Emissions*

Large gas turbines (> 3 MW) must meet BACT, which California Air Districts stipulate in parts per million (ppm) at 15% $O_2$. The large natural gas turbine BACT levels for most California air districts are shown in Table 9. Gas turbines equipped with low-NOx combustors and properly sized and operated SCR systems to control NOx and oxidation catalysts to control CO and VOCs can comfortably achieve these levels. CARB has a DG certification requirement (also shown in Table 9 for non-permitted natural gas DG that

[16] Fuel compressor not included. Actual compressor power requirements dependent on service gas pressure which is site specific.

currently does not apply to large turbines. Gas turbines with good heat recovery and emission control equipment can meet the CARB levels if required at some future date.

**Table 9: Gas Turbine Emission Regulations**

| Constituent | NOx[17] | CO[18] | VOC[19] | $NH_3$ |
|---|---|---|---|---|
| BACT (ppm at 15% $O_2$) | 2.0 | 3.0 | 2.0 | 5.0 |
| CARB DG (lbs/MWh)[20] | 0.07 | 0.10 | 0.02 | N/A |

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

Table 10 shows $CO_2$ emissions for CHP systems based solely on the power output and on an unfired CHP system. For the complete CHP system, $CO_2$ emissions are calculated with a thermal credit for natural gas fuel that would otherwise be used by an on-site boiler. With this credit, $CO_2$ emissions range from 584 - 735 lbs/MWh. Also illustrated is the additional improvement in $CO_2$ emissions that can be realized with supplemental firing of the exhaust. For comparison, a typical natural gas combined cycle power plant will have emissions of 800 - 900 lbs/MWh.

**Table 10: Gas Turbine $CO_2$ Emissions**

| Description | Simple Cycle | Simple Cycle | Recuperated | Simple Cycle |
|---|---|---|---|---|
| Net Electric Power (kW) | 3,300 | 4,300 | 4,300 | 5,300 |
| Electricity Only (lbs/MWh) | 1,634 | 1,563 | 1,191 | 1,456 |
| CHP Unfired (lbs/MWh) | 690 | 625 | 735 | 584 |
| CHP Exhaust Fired | 370 | 414 | N/A | 389 |

**Emissions are average values and are not intended to represent a specific product**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

### Microturbines

Microturbines are relatively small combustion turbines that can use gaseous or liquid fuels. While large gas turbines have been used for CHP applications for several decades, microturbines emerged as a CHP option in the 1990s. Individual microturbines range in

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17 NOx conversion: NOx [lbs/MWh] = NOx [ppm at 15% $O_2$] / 271 / electrical efficiency [%, HHV] X 3.412.

18 CO conversion: CO [lbs/MWh] = CO [ppm at 15% $O_2$] / 446 / electrical efficiency [%, HHV] X 3.412.

19 VOC conversion: VOC [lbs/MWh] = VOC [ppm at 15% $O_2$] / 779 / electrical efficiency [%, HHV] X 3.412.

20 For CHP systems with efficiencies of 60% or greater, a heat recovery credit is applicable at the rate of one MWh for each 3.4 MMBtu of heat recovered.

size from 30 to 330 kW and can be combined to provide modular packages with capacities exceeding 1,000 kW. Figure 6 shows an example of microturbines and Table 11 provides a summary of microturbine attributes.

**Figure 6: Microturbines**

Source: Capstone Turbine Corporation

**Table 11: Summary of Microturbine Attributes**

| Attribute | Description |
| --- | --- |
| **Size range** | Available from 30 to 330 kW with integrated modular packages exceeding 1,000 kW. |
| **Thermal Output** | Microturbines have exhaust temperatures in the range of 500 to 600°F, and this exhaust can be used to produce steam, hot water, or chilled water (with an absorption chiller). |
| **Part-load Operation** | The electrical generation efficiency of microturbines declines significantly as load decreases. Therefore, microturbines generally provide best economic performance in base load applications where the system operates at, or near, full load. An exception is modular packages where one or more individual microturbines can be shut down while the remaining microturbines operate at or near full load. |
| **Fuel** | Microturbines can be operated with a wide range of gas and liquid fuels. For CHP, natural gas is the most common fuel. |
| **Reliability** | Microturbines are based on the design principles used in larger capacity combustion turbines and, like combustion turbines, microturbines have high reliability. |
| **Other** | Microturbines have low emissions and require no cooling. Individual units are compact and can be easily shipped and sited in confined spaces. |

Source: Adapted from U.S. DOE. Microturbines CHP Technology Fact Sheet. July 2016.

### Applications

There are more than 180 sites in California that currently use microturbines for CHP, accounting for 51 MW of aggregate capacity.[21] Sites that use microturbines for CHP include hotels, nursing homes, health clubs, commercial buildings, food processing plants, and small manufacturing operations. In CHP applications, thermal energy from microturbine exhaust is recovered to produce either hot water or low pressure steam.

#### *Technology Description*

Microturbines operate on the same thermodynamic cycle (Brayton Cycle) as larger combustion turbines and share many of the same basic components. In the Brayton Cycle, atmospheric air is compressed, heated by burning fuel, such as natural gas, and then used to drive an expansion turbine that drives the inlet compressor and a drive shaft connected to an electrical power generator. Figure 7 shows a schematic of the basic microturbine components, which include the combined compressor/turbine unit, generator, recuperator, combustor, and CHP heat exchanger.

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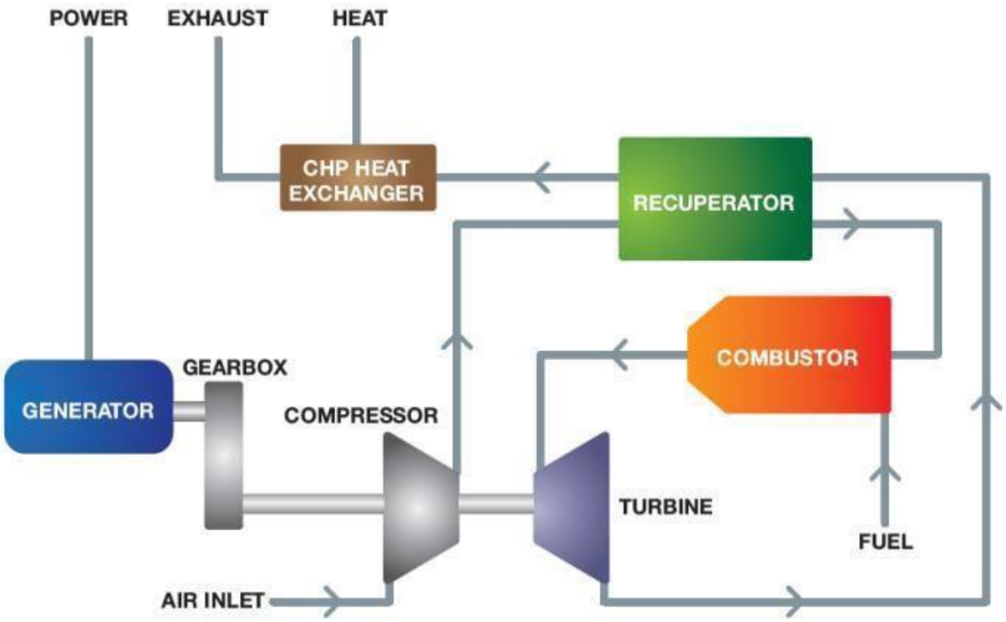
21 U.S. DOE Combined Heat and Power Installation Database, data compiled through December 31, 2015.

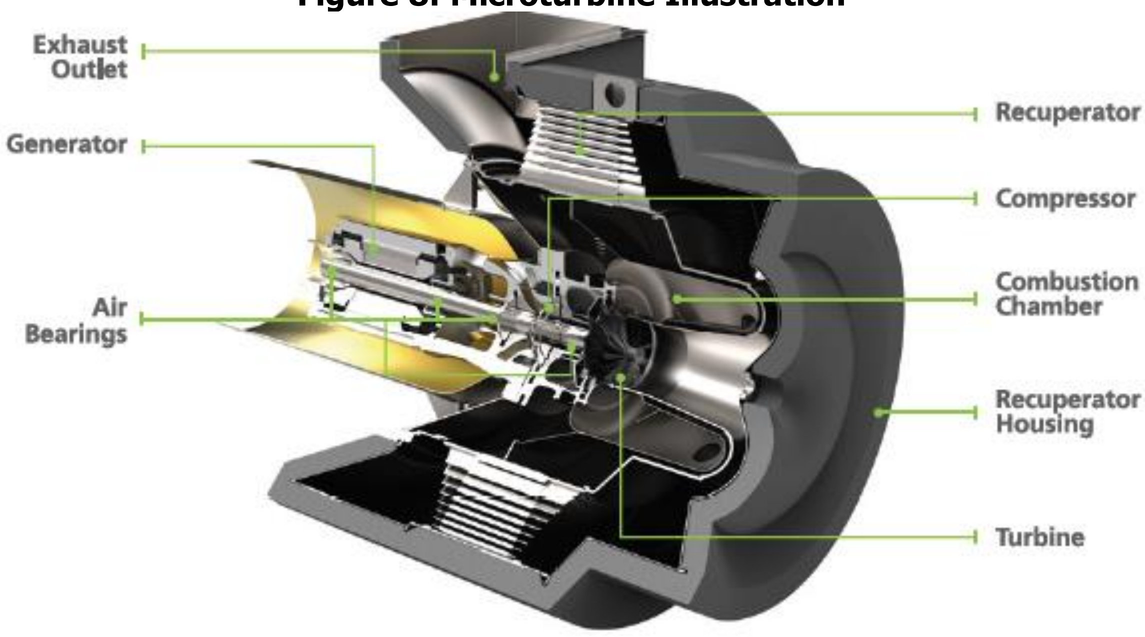
**Figure 7: Microturbine Configuration for CHP**




Source: Flex Energy leadership

Figure 8 shows an illustration of a microturbine.

**Figure 8: Microturbine Illustration**




Source: Capstone Turbine Corporation

Microturbines differ from larger combustion turbines not only in size, but they typically have lower compression ratios and operate at lower combustion temperatures. To increase electric efficiency, microturbines recover a portion of thexhaust heat in a recuperator that preheats the compressed air prior to the combustor, thereby boosting efficiency. Microturbines operate at relatively high rotational speeds, often reaching 60,000 revolutions per minute.

*Performance Characteristics*

Table 12 summarizes technical performance characteristics for microturbine CHP systems ranging in size from 65 to 1,000 kW. Microturbines typically require an inlet fuel pressure near 75 psig, and most microturbines include an onboard gas compressor to provide the required gas pressure. The net power shown in Table 12 represents the maximum power available both without the parasitic compressor load should High Pressure Natural Gas (HPNG) be available to the site, and after the parasitic compressor load has been subtracted should Low Pressure Natural Gas (LPNG) be the only option. Likewise, efficiencies are provided for a system with and without a compressor. As indicated, the overall CHP efficiency for the representative microturbine systems shown range from 67% to 73%.

**Table 12: Microturbine Performance Characteristics**

| Description[a] | HPNG/ LPNG | HPNG/ LPNG | HPNG/ LPNG | HPNG/ LPNG |
|---|---|---|---|---|
| Net Electric Power (kW) | 65/62 | 200/190 | 333/316 | 1,000/950 |
| Fuel Input (MMBtu/hr, HHV)[b] | 0.87 | 2.29 | 3.85 | 11.43 |
| Useful Thermal (MMBtu/hr)[c] | 0.41 | 0.89 | 1.62 | 4.45 |
| Electric Efficiency (%, HHV) | 25.5/24.3% | 30.0/28.2% | 29.5/28.0% | 30.0/28.2% |
| Thermal Efficiency (%, HHV) | 47.1% | 38.0% | 42.1% | 36.6% |
| Overall Efficiency (%, HHV) | 72.9/71.7% | 68.8/67.3% | 71.6/70.1% | 68.8/67.3% |

**Performance characteristics are average values and are not intended to represent a specific product.**

**a: HPNG – High Pressure Natural Gas available at or above 75 psig. LPNG – Low Pressure Natural Gas which necessitates the addition of a gas compressor.**

**b: Fuel consumption and efficiency values are based on the higher heating value (HHV) of natural gas unless noted otherwise.**

**c: Useful thermal energy is based on producing hot water at a temperature of 140°F, which requires a condensing heat exchanger (HX). 180°F hot water can be obtained without a condensing HX but results in a thermal output reduction of about 13%.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

*Capital and O&M Costs*

Table 13 provides cost estimates for microturbine systems used in CHP applications that produce hot water at 140°F. The basic microturbine package consists of the microturbine and power electronics. All commercially available microturbines offer basic interconnection and paralleling functionality as part of the package cost. Most microturbine CHP systems offer an integrated heat exchanger with the basic package. Note that cost estimates are provided for systems requiring a gas compressor (LPNG) and those that do not (HPNG). As indicated, installed capital costs range from $3,450 to $2,950 per kW, and decrease with increasing capacity. The costs shown are representative estimates and can vary significantly depending on the scope of the plant equipment, local emissions requirements, and other site specific requirements.

**Table 13: Microturbine Capital and O&M Costs**

| Description | HPNG/ LPNG | HPNG/ LPNG | HPNG/ LPNG | HPNG/ LPNG |
|---|---|---|---|---|
| Net Electric Power (kW) | 65/62 | 200/190 | 333/316 | 1,000/950 |
| Capital Cost | | | | |
| Microturbine Package ($/kW)* | $1,600/ 1700 | $1,600/ 1,850 | $1530/ 1,780 | $1,300/ 1,500 |
| Balance of Plant and Installation ($ | $1,750 | $1,700 | $1,700 | $1,650 |
| Installed Cost ($/kW) | $3,350/ 3,450 | $3,300/ 3,550 | $3,230/ 3,480 | $2,950/ 3,150 |
| Maintenance Cost | | | | |
| O&M, not including fuel (¢/kWh) | 1.8/2.0 | 1.8/2.0 | 1.8/2.0 | 1.8/2.0 |

**Costs are average values and are not intended to represent a specific product. Costs are based on vendor data, installation estimates, and information provided by project developers.**

*** The complete package includes the microturbine engine, fuel gas compressor, and heat recovery hardware. The package does not include the cost of an absorption chiller for applications that produce chilled water.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

Non-fuel operation and maintenance (O&M) costs are also shown in Table 13. As indicated, maintenance costs for microturbines range from 1.8 to 2.0 ¢/kWh (includes fixed and variable maintenance).

*Emissions*

Table 14 shows the various air criteria regulations applicable to microturbine CHP operating on natural gas in California. Some of the microturbines are CARB DG Certified as they are small enough to be exempt from local air district regulations in the turbine category. A CARB DG Certification requires that the package include the heat recovery equipment that the heat recovery credit is based on. For microturbines that are not CARB DG Certified, most air districts require permits that entail meeting BACT levels for small gas turbines less than 3 MW.

**Table 14: Microturbine Emissions Regulations**

| Constituent | NOx[a] | CO[b] | VOC |
|---|---|---|---|
| BACT (ppm at 15% $O_2$) | 11.0 | 70.0 | N/A |
| CARB DG (lbs/MWh) | 0.07 | 0.10 | 0.02 |

**a: NOx conversion: NOx [lbs/MWh] = NOx [ppm at 15% O2] / 271 / electrical efficiency [%, HHV] X 3.412.**

**b: CO conversion: CO [lbs/MWh] = CO [ppm at 15% $O_2$] / 446 / electrical efficiency [%, HHV] X 3.412.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

Table 15 shows $CO_2$ emissions for CHP systems based on the electric power output and the complete CHP system. For the complete CHP system, $CO_2$ emissions are calculated with a thermal credit for natural gas fuel that would otherwise be used by an on-site boiler. With this credit, $CO_2$ emissions range from 638 - 723 lbs/MWh. For comparison, a typical natural gas combined cycle power plant will have emissions of 800 - 900 lbs/MWh.

**Table 15: $CO_2$ Emissions for CHP Systems**

| Description | HPNG/LPNG | HPNG/LPNG | HPNG/LPNG | HPNG/LPNG |
|---|---|---|---|---|
| Net Electric Power (kW) | 65/62 | 200/190 | 333/316 | 1,000/950 |
| Electricity Only (lbs/MWh) | 1,568/1,644 | 1,337/1,408 | 1,353/1,425 | 1,337/1,408 |
| CHP (lbs/MWh) | 638/669 | 686/723 | 641/676 | 686/723 |

**Emissions are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

### Fuel Cells

Fuel cells use an electrochemical process to convert the chemical energy in a fuel to electricity. In contrast to reciprocating engines and gas turbines, fuel cells generate electricity without combusting the fuel. The first practical application for fuel cells emerged in the 1950s when fuel cells were used to provide onboard power for spacecraft.

Fuel cells continue to be used in space exploration, but over the past few decades the technology has migrated to other applications, including vehicle transportation and stationary power generation. For stationary power, fuel cells are used for distributed generation (electricity only) and are also configured for CHP (Figure 9). Table 16 provides an overview of fuel cell operation in CHP applications.

**Figure 9: CHP Fuel Cell Installation at Verizon Data Center**

Source: Verizon Communications

**Table 16: Fuel Cell Attributes for CHP Applications**

| Attribute | Description |
|---|---|
| Size Range | Fuel cells for CHP are available with capacities from 1 to 2,800 kW. |
| Thermal Output | Heat from fuel cells configured for CHP can be recovered to produce hot water, low pressure (<30 psig) steam, and chilled water (with an absorption chiller). |
| Part-load Operation | Fuel cells have good part-load performance. At 50% of full load, the efficiency of a fuel cell will typically decline less than 2% compared to the full load value. |
| Fuel | Most fuel cells for CHP applications use natural gas or biogas. The gas is reformed into hydrogen, and the hydrogen is then reacted to generate electricity. |
| Reliability | Fuel cells use an electrochemical process with few moving parts and offer high reliability. While mechanical wear is not an issue, fuel cells do require periodic replacement or refurbishment of catalysts and fuel cell stacks. |
| Other | Fuel cells are quiet, have low emissions, and produce high quality power. |

Source: Adapted from U.S. DOE, Fuel Cells CHP Technology Fact Sheet, July 2016

[22] U.S. Department of Energy, Case Study: Fuel Cells Provide Combined Heat and Power at Verizon's Garden City Central Office, 2010.

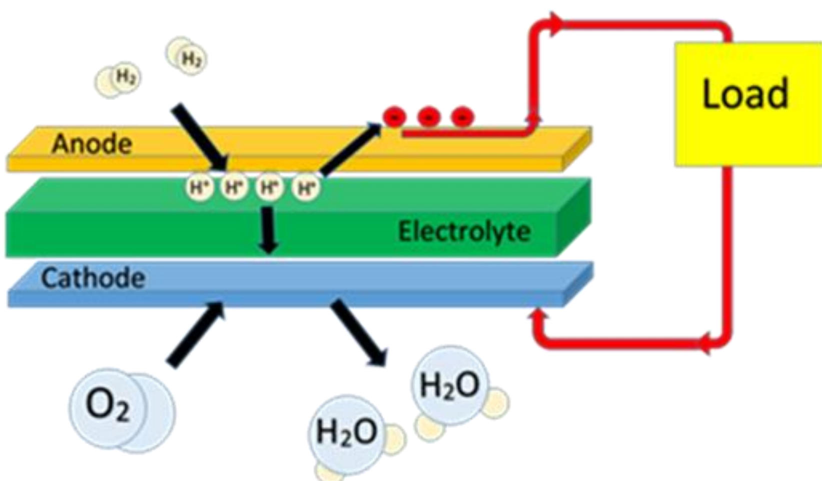
*Applications*

Based on data from the CHP Installation Database,[23] there are 81 fuel cell installations in California that are configured for CHP operation with a combined capacity of 54 MW. The majority of these fuel cells are used in commercial and institutional buildings where there is a relatively high coincident demand for electricity and thermal energy. Thermal energy recovered from fuel cells is most often used to satisfy hot water or space heating demands, although in some cases fuel cells have been integrated with absorption chillers to provide space cooling. Sites where fuel cell CHP systems have been used include universities, hospitals, nursing homes, hotels, and waste water treatment plants.

*Technology Description*

Figure 10 illustrates a single fuel cell element that consists of a cathode (positively charged electrode), an anode (negatively charged electrode), and an electrolyte. Hydrogen and oxygen are fed to the anode and cathode, respectively, and chemical reactions occur in the presence of catalysts at the anode and cathode. The chemical reactions generate ions and electrons that produce direct current (DC) electricity and water. The voltage generated from a single fuel cell element is low (< 1 volt DC). For practical applications, more than 100 cells are typically combined ("stacked") in series to generate voltages in the range of 200 to 400 volts DC.

**Figure 10: Fuel Cell Electrochemical Process**




Source: ICF International

Several electrolytes have been successfully developed, and fuel cells are often categorized by the type of electrolyte, or in some cases, the type of fuel. Six leading fuel cell technologies are alkaline (AFC), direct methanol (DMFC), phosphoric acid (PAFC), proton exchange membrane (PEMFC), molten carbonate (MCFC), and solid

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[23] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Data compiled through December 31, 2015. https://doe.icfwebservices.com/chpdb/

oxide (SOFC). Four of these technologies – PAFC, PEMFC, MCFC, and SOFC – have been used for CHP.

In addition to the fuel cell stack, commercially available fuel cells are typically packaged with two other integrated subsystems: a fuel processor and a power conditioner. The fuel processor, or reformer, converts the fuel (such as natural gas or biogas) into a hydrogen rich feed stream for the fuel cell stack. The power conditioner regulates the DC electricity generated from the stack and converts this DC power to alternating current (AC).

*Performance Characteristics*

PEMFC and SOFC systems have been developed for microCHP (< 10 kW) applications that are suitable for residential and small commercial buildings, with most microCHP installations in Europe and Asia. In the United States, nearly all CHP fuel cell systems utilize MCFC and PAFC technologies and are designed to meet loads that are typical for large commercial and institutional buildings.

Table 17 summarizes performance characteristics for three representative fuel cell CHP systems available in the United States, ranging in size from 440 kW - 2,800 kW. As indicated, all three systems operate at overall efficiencies between 75 and 81%. The thermal energy for all three fuel cells is based on producing 140°F water.

**Table 17: Fuel Cell Performance Characteristics**

| Description | PAFC | MCFC | MCFC |
|---|---|---|---|
| Net Electric Power (kW) | 440 | 1,400 | 2,800 |
| Fuel Cell Type | PAFC | MCFC | MCFC |
| Fuel | Natural Gas | Natural Gas | Natural Gas |
| Fuel Input (MMBtu/hr, HHV)[24] | 3.77 | 11.21 | 22.42 |
| Useful Thermal (MMBtu/hr)[25] | 1.55 | 3.73 | 7.46 |
| Electric Efficiency (%, HHV) | 39.8% | 42.6% | 42.6% |
| Thermal Efficiency (%, HHV) | 41.1% | 33.3% | 33.3% |
| Overall Efficiency (%, HHV) | 80.9% | 75.9% | 75.9% |

**Performance characteristics are average values and are not intended to represent a specific product.**

Source: Adapted from U.S. DOE, Fuel Cells CHP Technology Fact Sheet, July 2016

24 Manufacturers often express fuel input and efficiency values based on the lower heating value (LHV) of the fuel. All quantities in this factsheet are based on the higher heating value (HHV) unless noted otherwise. For natural gas, the ratio of LHV to HHV is approximately 0.9.

25 Useful thermal energy is based on producing hot water at a temperature of 140°F.

While PAFC and MCFC technologies are used for CHP, the technologies do have significantly different thermal characteristics. PAFC systems operate with temperatures in the range of 300 – 400°F compared to MCFC systems that operate at higher temperatures in the range of 1,100 – 1,300°F. For PAFC systems, thermal energy is typically used to generate hot water or low pressure (<30 psig) steam. With MCFC systems, low or medium pressure (<150 psig) steam can be generated along with hot water. For steam and hot water temperatures above 140°F, there will be a thermal output and overall efficiency derate from the values shown.

*Capital and O&M Costs*

Installed costs for fuel cell CHP systems are shown in Table 18. For the three representative systems, installed costs range from $3,600 to $6,700/kW. Similar to other CHP technologies, installed costs for fuel cell CHP systems decline on a per-kW basis as capacity increases. As is the case with most CHP systems, installed costs can vary significantly depending on the scope of the plant equipment, geographic location, and other site-specific conditions.

**Table 18: Fuel Cell Capital and O&M Costs**

| Description | PAFC | MCFC | MCFC |
|---|---|---|---|
| Net Electric Power (kW) | 440 | 1,400 | 2,800 |
| Capital Cost | | | |
| Fuel Cell Module ($/kW) | $4,900 | $2,940 | $2,500 |
| Balance of Plant and Installation ($ | $1,800 | $1,380 | $1,100 |
| Total Installed Cost ($/kW) | $6,700 | $4,320 | $3,600 |
| Maintenance Cost | | | |
| O&M Cost, excluding fuel (¢/kWh) | 3.2 | 3.0 | 2.6 |

**Costs are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

Several factors influence fuel cell O&M costs, including the type of fuel cell, capacity, and maturity of the equipment. For contracted maintenance, including periodic fuel cell stack replacement, maintenance costs range from 2.6 to 3.2 cents/kWh for the three representative fuel cell systems shown**.**

*Emissions*

A fuel cell stack uses an electrochemical process to convert fuel to electricity, and this process does not produce carbon monoxide (CO), nitrogen oxides (NOx), or volatile organic compounds (VOCs). Fuel cell reformers do rely on combustion, but reformer emissions are low. Anode off-gas, which is generated in the fuel cell stack, typically consists of 8% to 15% hydrogen. This hydrogen is combusted in the reformer with a catalytic or surface burner that operate at temperatures below 1,800°F, which minimizes NOx formation, but is sufficiently high to oxidize most of the CO and VOC emissions. Fuel cells are exempt from permitting throughout California but are required to obtain CARB DG Certifications.

Fuel cells, like other CHP technologies that use natural gas, produce carbon dioxide emissions. Table 19 shows $CO_2$ emissions based on electric power output and overall CHP performance. For CHP performance, $CO_2$ emissions are calculated with a thermal credit for natural gas fuel that would otherwise be used by an on-site boiler (Table 20). With this thermal credit, $CO_2$ emissions for the three representative CHP fuel cell systems range from 487 - 547 lbs/MWh. For comparison, a typical natural gas combined cycle power plant will have emissions of 800 -900 lbs/MWh.

**Table 19: Fuel Cell Emission Regulations**

| Constituent | NOx | CO | VOC |
|---|---|---|---|
| CARB DG (lbs/MWh)* | 0.07 | 0.10 | 0.02 |

* For CHP systems with efficiencies of 60% or greater, a heat recovery credit is applicable at the rate of one MW-hr for each 3.4 MMBtu of heat recovered.

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

**Table 20: Fuel Cell $CO_2$ Emissions**

| Description | PAFC | MCFC | MCFC |
|---|---|---|---|
| Net Electric Power (kW) | 440 | 1,400 | 2,800 |
| Electricity Only (lbs/MWh) | 1,002 | 937 | 937 |
| CHP (lbs/MWh) | 487 | 547 | 547 |

**Emissions are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

## Enabling Technologies

Enabling technologies are equipment or features that supplement the core CHP unit to enhance the value proposition or meet California efficiency and environmental thresholds. This section covers absorption chillers, thermal energy storage, and ultra-low emission technology.

### Absorption Chillers for CHP Systems

Chillers are used in commercial buildings and industrial facilities to produce chilled water for air conditioning, refrigeration, and process fluid cooling. Absorption chillers use heat, from a fueled burner or a source of waste heat, to generate chilled water. When an absorption chiller is paired with a CHP system, it is also known as CCHP (combined cooling, heat and power) or tri-generation.

Absorption chillers can use hot exhaust gases, medium pressure steam (greater than 100 psig), low pressure steam (15 psig or greater), or hot water (200 - 240°F). These are all thermal energy streams that can be provided by prime movers associated with

CHP. Absorption chillers are characterized as single effect or double effect. Single effect chillers take low quality heat such as low-pressure steam or hot water and produce chilled water. Double effect machines can be configured to take multiple sources of thermal energy (low and high quality) to produce chilled water and they do so more efficiently than single effect machines. Table 21 summarizes the attributes of absorption chillers.

**Table 21: Summary of Absorber Attributes**

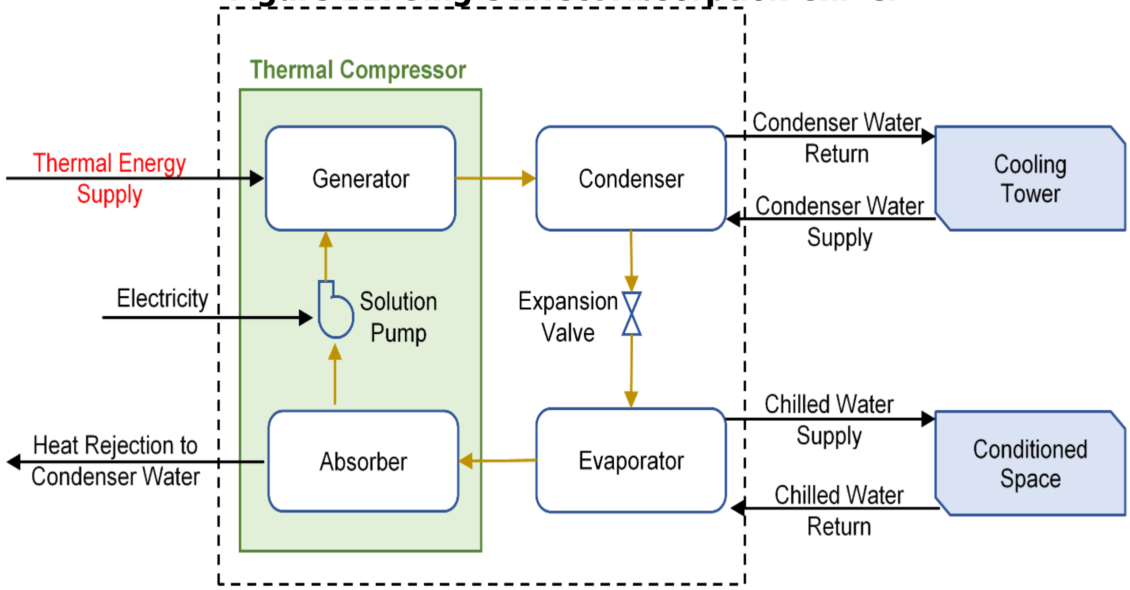
| Attribute | Description |
|---|---|
| **Size range** | 5 to 3,200 refrigeration tons. |
| **Input Heat** | Fuel, hot water, steam, or prime mover exhaust. |
| **Configuration** | Available in single and double effect designs. Single effect machines can be driven with hot water (200-240°F) or low pressure steam (15 psig) and are often used with reciprocating engine CHP installations. Compared to single stage chillers, double effect machines require higher temperature hot water (e.g., 350°F) or higher pressure steam (e.g., 100 psig) and are often used with combustion turbine CHP installations. In addition to hot water and steam, absorption chillers can also be exhaust fired (required exhaust temperatures typically above 500°F). |
| **Refrigerant/Absorbent** | For 40°F and higher chilling fluid temperatures (e.g., building air conditioning), a common mixture is water (refrigerant) and lithium bromide (absorbent). For chilling fluid temperatures below 40°F (e.g., cold storage), a common mixture is ammonia (refrigerant) and water (absorbent). |

Source: Adapted from U.S. DOE. Absorption Chillers for CHP Systems Technology Fact Sheet. May 2017

### *Technology Description*

Figure 11 illustrates the absorption refrigeration cycle with a single-effect absorption chiller. The absorption cycle is similar to the vapor compression cycle except the prime mover and compressor are replaced by a thermal compressor system consisting of an absorber, solution pump and generator). Like a mechanical compressor in a vapor compression chiller, the thermal compressor takes low pressure/low temperature refrigerant vapor from the evaporator and delivers high pressure/high temperature refrigerant vapor to the refrigerant condenser. A thermal compressor uses an absorbent fluid to chemically bond with the refrigerant vapor (essentially compressing it by changing phase from a gas to a liquid). This dilute solution of absorbent/refrigerant is pumped to the generator, where the refrigerant is boiled using the thermal energy supply. Then the refrigerant is sent through the condenser and the evaporator, where chilled water is produced, and finally returned to the thermal compressor.

**Figure 11: Single Effect Absorption Chiller**




Source: ICF

The absorption process is exothermic, and heat must be rejected from the absorber to the condenser water and cooling tower loop. Because of this additional heat rejection load, absorption chillers require a slightly larger cooling tower compared to a mechanical chiller with the same capacity.

Figure 12 is an example of a Flue Gas Double Effect Absorption Chiller. The use of the second stage (or effect) increases the amount of concentrated absorbent thus increasing the "drive" that creates the pressure differential for the refrigeration process.

**Figure 12: Flue Gas Double Effect Absorption Chiller**

Source: Shuangliang Eco-Energy

*Potential CCHP Systems*

This section includes several graphical representations of CCHP systems that use prime mover heat to drive absorption chillers in different configurations.

Figure 13 shows a 4.3 MW combustion turbine providing hot exhaust directly into a large double effect absorption chiller.

**Figure 13: Un-recuperated Combustion Turbine with Double Effect Absorption Chiller**

Source: ICF

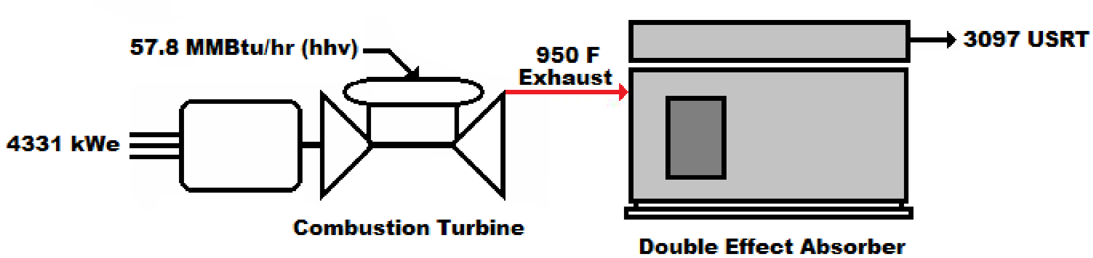
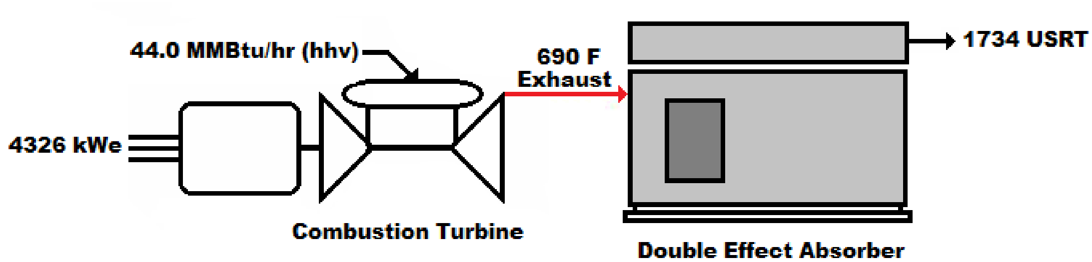



Figure 14 shows a CCHP system with a combustion turbine of similar capacity; only this one is recuperated.[26] Recuperation has resulted in a significantly lower fuel consumption for virtually the same generation. However, recuperation also has led to a reduction in the recoverable thermal energy available at the turbine's exhaust. This led to lower chilled water production from the absorption chiller.

**Figure 14: Recuperated Combustion Turbine w/ Double Effect Absorption Chiller**




Source: ICF

Figure 15 illustrates a CCHP system using a similar capacity, lean burn reciprocating engine. The engine provides thermal energy both with its exhaust into a double effect

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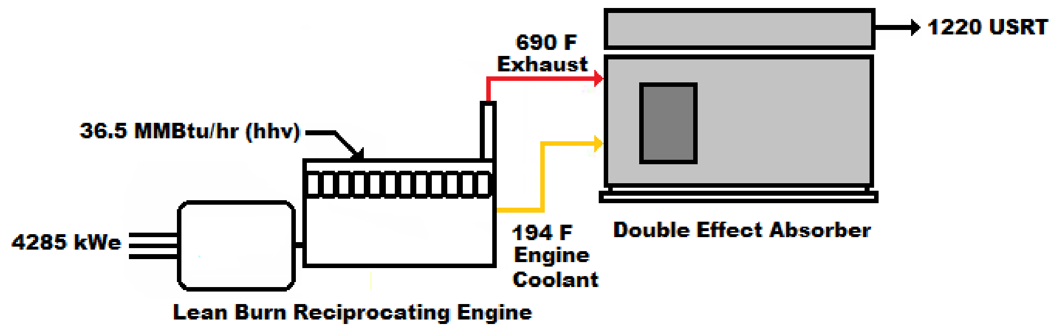
[26] A recuperated combustion turbine is one where the exhaust emerging from expansion turbines is routed through a heat exchanger that preheats compressed combustion air destined for the combustion turbine's combustor. This reduces fuel consumption and also the combustion turbine's final exhaust temperature.

absorber and lower quality thermal energy from primarily engine jacket cooling into a larger lower temperature effect stage.

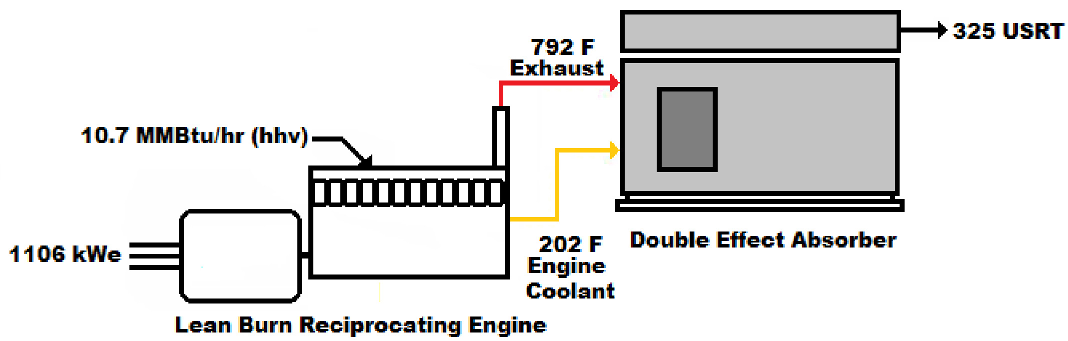
**Figure 15: Large Lean Burn Reciprocating Engine w/ Double Effect Absorption Chiller**




Source: ICF

Figure 16 depicts a smaller (1.1 MW) lean burn engine with a double effect absorber. Once again heat is used directly from the exhaust as well as thermal energy from engine cooling in a larger second effect stage.

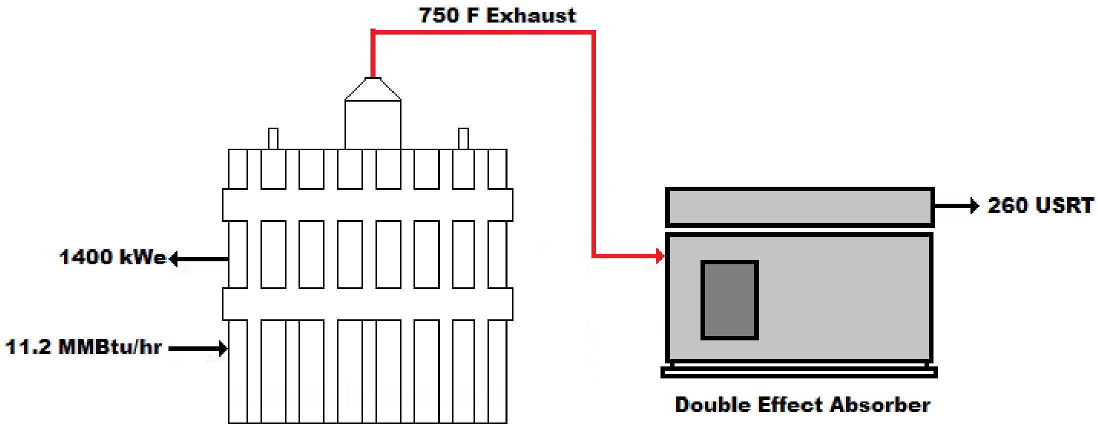
**Figure 16: Medium Sized Lean Burn Reciprocating Engine w/ Double Effect Absorption Chiller**




Source: ICF

Figure 17 shows how an absorber would be used with a fuel cell. Exhaust from the fuel cell provides the thermal energy for the double effect absorber.

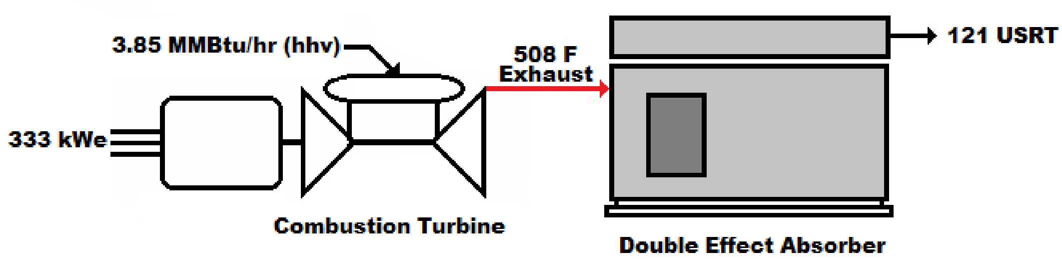
**Figure 17: Fuel Cell with a Double Effect Absorber**




Source: ICF

Figure 18 shows a small recuperated microturbine with a double effect absorber. It can once again be seen that the recuperator reduces the amount of thermal energy available to the absorber.

**Figure 18: Small Recuperated Microturbine with a Double Effect Absorber**

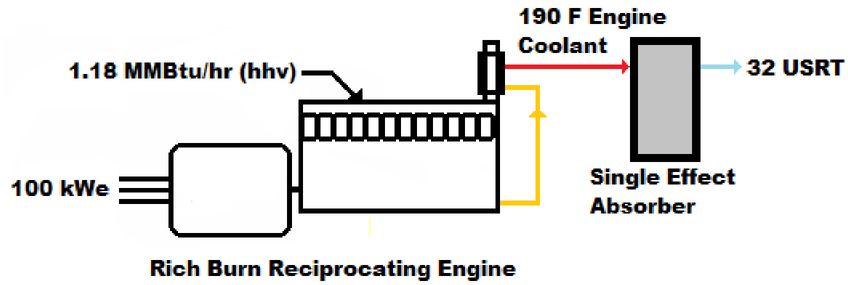



Source: ICF

Figure 19 shows the use of a 100 kW reciprocating gas engine with an absorption chiller.

Thermal energy is taken from the engine from both the engine's cooling jacket as well as an exhaust heat exchanger.

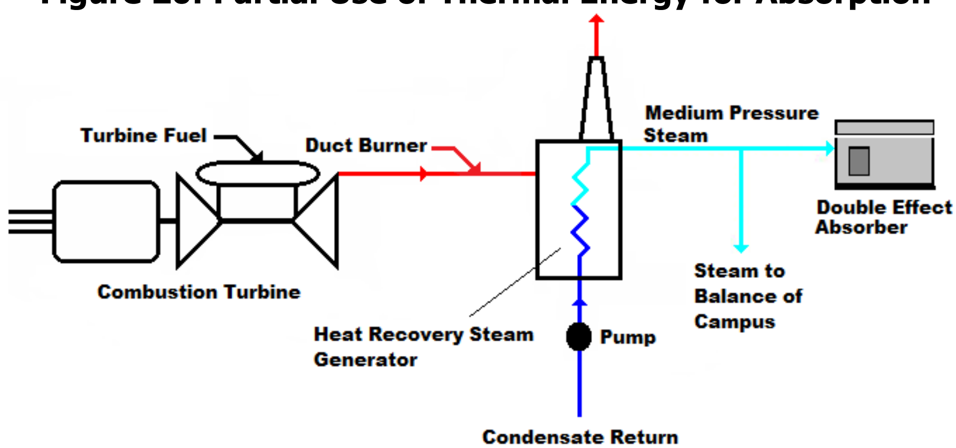
**Figure 19: Small Rich Burn Reciprocating Engine with Single Effect Absorber**




Source: ICF

In the instances previous described, the thermal energy was assumed to be exclusively used in the absorption chiller. However, systems can be designed to produce thermal energy for heating and cooling simultaneously. For example, in the large combustion turbine case (Figure 13), the exhaust of the turbine could be routed instead to a heat recovery steam generator (HRSG). This is illustrated in Figure 20.

**Figure 20: Partial Use of Thermal Energy for Absorption**




Source: ICF

*Performance Characteristics*

The efficiency of an absorption chiller can be measured by the coefficient of performance (COP), which is defined as useful thermal energy output (i.e., chiller load) divided by heat input. COP[27] is a unit-less number and does not include energy consumed by pumps, fans, or other ancillary components. COP values for single stage chillers are less than one, and COP values for two stage systems are greater than one (specifically chilled energy delivered exceeds heat required to drive the system).

Because absorption chiller capacity is a function of thermal energy input quantity and quality, as well as chiller design (single or double effect), it is important to match CHP prime movers with the right absorption chillers. While a double effect absorption chiller has a higher COP compared to a single effect chiller, a double effect chiller also requires a generator temperature about 150°F higher, and it is typically more expensive than a single-effect chiller.

Table 22 shows representative performance characteristics for single and double effect water/lithium bromide absorption chillers ranging in capacity from 50 to 1,320 tons. Four capacities are included for single effect chillers, and four capacities are included for double effect units. The single effect examples are based on using either hot water or low-pressure steam to drive the absorption chiller. The double effect examples are based on using either medium-pressure steam or prime mover exhaust as the heat source. All systems deliver 44°F chilled water based on a return water temperature of 54°F.

[27] The actual COP at which a chiller is operating at will be influenced by its loading and the specific conditions (cooling tower water temperature, chilled water supply and return temperatures and heat source flow and temperature) at which it is actually operating.

**Table 22: Absorber Performance Characteristics**

| Description | System | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Design | Single Effect | | | | Double Effect | | | |
| Heat Source | Hot Water | | | LP Steam | HP Steam | | Exhaust Fired | |
| Nominal Capacity (tons) | 5 | 50 | 440 | 1320 | 330 | 1320 | 121 | 3097 |
| Thermal Energy Input | | | | | | | | |
| Hot Water Inlet Temp (F) | 190 | 190 | 208 | N/A | N/A | N/A | N/A | N/A |
| Hot Water Outlet Temp | 181 | 181 | 190 | N/A | N/A | N/A | N/A | N/A |
| Steam Pressure (psig) | N/A | N/A | N/A | 14.5 | 116 | 116 | N/A | N/A |
| Exhaust Gas Temp (F) | N/A | N/A | N/A | N/A | N/A | N/A | 508 | 950 |
| Heat Required (MMBtu/hr) | 0.085 | 0.85 | 7.1 | 20.1 | 2.8 | 11.2 | 1.15 | 27.2 |
| Thermal Energy Output | | | | | | | | |
| Inlet Water Temp (F) | 54 | | | | | | | |
| Outlet Water Temp (F) | 44 | | | | | | | |
| Cooling COP (Full Load) | 0.70 | 0.70 | 0.74 | 0.79 | 1.42 | 1.42 | 1.26 | 1.37 |

**Performance characteristics are based on multiple sources, including vendor data and discussions with industry experts. The characteristics are intended to illustrate typical absorption chillers, and are not intended to represent performance of specific products.**

Source: Adapted from U.S. DOE, Absorption Chillers for CHP Systems Technology Fact Sheet, May 2017

### *Capital and O&M Costs*

Table 23 shows estimated capital and maintenance costs for the same eight systems described in Table 22. Installed costs range from $1,800 to $16,800 per ton for the four single effect systems, and from $1,600 to $3,000 per ton for the four double effect chillers. Capital costs decline as chiller capacity increases, with costs being comparable for both single and double effect units. O&M costs range from 0.1 to 1.7 ¢/ton-hr for the four single effect chillers, and 0.1 to 0.3 ¢/ton-hr for the four double effect chillers. O&M costs do not include energy costs required for operation, but they include all maintenance requirements associated with an absorption chiller, including periodic purging of non-condensable gases, and monitoring cooling tower and chilled water quality.

**Table 23: Absorption Chiller Capital and O&M Costs**

| Description | System | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Design | Single Effect | | | | Double Effect | | | |
| Heat Source | Hot Water | | | LP | HP Steam | | Exhaust Fired | |
| Nominal Capacity | 5 | 50 | 440 | 1320 | 330 | 1320 | 121 | 3097 |
| Equipment Cost | $5,600 | $2,010 | $930 | $820 | $1,190 | $1,000 | $2,110 | $700 |
| Installation Cost | $11,200 | $3,990 | $1,370 | $980 | $1,810 | $1,200 | $3,170 | $900 |
| Total Installed Cost | $16,800 | $6,000 | $2,300 | $1,800 | $3,000 | $2,200 | $5,100 | $1,600 |
| O&M Cost (¢/ton-hr) | 1.7 | 0.6 | 0.2 | 0.1 | 0.3 | 0.1 | 0.3 | 0.1 |

Source: Adapted from U.S. DOE, Absorption Chillers for CHP Systems Technology Fact Sheet, May 2017

## Thermal Storage

### *Hot Water Storage*

Small and micro-CHP systems less than 100 kW often serve residential and commercial applications that typically have highly variable thermal demands driven by domestic hot water ("DHW") use patterns. Hot water storage is essential to achieve high thermal heat use from a CHP system. Sizing of the thermal storage systems is site specific and is a function of the thermal demand profile and the CHP system thermal rating. Variability in thermal demand can also be addressed by thermal load following with the CHP unit or a combination of thermal load following and thermal storage.

Hot water storage tanks are off-the-shelf equipment originally manufactured for the solar thermal industry. A double wall heat exchanger is generally required that separates the prime mover heat recovery loop from the DHW tank. The heat exchanger can be immersed in the hot water tank or it can be located external to the tank. Table 24 shows approximate costs of thermal storage for a variety of small CHP system sizes and types.

**Table 24: Thermal Storage Costs for Small CHP**

| Description[28] | SOFC | ICE | Microturbine | ICE |
|---|---|---|---|---|
| Net Electric Power (kW) | 1.5 | 4.4 | 30 | 75 |
| Representative Storage Size (gallons) | 60 | 250 | 950 | 2,000 |
| Tank Cost ($) | $1,100 | $5,900 | $16,200 | $31,000 |
| Balance of Plant and Installation | $700 | $2,600 | $5,800 | $9,000 |
| Total Cost ($) | $2,000 | $8,500 | $22,000 | $40,000 |

Source: Based on discussions with equipment vendors

*Chilled Water Storage*

Chilled water storage systems can add significant economic value to a facility's energy system. They can peak-shave, participate in utility demand response programs, reduce the size or amount of chiller equipment, and serve the facility during grid outages reducing the requirement for backup generator sets on-site. Chilled water storage is recognized as an energy storage technology in California and is eligible for the Self-Generation Incentive Program. According to the Cool Solutions Company, chilled water storage is the most cost effective energy storage option when compared against pumped hydro, batteries, flywheels and compressed air energy storage.[29]

When used in conjunction with CHP and an absorption chiller, excess chilled water can be produced and stored at night and dispatched during the day when its value is substantially greater. Chilled water storage is a proven technology, complements a variety of energy systems and can adapt to contribute value in many ways.

### Emission Control Technologies

The criteria air pollutant regulations for CHP in California are among the toughest in the world. According to the American Lung Association "State of the Air 2017," California has the highest ozone and particulate levels of any state and eight of the ten worst polluted US cities are in California.[30] There are 35 autonomous air districts in California. South Coast Air Quality Management District (SCAQMD) is described as the most challenged air district in the nation by the Environmental Protection Agency (EPA) and

[28] SOFC: Solid Oxide Fuel Cell. ICE: Internal Combustion Engine.

[29] John S. Andrepont. "An Enormous Emerging Opportunity for District Cooling Developments." The Cool Solutions Company. International District Energy Association Conference. June 9, 2014.

[30] American Lung Association. State of the Air. 2017.

houses about 50% of California's population. SCAQMD has historically led the state with ever tightening emission control regulations. There are three primary sets of regulations that have shaped CHP emission requirements in California: BACT, CARB DG Certification, and SCAQMD Rule 1110.2.

*Best Available Control Technology (BACT)*

BACT has been the traditional benchmark regulating emissions for permitted CHP technologies. It is generally applicable to new, relocated and modified CHP emission sources. The historical metric has been ppm at 15% $O_2$. No credit is given for electric efficiency or heat recovery. The BACT levels for natural gas CHP combustion technologies are determined by the individual air districts in California, so there is not just one BACT determination throughout California. However, the California Air Pollution Control Officers Association's (CAPCOA) oversees a Statewide BACT Clearinghouse[31] that is managed by the CARB that the air districts generally align themselves with. Typical BACT levels for most of the California air districts are shown in Table 25 for various CHP technologies.

**Table 25: California Typical BACT**

| BACT | ppm at 15% $O_2$ | | | |
|---|---|---|---|---|
| | NOx | CO | VOC | NH3 |
| Combined Cycle | 2.0 | 3.0 | 2.0 | 5.0 |
| Combustion Turbines ≥ 3 MW | 2.0 | 3.0 | 2.0 | 5.0 |
| Combustion Turbines < 3 MW | 9.0 | 10.0 | N/A | N/A |
| Internal Combustion Engines | 11.0 | 70.0 | N/A | N/A |

Source: DE Solutions

Major polluting facilities that are subject to New Source Review (NSR) are required by the Clean Air Act to operate at the Lowest Achievable Emission Rate (LAER). LAER is determined with little regard for cost, and pursuant to USEPA's LAER policy as to what is achieved in practice.

*California Air Resources Board Certification*

Prompted by legislation, CARB adopted a regulation that established a certification program for DG that was exempt from permitting by local air districts.

Exempt DG sources included the following:

- All fuel cells.
- Turbines < 300 kW. Some air districts exempt turbines < 3 MMBtu/hr input, which is different but in the same range as 300 kW.

[31] Additional details regarding the BACT Clearinghouse are available online at: https://www.arb.ca.gov/bact/bact.htm

- Engines < 50 hp.

CARB DG Certification standards are output based and include a heat recovery credit. The standards for exempt DG sources on fossil fuel are expressed in lb/MWh are listed in Table 26.

**Table 26: CARB DG Certification Standards**

| Pollutant | Emission Standard (lb/MWh) |
|---|---|
| NOx | 0.07 |
| CO | 0.10 |
| VOC | 0.02 |

Source: California Air Resources Board

The CARB Certification Standards were originally pegged to Combined Cycle BACT, which is not output based and does not include a heat recovery credit. Therefore, gas turbine CHP that meets the CARB Certification Standards is cleaner still because of the additional uncounted thermal output.

*SCAQMD Engine Rule 1110.2*

In 2008, SCAQMD amended their internal combustion engine rule (1110.2) to require new fossil fueled non-emergency engine generators to comply with the following output based emission standards, with heat recovery credits show in Table 27.

**Table 27: SCAQMD Rule 1110.2**

| Pollutant | Emission Standard (lb/MWh) |
|---|---|
| NOx | 0.07 |
| CO | 0.20 |
| VOC | 0.10 |

Source: SCAQMD

The updated Rule 1110.2 also required frequent testing using portable emission analyzers. Out of compliance, test results required a fix and a report to the SCAQMD. SCAQMD initially targeted equivalency with the CARB DG Certification requirements. Since NOx is SCAQMD's dominant non-compliance issue, they did not push CO and VOC requirements all the way down to CARB Certification levels. These standards have become applicable to biogas fuel effective 2018. As there are now several engine DG systems permitted at these levels, in February 2018, the SCAQMD Board approved a BACT determination update to reference Rule 1110.2 for non-emergency engine generators. This determination will be considered by other California and U.S. air districts when permitting reciprocating engine generators in the future,

## Emission Control Technologies

In most cases, emission control begins with the combustion process to get as complete combustion as practical and minimizing NOx formation. The exhaust, if necessary, is treated with emission after-treatment.

*Gas Turbines and Microturbines*

Simple cycle natural gas turbines fitted with low-NOx combustors will reduce NOx emissions to between 15 and 25 ppm at 15% $O_2$, depending on the turbine. For California's tougher NOx requirements, the gas turbine exhaust is first passed through a passive oxidation catalyst that oxidizes the CO and VOCs. It then passes through the selective catalytic reduction (SCR) system where ammonia is injected to reduce the NOx.

Recuperated gas turbines, which include all microturbines, operate at a lower compression ratio and a lower turbine inlet temperature than simple cycle gas turbines. These characteristics, when coupled with a low-NOx burner, enable recuperated gas turbines to achieve very low emission levels without exhaust after-treatment. Some microturbines may require a low cost oxidation catalyst to meet CARB DG levels but are spared the need for an expensive SCR.

Gas turbines require a Continuous Emission Monitoring System (CEMS) that tracks emission levels in real time and alerts the plant operator should the turbine drift out of compliance. Plant operators are required to retain data generated by these monitoring systems.

*Internal Combustion Engines (ICE)*

Modern ICEs above 600 kW are usually configured with lean-burn combustion which operate with more air than necessary to fully combust the fuel. Consequently, these engines combust at lower temperatures and generate much less NOx, and they can operate at higher compression ratios to increase fuel efficiency. In environmentally sensitive regions like California, exhaust after-treatment is still required which necessitates an oxidation catalyst and pricey SCR similar to the simple-cycle gas turbine emission fix.

For smaller engines, generally less than 600 kW, a rich burn engine with a 3-way catalyst makes more sense because the cost of SCR on a $/kW basis becomes cost prohibitive at smaller sizes. But achieving SCAQMD Rule 1110.2 or CARB DG levels on a continuous basis with a 3-way catalyst is challenging. Very sophisticated air-fuel-ratio (AFR) control systems with real-time exhaust sensor feedback would be required. However, this solution has not yet been permitted in SCAQMD since the engine rule was modified in 2008. Another technique, which has been successfully permitted and deployed in the SCAQMD employs two passive catalysts in a patented configuration where the hot engine exhaust gases are first passed through a conventional 3-way catalyst, with the air-fuel-ratio controller (AFRC) set slightly rich to reduce NOx to very low levels. The exhaust is then conditioned and passed through a second stage oxidation catalyst where CO and VOCs are reduced to near-zero levels. This system was developed with support from the California Energy Commission.[32]

*Fuel Cells*

As discussed earlier, the fuel cell electrochemical process to convert fuel to electricity does not produce CO, NOx, or VOCs. The fuel cell reformers do rely on combustion, but reformer emissions are low. Anode off-gas, laden with hydrogen, is combusted in the reformer with a low-NOx catalytic or surface burner that oxidizes most of the CO and VOC emissions. Fuel cells are exempt from local air district permitting but do require a CARB DG certification which all fuel cells active in California have obtained.

## Micro-CHP Technologies

Micro-CHP products, defined to have a capacity <50 kW for purposes of this assessment, have emerged in recent years. Micro-CHP technology options include fuel cells, Stirling engines, internal combustion engines (ICE), microturbines, and organic Rankine cycles (ORC). Micro-CHP products are designed for residential and small commercial markets. In Europe and Asia, these markets are driven by relatively high energy rates and incentives such as capital cost subsidies, feed-in tariffs (FIT), net metering, and low interest loans.

With micro-CHP equipment being commercially available for well over a decade, worldwide sales have approached 300,000 units with Japan accounting for 80% of the volume, Europe 15%, the US 0.2%, and the rest of the world the remainder.[33] The market for micro-CHP technologies in the U.S. has yet to gain traction. Worldwide, there are more than twenty micro-CHP products commercially available or emerging into the market, but only a half dozen or so of these systems are currently available in the U.S.

Figure 21 illustrates the micro-CHP product/technology activity globally. Shown as a single mark in the figure is the Department of Energy target for ARPA-E Gensets, which is a $32 million initiative funding twelve separate projects aimed at developing micro-CHP products suitable for single-family homes.[34] Included in the mix of products are six ICEs, four Stirling engines and two microturbines. This three-year program culminates

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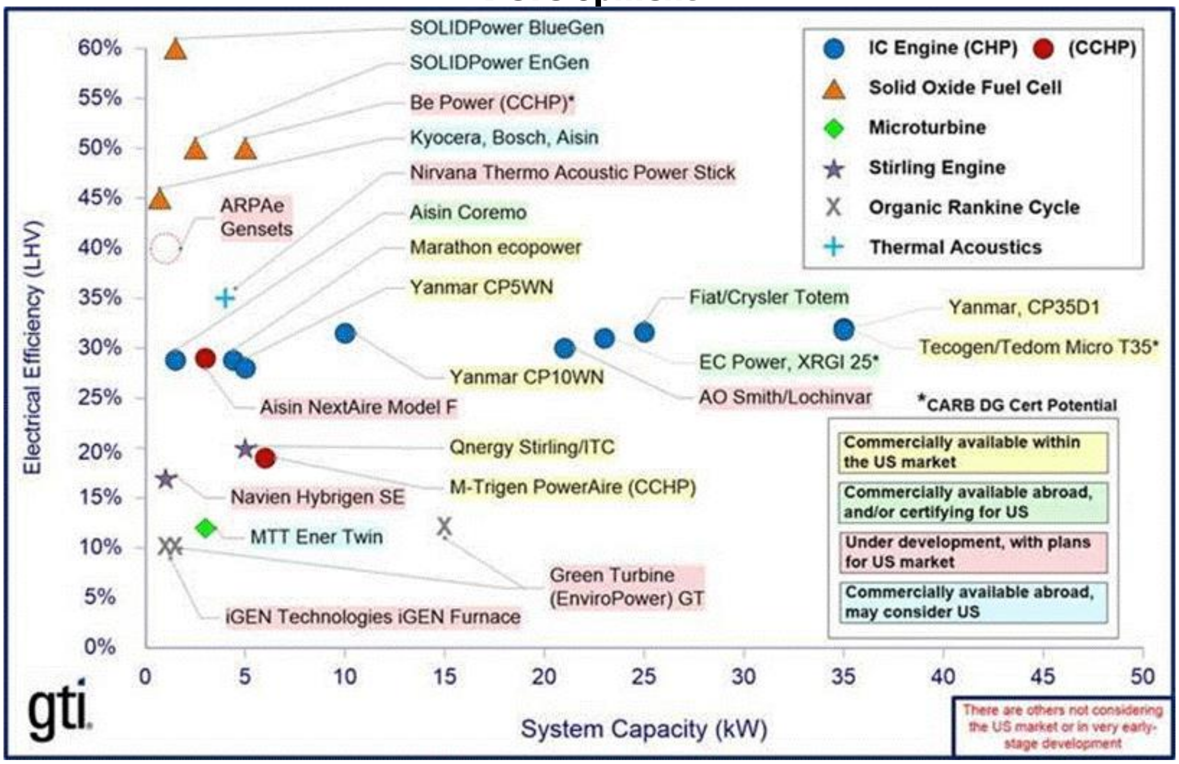
[32] Davidson, Keith, Roy, Jean, and Ranson Roser (DE Solutions, Inc., Tecogen, Inc.). 2011. *Engine CHP Emission Control Technology.* California Energy Commission. Publication Number: CEC-500-2013-087.

[33] Wisconsin Distributed Resources Collaborative. Introduction to Micro Combined Heat & Power (mCHP) Technology and Marketability (i.e., does it have a future). Slide 10. Presentation provided on January 16, 2015. Available online at: http://www.wisconsindr.org/library/presentations/WiDRC%20Presentation%20011615.pdf

[34] U.S. Department of Energy ARPA-E *Generators for Small Electrical and Thermal Systems (GENSETS)* Program. http://arpa-e.energy.gov/?q=events/efficient-small-engines-combined-heat-and-power-workshop

in 2019 after completing field demonstration testing. The ARPA-E micro-CHP program objectives and metrics are listed in Table 28. One interesting project involves a demonstration of ICE micro-CHP systems by AO Smith, a prominent water heater manufacturer with the wherewithal to serve the mass markets necessary to achieve economies of large volume production.[35]

**Figure 21: Micro-CHP Products Commercially Available and Under Development**




Source: Gas Technology Institute

**Table 28: ARPA-E Micro-CHP Objectives and Metrics**

| Metric | Target |
|---|---|
| Electric Generation Capacity (kW) | 1 kWe |
| Electric Conversion Efficiency (HHV) | ≥36.2% |
| Useful Heat Output >80°C (Btu/hr) | >3,420 |
| Unit Cost (uninstalled) | ≤$3,000 |
| Capacity Factor | ≥99.9% |
| Emissions | CARB DG |

Source: Based on discussions with ARPA-E personnel

[35] Advanced Research Projects Agency – US DOE. Sustainable Economic mCHP Stirling (SEMS) Generator. 2018. Retrieved from: https://arpa-e.energy.gov/?q=slick-sheet-project/sustainable-economic-mchp-stirling-sems-generator

*Technology Description*

Among the micro-CHP units currently available in North America are the Marathon 4.4 kW ICE, the Yanmar 5 kW and 10 kW ICE units, the EC Power 19 kW ICE module, the Tedom 35 kW system and the Capstone 30 kW microturbine.

The market activity in the U.S. has been lackluster for numerous reasons including:

- Installed costs for equipment exceed $4,000/kW and in some cases top the $20,000/kW mark. Factors which drive up costs include low volume production, grid interconnection challenges, and high installation costs to retrofit existing facilities.
- Except for a few locations, the "spark" spread between the utility price for electricity and the cost of natural gas is not sufficiently large to overcome the high capital costs.
- Large diurnal fluctuations in electricity and thermal demand for many of the small commercial and multifamily applications make it challenging to achieve high capacity factor and high energy utilization.
- Low cost photovoltaic panels coupled with ongoing incentives and attractive electric tariffs creates serious competition for micro-CHP where there is space to properly locate PV panels.

There are other technologies that are commercially available outside of the US or have a developed product in search of volume commitments to justify the start-up expenses. Representative product manufacturers include Solid Power's 1.5 kW, 6 kW and 12 kW BlueGen SOFCs, and Ametek's 1 kW Sunpower Stirling Engine.

High overall efficiencies are important for economic and environmental performance. Reciprocating engine systems, which have been on the micro-CHP scene the longest, have modest electric efficiencies and require relatively large thermal loads to make use of all the available heat. In most parts of California, with short heating seasons, thermal loads are limited to domestic hot water, pool heating and laundries. While these heat loads may be adequate for reciprocating engines in many California multifamily and light commercial applications, single family residences are not very well matched for reciprocating engines. Unlike larger CHP technologies that can elevate and level out thermal profiles with absorption cooling, this option is much too costly at single family home sizes. Advanced technologies with high electric efficiencies that scale down to the 1 kW size range hold the best promise for California's single family home market.

Another issue that hinders small reciprocating engines in California is emissions. For DG technologies that are exempt from local air district regulations, a CARB DG Certification is necessary requiring ultra-low emission levels be achieved. CARB DG Certification is required for ICEs less than 35 kW and for all other micro-CHP technologies less than 50 kW. The regulation allows a heat recovery credit to be applied: NOx – 0.07 lbs/MWh, CO – 0.10 lbs/MWh, and VOC – 0.02 lbs/MWh. ICEs greater than 35 kW must obtain local air district permits for every installation. Many micro-CHP engines use lean-burn combustion which reduces emissions to acceptable levels in many parts of the world without emission control equipment. But in California, a high-effectiveness SCR would be required to meet these regulations, which would elevate capital costs to prohibitively expensive levels. There are a few micro-CHP rich-burn ICE systems available that come outfitted with relatively inexpensive 3-way catalysts that have the potential to achieve CARB levels. To date none have received a CARB DG Certification.

In addition to emissions regulations, California's Rule 21 for grid interconnection and UL 1741 can make it difficult for small non-inverter based micro-CHP equipment to acquire interconnect approvals without onerously expensive protective equipment. Therefore, inverters are economically essential in California for micro-CHP technologies.

*Performance Characteristics*

Representative micro-CHP products that could serve California's somewhat unique market requirements are shown in Table 29 along with their performance characteristics. They all employ condensing heat recovery which produces hot water at temperatures around 140°F and achieve high overall efficiencies. And although none have obtained CARB DG certification to-date, they are all considered capable of acquiring the certification, with in some cases, the integration of high effectiveness emission control technology.

**Table 29: Micro-CHP Performance Characteristics**

| Description | SOFC | Stirling Engine | Rich-Burn ICE | Rich-Burn ICE | Microturbine |
|---|---|---|---|---|---|
| Net Electric Power (kW) | 1.5 | 1.0 | 4.4 | 19.2 | 28 |
| Fuel Input (Btu/hr, HHV) | 9,426 | 9,425 | 71,800 | 233,100 | 420,000 |
| Useful Thermal (Btu/hr) | 2,356 | 3,412 | 42,200 | 130,000 | 210,000 |
| Heat Quality | 140°F HW* | 140°F HW | 140°F HW | 140°F HW | 140°F HW |
| Electric Heat Rate (Btu/kWh) | 6,284 | 9,425 | 16,300 | 12,140 | 15,000 |
| Electric Efficiency (%, HHV) | 54.3% | 36.2% | 20.9% | 28.1% | 22.7% |
| Thermal Efficiency (%, HHV) | 25.0% | 36.2% | 58.8% | 55.8% | 50.0% |
| Overall Efficiency (%, HHV) | 79.3% | 72.4% | 79.7% | 83.9% | 72.7% |

***HW – hot water**

Source: Based on discussions with equipment vendors

*Capital and O&M Costs*

Table 30 shows representative capital costs for micro-CHP products that potentially could be applicable in California CHP applications. The costs are average values based on data collected from multiple manufacturers. Installed costs can vary significantly depending on the scope of the plant equipment, geographical area, competitive market conditions, special site requirements, emission control hardware (CARB DG Certification Requirements), and prevailing labor rates. It will be a challenge to contain installation costs. Two trades (electrician and plumber) will be required and likely an inspector upon commissioning. A utility interconnection agreement will be required, but ideally under similar conditions as are now required for solar PV systems. With the ultra-high electric efficiency fuel cell, heat recovery may be optional simplifying installation and reducing upfront costs.

**Table 30: Micro-CHP Capital and O&M Costs**

| Description | SOFC[a] | Stirling Engine[b] | Rich-Burn ICE[c] | Rich-Burn ICE | Microturbine[d] |
|---|---|---|---|---|---|
| Net Electric Power (kW) | 1.5 | 1.0 | 4.4 | 19.2 | 28 |
| **Capital Cost** | | | | | |
| Micro-CHP Module ($/k | $10,000 | $3,000 | $6,000 | $2,800 | $2,275 |
| Balance of Plant & Installation ($/kW) | $4,000 | $4,000 | $3,000 | $2,500 | $2,750 |
| Total Installed Cost ($/k\ | $14,000 | $7,000 | $9,000 | $5,300 | $5,025 |
| **Maintenance Cost** | | | | | |
| O&M Cost (¢/kWh) | 3.0 | 1.0 | 3.0 | 2.5 | 2.3 |

**a: With signed deployment agreements for sufficient volumes, a $4,000 module price is projected, reducing installed cost to approximately $8,000.**

**b: Based on production of 100,000 units.**

**c: With higher production volumes (10,000/yr), equipment costs are projected to be < $2,000/kW.**

**d: Assumes low pressure gas is available requiring a fuel gas compressor.**

Source: Based on discussions with equipment vendors

# CHAPTER 3: Market Assessment for Small Combined Heat and Power Applications in California

Combined heat and power is an efficient and low-emissions solution for reliable on-site baseload power. CHP installations can also be beneficial to utilities based on locational factors such as renewable energy penetration and transmission and distribution system conditions. In this CHP market assessment for the California Energy Commission, the project team evaluated the technical, economic, and market adoption potential for small (<5 MW) CHP applications in California.

Assessing the potential for CHP applications requires knowledge of facility electric and thermal loads in relation to CHP performance characteristics along with an inventory of buildings that have sufficient energy loads to support CHP. For this market analysis, the project team had access to ICF's CHP Technical Potential Database,[36] which was used to estimate the total CHP potential throughout the U.S. for a 2016 Department of Energy (DOE) report.[37] The database contains site-level information on commercial, institutional, and industrial buildings estimated to be capable of supporting CHP systems sized 50 kW or larger. ICF's Technical Potential Database formed the basis of the market assessment for traditional CHP systems 50 kW to 5 MW in size in this report.

For micro-CHP (<50 kW) applications, building sizing assumptions from ICF's Technical Potential Database were applied to county-level facility data to estimate the total potential for California CHP installations in the 10-50 kW size range. In addition, the potential market for residential single family home CHP applications in California, with CHP systems 1-2 kW in size, was considered and quantified.

Previous studies have evaluated the market potential for CHP in California, focused on traditional CHP applications 50 kW or larger. In a 2012 Energy Commission report, ICF was contracted to assess the potential market for California CHP applications.[38] With no upper limit on CHP size other than estimated facility requirements, ICF estimated 14 GW of technical potential for CHP in California, and 2.3 GW of market adoption over a

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36 U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Data retrieved September 2017. https://doe.icfwebservices.com/chpdb/

37 U.S. Department of Energy, Combined Heat and Power (CHP) Technical Potential in the United States, March 2016, https://www.energy.gov/eere/amo/downloads/new-release-us-doe-analysis-combined-heat-and-power-chp-technical-potential

38 California Energy Commission, Combined Heat and Power: Policy Analysis and 2011-2030 Market Assessment, prepared by ICF International, February 2012, http://www.energy.ca.gov/2012publications/CEC-200-2012-002/CEC-200-2012-002.pdf

20-year period. As the results of this market assessment are presented, they are compared to the results of the 2012 Energy Commission analysis.

## Application Identification and Characterization

Potential applications for CHP consist of industrial, institutional, commercial, and residential buildings with coincident power and thermal loads. Facilities with consistent 24/7 electric and thermal requirements, such as industrial manufacturing plants, colleges, and hospitals, are ideal hosts for CHP and have historically been the most prevalent for CHP installations. However, any site with coincident power and thermal loads with a significant percentage of operational time is a potential CHP candidate.

In this section, California CHP applications smaller than 5 MW are identified, and potential sites and energy prices for CHP installations are characterized. The results from identifying and characterizing applications were used to help inform the market assessment described in in this chapter.

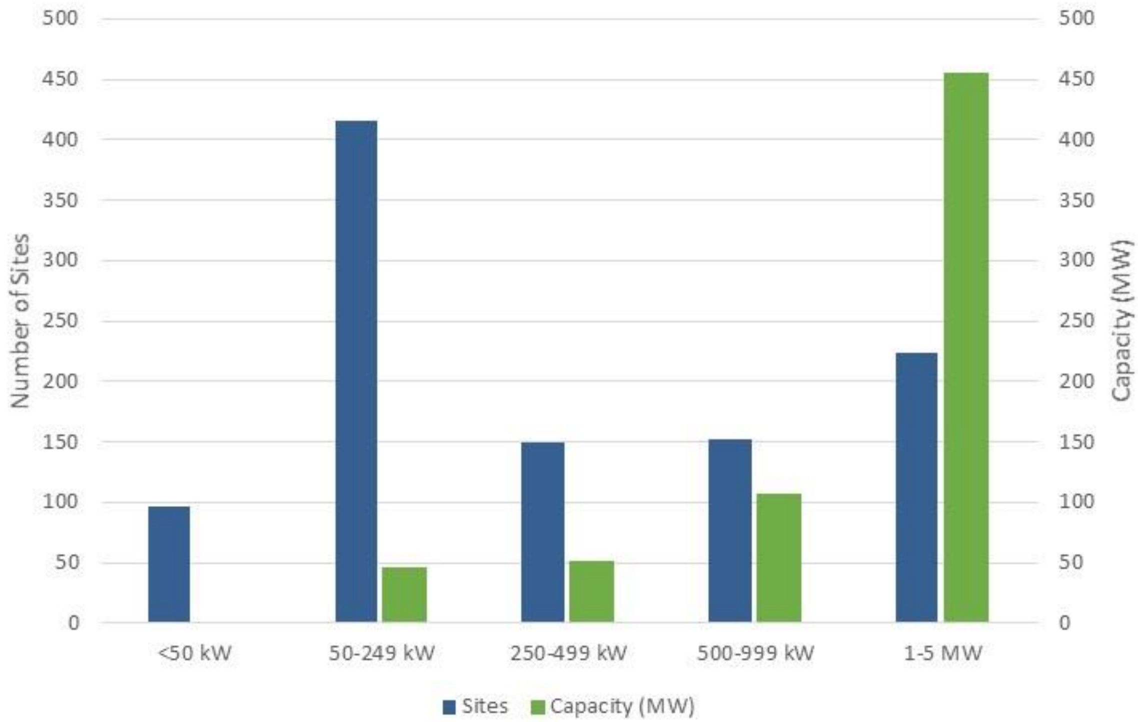
### Current California CHP Applications

To inform the potential for new CHP applications, the project team evaluated the inventory of existing CHP installations in California using the Department of Energy (DOE) CHP Installation Database.[39] A review of current CHP installations indicated which sectors and sub-sectors are a good fit for CHP. Overall, 663 MW of CHP capacity was found in California for systems 5 MW or smaller in size, at a total of 1,035 sites. Facilities with existing CHP installations were removed from the pool of California sites with technical potential for CHP.

Figure 22 shows existing California CHP installations, with the number of sites and the total capacity by CHP size range. See APPENDIX A for the corresponding data table for Figure 22.

[39] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Updated 2017. https://doe.icfwebservices.com/chpdb/

**Figure 22: Number of Sites and Installed Capacity (MW) for <5 MW CHP, by Size Range**



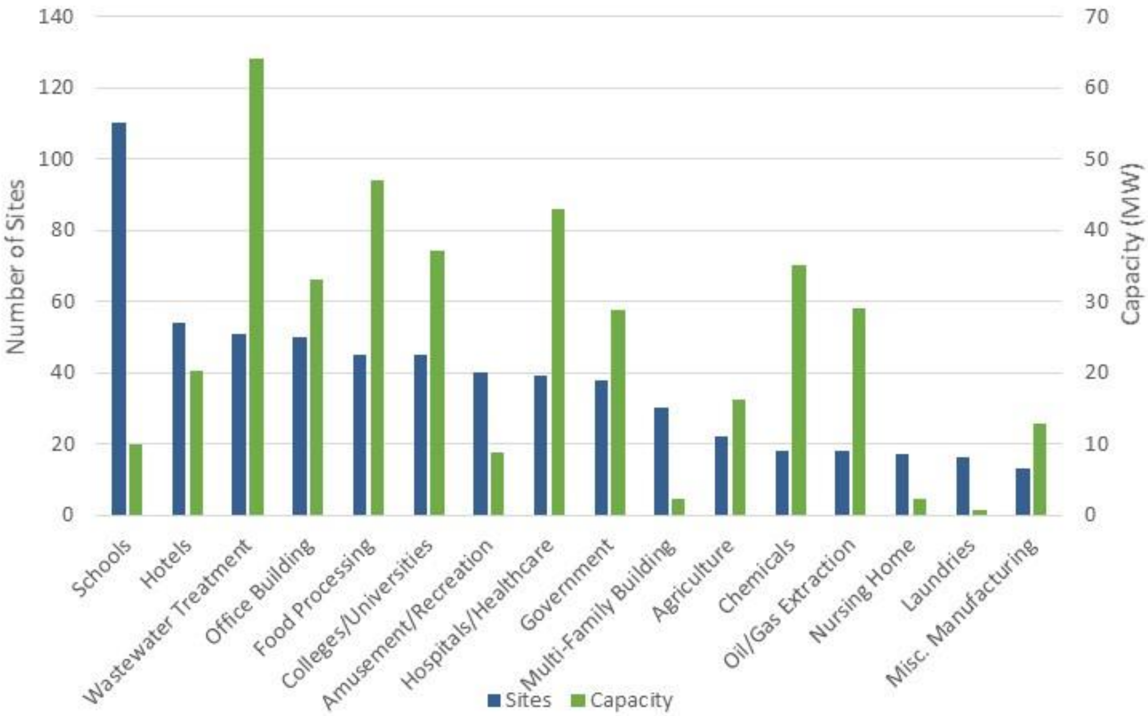

Source: DOE CHP Installation Database (U.S. installations as of Dec. 31, 2016)

A majority of the existing 50 kW to 5 MW systems in California, more than 400, are found in the 50-249 kW size range. However, the largest amount of capacity for CHP technical potential is found in the 1-5 MW size range, with over 450 MW. This is to be expected, since these systems are larger, and fewer sites are necessary to produce more total capacity.

Based on the review of the current CHP applications, the industrial sector represents more than 75% of existing CHP capacity in California, when considering the full range of system sizes. The industrial CHP capacity is heavily weighted towards large installations, sometimes more than 100 MW. For CHP applications smaller than 5 MW, industrial facilities only represent 25% of existing California capacity, including several installations in the food processing, chemicals, and oil/gas extraction industries. The remaining CHP capacity under 5 MW, close to 75% of this market, primarily consists of buildings in the commercial and institutional sectors, led by wastewater treatment plants, hospitals, and colleges/universities. California also has a large number of CHP systems in office buildings, which are typically considered marginal hosts for CHP due to low nighttime loads and limited thermal requirements. High retail prices for electricity, particularly during peak daytime hours, can lead to attractive economics for office building CHP applications in California markets.

Figure 23 shows the top applications for California CHP installations by number of sites and total CHP capacity. See APPENDIX A for the corresponding data table for Figure 23.

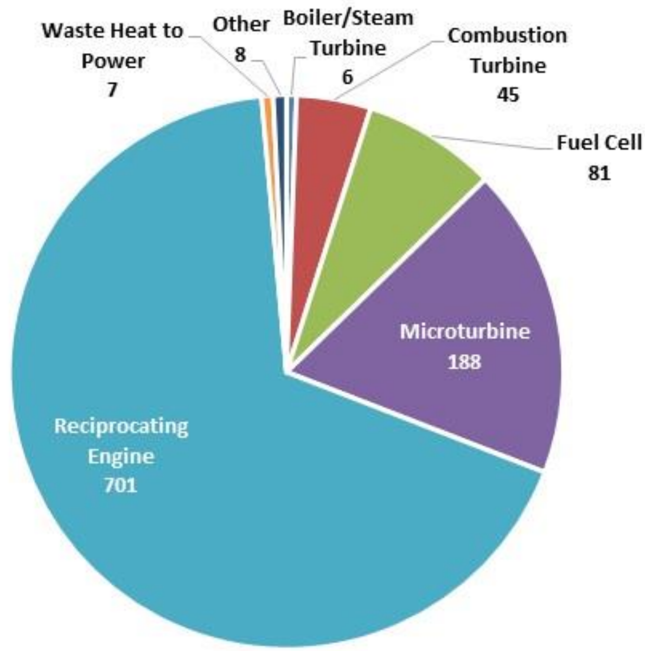
**Figure 23: Number of Sites and Installed Capacity (MW) for <5 MW CHP: Top Applications**




Source: U.S. DOE CHP Installation Database, July 2017

Current California CHP installations under 5 MW are broken down by prime mover in Figure 24.

**Figure 24: Installed CHP Systems in California by Prime Mover (Number of Sites)**




Source: U.S. DOE CHP Installation Database. July 2017

Of these 1,035 CHP installations, there are currently 96 installations of micro-CHP systems under 50 kW in California, including hotels, laundries, and multifamily buildings, with a total capacity of 1,790 kW.[40] The top application types for micro-CHP installations are shown in Figure 25. See Appendix A for the corresponding data table for Figure 25.

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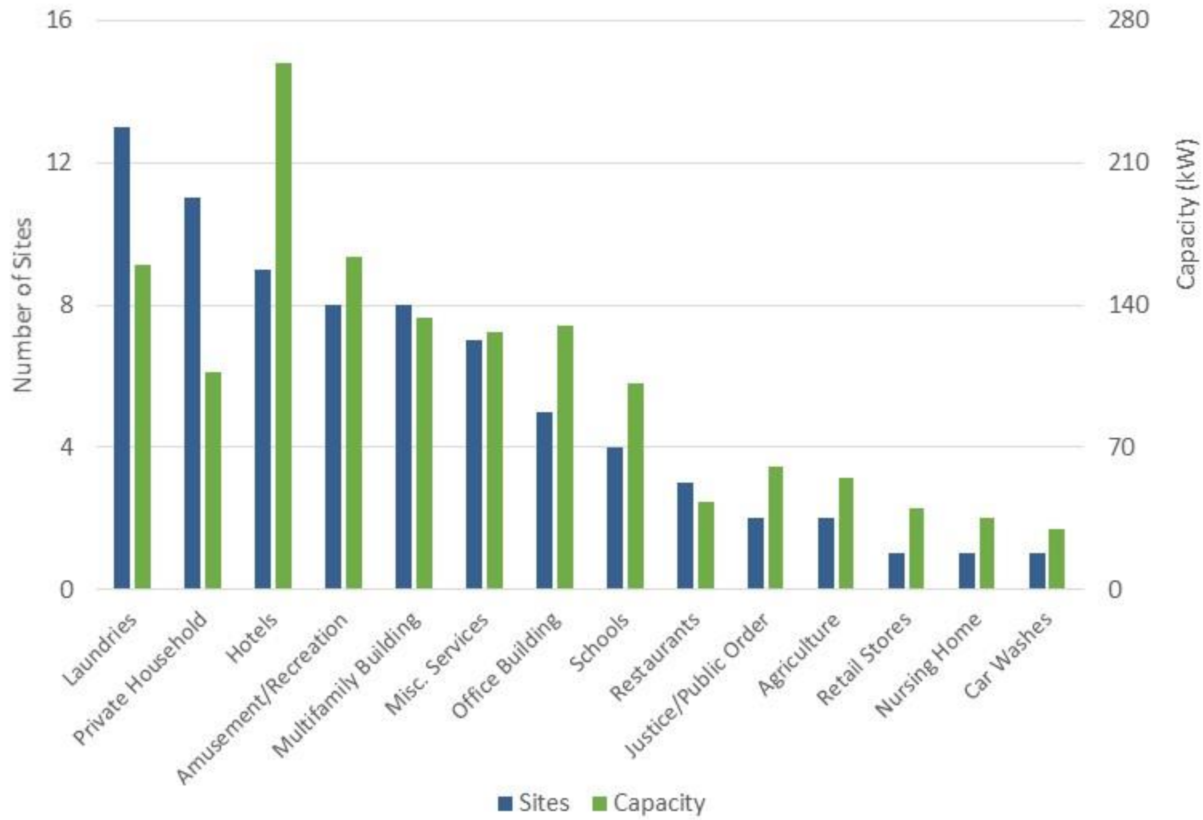
40 Ibid.

**Figure 25: Number of Sites and Installed Capacity (kW) for <50 kW micro-CHP: Top Applications**




Source: U.S. DOE CHP Installation Database, July 2017

The vast majority (95%) of micro-CHP installations reviewed were used for commercial, institutional, or residential applications. Most of these <50 kW systems in the database are reciprocating engines installed before 1990, although anecdotal evidence from CHP vendors suggests that these systems are no longer operational. There have been several recent micro-CHP installations in California, including fuel cells and microturbines. The recent market has been slow, however, with only 18 documented micro-CHP installations in this size range during the ten-year period between 2007 and 2016.[41]

## Identifying the Market for New CHP Applications

Through the analysis of operational CHP systems in California, more than 50 different applications were identified. The full list of applications found among current California CHP installations is shown in Table 31. Several of these sub-sectors can be consolidated with others based on similar building load profiles and functionality.

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[41] Ibid.

**Table 31: CHP Applications Identified From Existing California Installations**

| Industrial | Commercial, Institutional, and Residential | |
|---|---|---|
| Agriculture | Air Transportation | Laundries |
| Chemicals | Amusement/Recreation | Military/National Security |
| Electronics | Automotive Services | Misc. Services |
| Fabricated Metals | Banks | Motion Pictures |
| Food Processing | Car Washes | Multi-Family Building |
| Instruments | Colleges/Universities | Museums/Zoos |
| Machinery | Commodity Brokers | Assisted Living |
| Misc. Manufacturing | Communications | Office Building |
| Oil/Gas Extraction | Community Services | Postal Service |
| Primary Metals | Construction | Private Household |
| Printing/Publishing | Data Centers | Restaurants |
| Pulp and Paper | District Energy | Schools |
| Refining | Energy Management Services | Solid Waste Facilities |
| Rubber/Plastics | Food Stores | Space Research and Technology |
| Stone/Clay/Glass | General Merch. Stores | Utilities |
| Textiles | Government | Warehouses |
| Transportation Equipment | Hospitals/Healthcare | Wastewater Treatment |
| Wood Products | Hotels | Wholesale Trade |
| | Justice/Public Order | |

Source: ICF

Generally, these sub-sectors matched up with those identified in the ICF-produced 2016 DOE report which evaluated the technical potential for new CHP applications 50 kW and larger across the United States.[42] The site-level data and energy load estimates in the 2016 DOE report formed the basis of the market evaluation for California CHP applications 50 kW to 5 MW in size. For CHP applications smaller than 50 kW, the U.S. Census Division's County Business Patterns data for California was used to estimate the total number of potential micro-CHP applications in commercial and institutional markets. The results of the market evaluation are described later in this chapter.

A detailed discussion of CHP applications and load profiles for different facility types is provided in the following sections.

[42] U.S. Department of Energy. Combined Heat and Power (CHP) Technical Potential in the United States. March 2016. Retrieved from: https://www.energy.gov/eere/amo/downloads/new-release-us-doe-analysis-combined-heat-and-power-chp-technical-potential

**Industrial Facilities**

CHP is well-suited for industrial facilities[43] with consistent electric and thermal loads. Most industrial manufacturing plants are sized relatively large for economies of scale, and they have a strong demand for electricity and thermal energy as steam or process heating. While many of the potential CHP applications are significantly larger than 5 MW, there are some industrial manufacturing plants with baseload electricity requirements below 5 MW, where smaller CHP systems can be used.

Industrial manufacturing plants are typically either two-shift or three-shift facilities, requiring a continuous supply of electricity and thermal energy for 16 or 24 hours a day. Industrial facilities generally have high load factors, meaning their load does not vary substantially from hour to hour, and seasonal variations are not significant. For economic reasons, most industrial facilities operate 24/7, making CHP well-suited for baseload power applications.

CHP systems at industrial facilities are typically sized to take full advantage of the recovered heat. For industrial facilities that require large amounts of thermal energy, CHP systems may be sized close to the average electric load in order to maximize operational efficiency. For some larger facilities, CHP systems may export excess power to the utility while utilizing all of the thermal energy on-site. With the scope of this study limited to applications under 5 MW, power export options are not considered.

A full list of the sub-sectors for industrial CHP applications in California is shown in Table 32, with the associated Standard Industrial Classification (SIC) code and North American Industry Classification System (NAICS) code.

[43] Industrial facilities consist primarily of those in the manufacturing industries (SIC 20-39, NAICS 311-339) as well as agriculture, oil and gas extraction, and gas processing facilities.

**Table 32: Industrial CHP Applications for California Market Analysis**

| SIC | NAICS | Industrial Facility Type |
|---|---|---|
| 20 | 311 | Food & Beverage |
| 22 | 313 | Textiles |
| 24 | 321 | Lumber and Wood |
| 25 | 337 | Furniture |
| 26 | 322 | Paper |
| 27 | 323 | Printing/Publishing |
| 28 | 325 | Chemicals |
| 29 | 324 | Petroleum Refining |
| 30 | 326 | Rubber/Miscellaneous Plastics |
| 32 | 327 | Stone/Clay/Glass |
| 33 | 331 | Primary Metals |
| 34 | 332 | Fabricated Metals |
| 35 | 333 | Machinery/Computer Equip. |
| 37 | 336 | Transportation Equip. |
| 38 | 334 | Instruments |
| 39 | 339 | Miscellaneous Manufacturing |
| 49 | 486 | Gas Processing |

Source: ICF

While some industrial facilities could benefit from a CHP installation under 50 kW, this market is limited. Only 5 out of 96 current California CHP applications in this size range are from the industrial sector. For this reason, in the California market analysis, industrial facilities are only considered for CHP applications 50 kW or larger.

### Commercial and Institutional Buildings

Commercial and institutional buildings, including hotels, office buildings, hospitals, and schools, tend to have smaller electric and thermal demands compared to industrial facilities. Additionally, commercial buildings tend to have lower load factors, with larger differences between peak and average loads, and more seasonal variation in their energy requirements. CHP installations are most ideal for commercial and institutional buildings with consistent electric and thermal loads that operate 24 hours a day, 7 days a week. However, applications such as office buildings and retail establishments with low nighttime loads have the potential to economically and efficiently utilize CHP during operational hours.

Electric and thermal load profiles for commercial and institutional buildings can vary depending on a number of factors, including:

- Site specific electric/thermal loads (i.e. food storage, cooking, lighting, office equipment).
- Climate and seasonality.
- Construction materials.

- Hours of operation.
- Installed HVAC equipment.
- On-site thermal loads (hot water, space heating, space cooling).

These factors tend to affect the magnitude and duration of peak load requirements, which are important factors in determining the potential energy savings for CHP installations. CHP is most efficient and cost-effective when sized to fully use the electric and thermal outputs 24 hours a day. Buildings that shut down operations on nights and weekends are not able to recoup the same energy savings as buildings that can utilize a CHP system 24 hours a day, 7 days a week.

Table 33 shows the commercial and institutional applications for CHP that are evaluated in this California market study, with their associated SIC and NAICS codes.

**Table 33: Commercial and Institutional CHP Applications for California Market Analysis**

| SIC | NAICS | Building Type |
|---|---|---|
| 43 | 491 | Post Offices |
| 52-53 | 44-45 | Retail Stores |
| 4222 | 493 | Refrigerated Warehouses |
| 4581 | 488 | Airports |
| 4952 | 221 | Waste Water Treatment Plants |
| 5411 | 445 | Food Sales |
| 5812 | 722 | Restaurants |
| 60-67 | 52-56 | Commercial Office Buildings |
| 7011 | 721 | Hotels |
| 7211 | 812 | Laundries |
| 7374 | 518 | Data Centers |
| 7542 | 811 | Carwashes |
| 7832 | 512 | Movie Theaters |
| 7991 | 713 | Health Clubs |
| 7997 | 713 | Golf/Country Clubs |
| 8051 | 623 | Nursing Homes |
| 8062 | 622 | Hospitals |
| 8211 | 611 | Schools |
| 8221 | 611 | Colleges/Universities |
| 8412 | 712 | Museums |
| 9100 | 921 | Government Facilities |
| 9223 | 922 | Prisons |
| 9711 | 928 | Military |

Source: ICF

For many of these applications, thermal loads are limited to hot water, although there could be opportunities to use thermal energy from CHP for space heating and cooling (with the use of an absorption chiller). CHP systems are generally sized to provide baseload electricity while utilizing a very high percentage of the thermal output. In the market analysis, the project team used application-specific size and utilization factors developed for ICF's CHP Technical Potential Database and the DOE CHP technical potential assessment.

### Residential Buildings

To date, residential CHP applications in California have been limited, with 30 installations in multifamily buildings and 12 installations in spacious private residences. Although residential buildings do not close down on nights or weekends, loads for residential applications vary significantly according to both time of day and season, and baseload CHP systems are typically sized small compared to a residential building's peak load. If net energy metering and thermal storage can be employed, this allows for larger CHP sizing and more flexible operation.

There is a significant amount of potential for CHP applications at large high-rise multifamily buildings in urban areas, like Los Angeles and San Francisco, but the majority of residential applications fall in the micro-CHP category. The potential market for CHP in residential buildings will depend on future advancements in micro-CHP technologies.

Currently, there is a lack of economically viable and commercially available CHP technologies for single-family households. Several promising technologies were highlighted in CHAPTER 2 but for the current and near-term market, there is expected to be limited uptake in residential CHP for single-family homes.

Multifamily apartment buildings with central water heating and master-metered electricity are ideal applications for both traditional CHP and micro-CHP systems in the 10-50 kW size range. In the market assessment, potential multifamily CHP applications are explored along with applications in the commercial, institutional, and industrial sectors. A separate analysis considered the potential for future residential micro-CHP applications at single family homes.

## Methodology for Evaluating California CHP Potential

This section provides a high-level overview for the methodology used to develop estimates for technical potential, economic potential, and market adoption for CHP in California. Additional analysis details are provided in each of the respective sections.

### Technical Potential

The technical potential for CHP is an estimation of the total market size, constrained only by technological limits, or the ability of CHP technologies to meet building energy needs without considering economic or market factors. For this analysis, three different application types were considered:

1. Traditional CHP Applications, 50 kW – 5 MW in size
2. Micro-CHP Applications, 10-50 kW in size

3. Single Family Home Micro-CHP Applications, 1-2 kW in size.

Determining the technical potential for CHP in California was estimated by quantifying the number of buildings with technical potential for CHP, with estimated baseload CHP sizes, for each of the three application types. CHP sizes are based on estimated on-site thermal requirements, capped at the facility's average electric load. Three different approaches were taken for estimating the technical potential for CHP, based on the three different application types.

- For traditional CHP applications, data from ICF's Technical Potential Database was used. This data includes site-by-site facility information with specific locations and estimated CHP sizes. Existing CHP installations are removed.
- For micro-CHP applications 10-50 kW in size, data from U.S. Census County Business Patterns[44] and the Hoovers (Dun & Bradstreet) database,[45] combined with CHP sizing data for traditional applications, was used to estimate the number of CHP opportunities.
- For single family homes, housing statistics from the U.S. Census Bureau and the Energy Information Administration (EIA)[46] were used to estimate the number of detached, owner-occupied, single family homes by size range and utility territory.

## Economic Potential

The economic potential for CHP was evaluated using ICF's CHPower model. Project economics are estimated by calculating the simple payback for CHP systems at each potential location, based on size and application data from the technical potential analysis. Electricity and gas rates for CHP customers were analyzed for the five major electric utilities and three major gas utilities. As a proxy, facilities located in small utility territories in Northern California used Sacramento Municipal Utility District (SMUD) electric rates, while facilities in Southern California territories used Los Angeles Department of Water and Power (LADWP) rates. Table 34 provides a breakdown of the electric and gas utilities modeled for this analysis.

[44] United States Census Bureau. County Business Patterns. 2015. https://www.census.gov/programs-surveys/cbp.html

[45] Dun & Bradstreet. D&B Hoovers Database. August 2017. Retrieved from: http://www.hoovers.com

[46] United States Department of Energy. Energy Information Administration. Electricity Sales, Revenue, Prices & Customers. 2017. Retrieved from: https://www.eia.gov/electricity/data.php#sales

**Table 34: Electric and Gas Utilities Modeled for California CHP Market Assessment**

| Area Covered | Electric Utility | Gas Utility |
|---|---|---|
| Los Angeles County | Los Angeles Department of Water and Power | SoCalGas |
| Northern California | Pacific Gas & Electric | Pacific Gas & Electric |
| Northern California - small municipal utilities and coops | Sacramento Municipal Utility District | Pacific Gas & Electric |
| Sacramento County | Sacramento Municipal Utility District | Pacific Gas & Electric |
| San Diego County | San Diego Gas & Electric | San Diego Gas & Electric |
| Southern California | Southern California Edison | SoCalGas |
| Southern California - small municipal utilities and coops | Los Angeles Department of Water and Power | SoCalGas |

Source: ICF

CHP cost and performance characteristics, as described in CHAPTER 2, were applied to the technical potential estimates for each site, in each service territory, to calculate a simple payback period for each potential application. The economic potential was estimated using the following assumptions:

- Facilities are designated as high load factor or low load factor facilities, based on their operational hours. Facilities with year-round cooling loads are evaluated with absorption chillers, using data collected from the technology assessment described in CHAPTER 2, while facilities with seasonal cooling loads may consider absorption chillers as an option. For this analysis, absorption chillers were not applied to facilities with seasonal cooling loads.
- Each potential CHP application used an estimated number of full-load equivalent hours for a representative CHP installation, ranging from 4,000 to 8,000 hours depending on the typical operational schedule for the application.
- A thermal utilization factor was assigned to each CHP application based on the percent of thermal energy that can typically be used for the system given the customer class. CHP systems are assumed to operate according to the site's electric load, with thermal energy used as available for site thermal loads.

Representative buildings, full load equivalent hours, and thermal utilization assumptions used for different CHP application types are shown in Table 35.

**Table 35: CHP Operational Assumptions by Application Type**

| Application Type | Representative Buildings | Full Load Hours | Thermal Utilization |
|---|---|---|---|
| High Load Factor, Traditional CHP | Food processing, Chemicals, Paper, Hospitals, Hotels, Colleges/Universities | 7,000-8,000 | 80-90% |
| High Load Factor, Cooling CHP | Data Centers, Airports, Refrigerated Warehouses | 8,000 | 90% |
| Low Load Factor, Traditional CHP | Office Buildings, Recreational Facilities, Retail Stores, K-12 Schools | 4,000-5,000 | 70-80% |
| Low Load Factor, Cooling CHP | Supermarkets, Food Stores | 5,000 | 90% |

Cost and performance parameters for commercially available CHP equipment in California, as described in CHAPTER 2, were used for this assessment. For each CHP size range, economics were evaluated using one engine and one turbine option (microturbines for systems <1 MW, combustion turbines for 1-5 MW). For residential single family homes, only the emerging 1.5 kW solid oxide fuel cell was considered, as it had the most favorable cost and performance along with the option for net metering.

CHP cost and performance values used in the analysis are presented in Table 36 for traditional CHP applications, and Source: ICF

Table 37 for micro-CHP applications.

**Table 36: Cost and Performance Parameters for Traditional CHP Applications**

| Parameter | 50-249 kW | | 250-499 kW | | 500-999 kW | | 1-5 MW | |
|---|---|---|---|---|---|---|---|---|
| | Engine | Micro-turbine | Engine | Micro-turbine | Engine | Micro-turbine | Engine | Gas Turbine |
| Net Capacity (kW) | 100 | 62 | 100 | 190 | 820 | 950 | 1,320 | 3,300 |
| Average Installed Cost, $/kW | $3,750 | $3,450 | $3,750 | $3,550 | $2,850 | $3,150 | $2,570 | $3,580 |
| Heart Rate, Btu/kWh | 11,750 | 14,041 | 11,750 | 12,099 | 9,730 | 12,099 | 9,630 | 13,967 |
| Thermal out | 6,100 | 6,307 | 6,100 | 4,684 | 4,220 | 4,684 | 4,144 | 6,455 |
| O&M Costs, $/kWh | $0.024 | $0.020 | $0.024 | $0.020 | $0.019 | $0.020 | $0.015 | $0.014 |
| Electric Efficiency (HHV) | 29.0% | 24.3% | 29.0% | 28.2% | 35.1% | 28.2% | 35.4% | 24.4% |
| CHP Efficiency (HHV) | 81.2% | 71.7% | 81.2% | 67.3% | 78.1% | 67.3% | 74.0% | 70.5% |

Source: ICF

**Table 37: Cost and Performance Parameters for Micro-CHP Applications**

| Parameter | 1-2 kW | 10-49 kW | |
|---|---|---|---|
| | Fuel Cell | Engine | Microturbine |
| Capacity | 1.5 | 19.2 | 28.0 |
| Average Installed Cost, $/kW | $14,000 | $5,300 | $5,025 |
| Heart Rate, Btu/kWh | 6,284 | 12,141 | 15,000 |
| Thermal Output, Btu/kWh | 1,571 | 6,771 | 7,500 |
| Electric Efficiency (HHV) | 54.3% | 28.1% | 22.7% |
| CHP Efficiency (HHV) | 79.3% | 83.9% | 72.7% |
| O&M Costs, $/kWh | $0.030 | $0.025 | $0.023 |

Source: ICF

A full evaluation of CHP cost and performance parameters that were considered for this assessment can be found in CHAPTER 2.

The simple payback calculation for estimating economic potential is based on two main factors: the on-site annual savings from CHP and the on-site net capital cost of the system. Using the assumptions above, the CHP economic potential for each site was calculated using the following steps:

**On-site Annual Savings**

- The on-site electric savings ($) were calculated based on the avoided electric rate ($/kWh), the CHP system size (kW), and the annual hours of CHP operation.
- The on-site CHP gas cost ($) was calculated using the CHP gas rate ($/MMBtu) and the annual hours of CHP operation. The boiler gas savings ($) were also calculated using the boiler gas rate ($/MMBtu) and the annual hours of CHP operation, with the thermal utilization factor.
- The on-site annual O&M costs ($) were calculated based on the annual CHP system operation (kWh).
- On-site annual savings = electric savings + boiler gas savings - CHP gas cost - CHP O&M costs.

**On-site Net Capital Cost**

- The on-site base capital cost ($) was calculated based on the CHP size (kW) and cost and performance assumptions for installed cost estimates ($/kW), derived from the technology analysis described in CHAPTER 2.

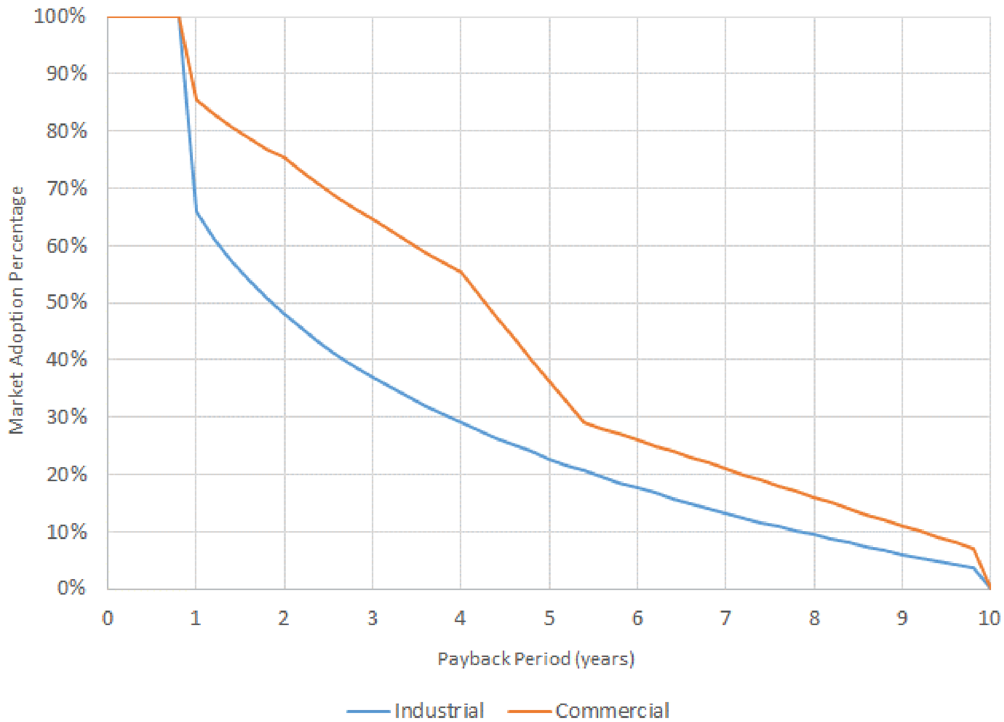
**On-site Payback**

- The on-site payback was calculated by taking the quotient of the on-site net capital cost ($) and the on-site annual savings ($).

## Market Adoption

The results of the economic potential analysis are applied to ICF's market adoption model, which estimates the rate of CHP adoption over a 20-year period. Industrial customers may require a payback of less than five years, while commercial and institutional customers may be willing to accept a longer payback period, in the 5-10-year range. In general, customers with a payback period of more than 10 years are not expected to adopt CHP, and customers are more likely to adopt as the payback period gets closer to zero, and this is reflected in the acceptance percentages that were developed by ICF. The market acceptance curve used for this analysis is shown in Figure 26.

**Figure 26: Market Acceptance Percentages for Industrial and Commercial/Institutional Customers**




Source: ICF

From the chart, if industrial customers could obtain a 3-year payback period with CHP, about 37 percent would be expected to move forward with the decision. Meanwhile, a 3-year payback would be accepted by about 64 percent of commercial customers, who are more likely to accept longer payback periods. The market acceptance percentages for each customer are applied to the total CHP potential based on the customer type and the estimated payback period.

A Bass Diffusion model is applied to the market-accepted CHP potential to estimate the rate of CHP adoption over time. Estimated market growth rates and changes in electricity and gas prices are considered throughout the timeframe of the adoption analysis. Larger sites capable of installing more traditional CHP systems are expected to move forward with projects more quickly than sites capable of installing smaller CHP systems.

## Technical Potential for Small CHP Applications

The analysis presented in this section uses data from ICF's CHP Technical Potential Database, which was also used to develop estimates for the 2016 DOE report on the technical potential for CHP.[47] Members of the project team developed estimates of facility energy loads and CHP potential for facilities across the United States, which focused on opportunities sized 50 kW or larger. See the 2016 DOE technical potential report for details on building assumptions and data collection methodologies. For this assessment, the sites in California with potential to install CHP systems sized 50 kW to 5 MW were identified.

Sites with technical potential for CHP are defined as buildings with sufficient on-site electric and thermal requirements to support a baseload CHP installation. To determine the potential size of an individual site, the site electric load is initially estimated based on:

- Application-specific factors for the site, such as production capacity (industrial facilities), or number of beds, inmates, or students (commercial facilities), or
- Application-specific factors based on the number of employees at the site.

Average application-specific load data, developed by ICF for their CHP Technical Potential Database,[48] was applied to the sites to estimate on-site electric and thermal loads for each facility. First, the facility's average electric load is estimated based on the application type and the facility size. Then, the estimated thermal energy requirements were applied, along with typical CHP efficiencies, to determine the modeled size for a baseload CHP system that can efficiently utilize both the electric and thermal output.

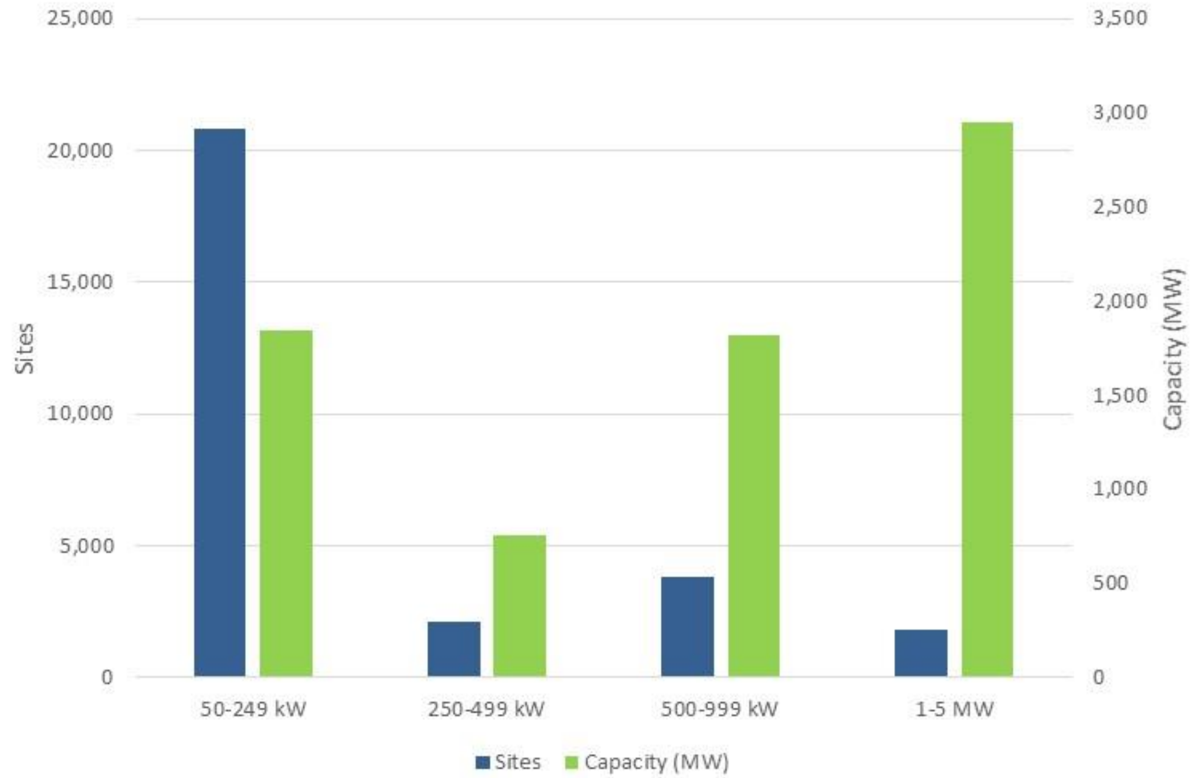
## Traditional CHP Applications: 50 kW to 5 MW

California sites capable of installing CHP systems between 50 kW and 5 MW were assembled, including potential applications in the industrial, commercial, institutional and residential (multifamily) sectors. Overall, there is an estimated 7.4 GW of technical potential across more 28,600 sites for California CHP applications sized 50 kW to 5 MW. By comparison, the 2012 Energy Commission market assessment estimated 9.6 GW of technical potential for California CHP systems in this same size range. The lower potential for this analysis reflects increased CHP adoption and revised estimates with more recent and accurate data sources. The technical potential for CHP capacity and number of sites are broken down by size range in Figure 27. Detailed technical potential data for the following figures can be found in APPENDIX B.

[47] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. March 2016. https://doe.icfwebservices.com/chpdb/

[48] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Retrieved on December 31, 2017. https://doe.icfwebservices.com/chpdb/

**Figure 27: Technical Potential for 50 kW to 5 MW CHP in California, by Size Range**

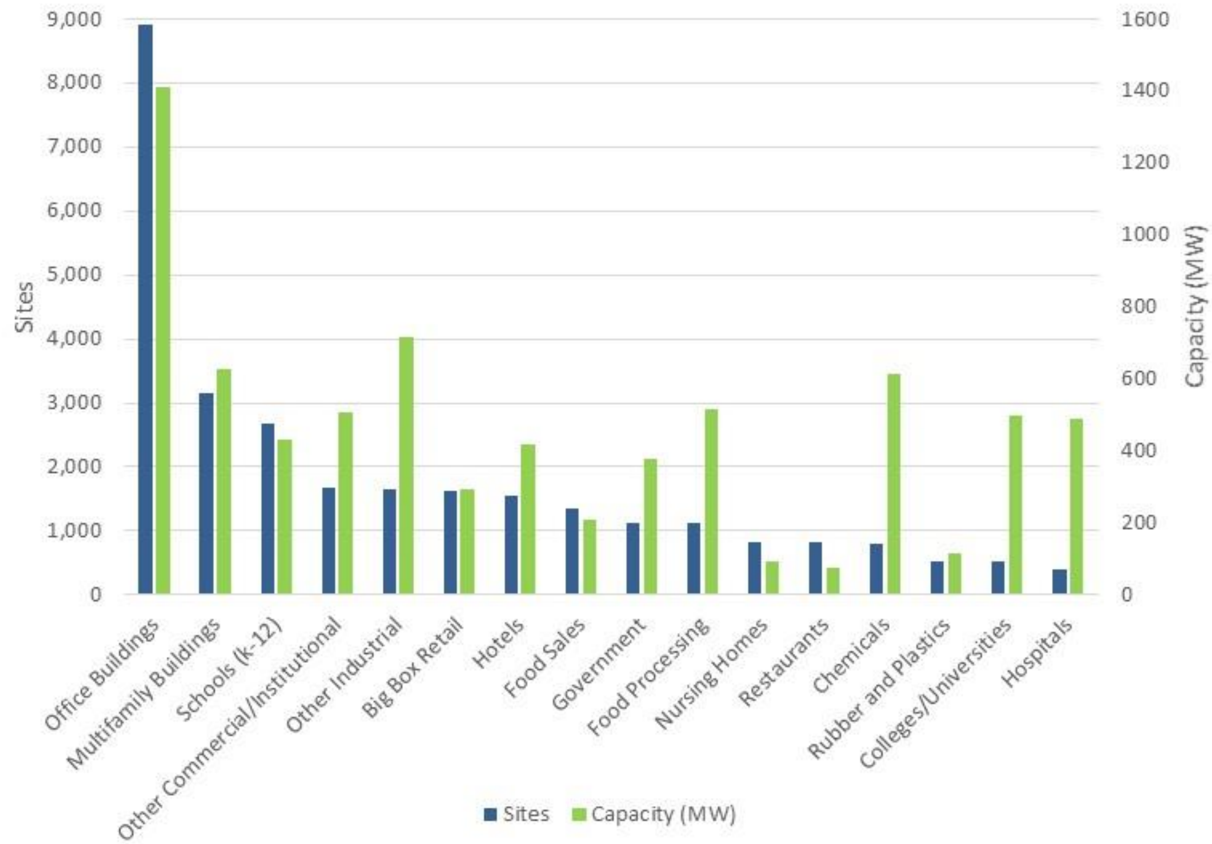



Source: ICF analysis.

The majority of opportunities for 50 kW to 5 MW systems in California are found in the 50-249 kW size range, with over 20,000 potential sites, with an associated capacity of nearly 2 GW. The largest amount of capacity for CHP technical potential is found in the 1-5 MW size range. While there are fewer sites that can support CHP in this size range, the systems are larger systems and therefore contribute more towards the total potential capacity.

Figure 28 shows the technical potential for traditional CHP installations in California by application type.

**Figure 28: Technical Potential for 50 kW to 5 MW CHP in California, by Application**



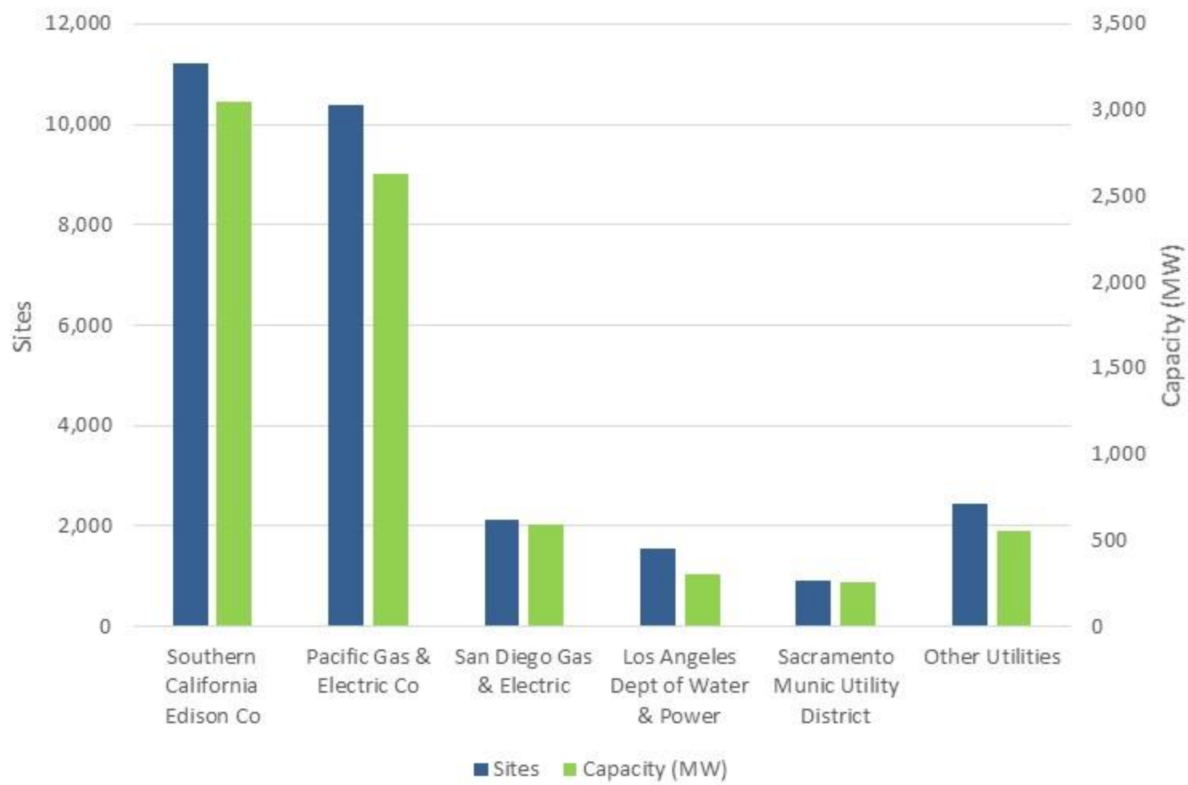

Source: ICF analysis

A wide variety of applications can support 50 kW to 5 MW CHP systems in California, but the largest opportunity lies with commercial office buildings. There are nearly 9,000 office buildings with potential for CHP in the 50 kW to 5 MW size range, resulting in nearly 1,300 MW of technical potential. There are also a large number of multifamily buildings (over 600 MW at more than 3,000 sites) and K-12 schools (over 400 MW at more than 2,500 sites) with CHP potential. Additionally, hotels, government facilities, and various other commercial and institutional applications present a high amount potential capacity, albeit at a fewer number of sites. While there are some industrial applications with a large amount of potential in the 50 kW to 5 MW range, such as food processing and chemicals, the majority of potential sites in this size range come from the commercial and institutional sectors.

Of the five major utilities in California, Southern California Edison (SCE) and Pacific Gas and Electric (PG&E) show the most technical potential for traditional CHP applications due to their large and diverse base of customers. These utilities are followed by San Diego Gas & Electric (SDG&E), LADWP, and SMUD, as well as a collection of other smaller utilities throughout the state, all with significantly less technical potential than

SCE and PG&E in the 50 kW – 5 MW CHP size range. The technical potential for 50 kW to 5 MW CHP in California is broken down by utility territory in Figure 29.

**Figure 29: Technical Potential for 50 kW to 5 MW CHP in California, by Utility Territory**




Source: ICF analysis

## Micro-CHP Applications: 10-50 kW

The market for micro-CHP applications less than 50 kW in California is not as mature as the market for traditional CHP, but there is a substantial number of potential applications in this size range.

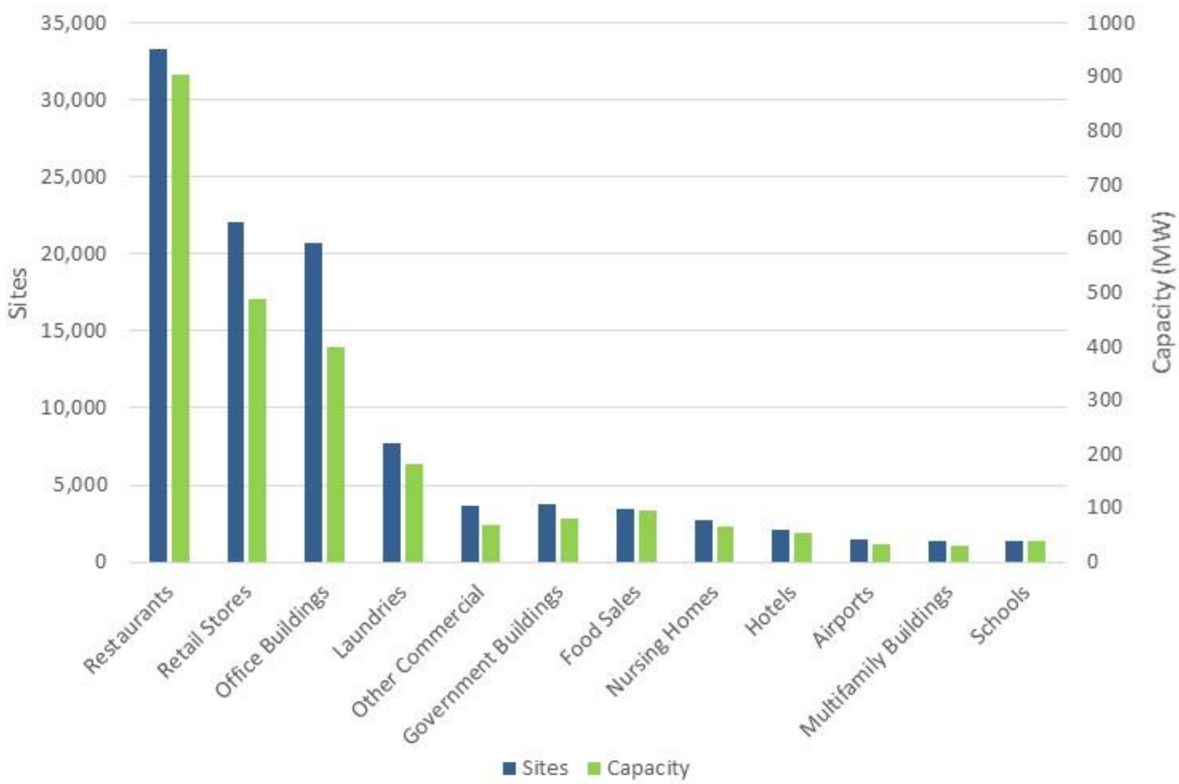
Micro-CHP applications in the 10-50 kW size range are primarily limited to the residential, commercial, and institutional sectors. There are relatively few CHP manufacturers with commercially available systems in this size range, especially for smaller systems under 10 kW. The CHP systems that are available under 50 kW consist of standardized CHP packages with simplified installation and all-inclusive operation and maintenance contracts. These systems are marketed toward commercial and institutional facilities that may not have the resources to operate and maintain on-site CHP equipment. Only 5 out of the 96 current California micro-CHP installations are located at industrial facilities, with the majority of installations in the commercial sector.

The same types of residential, commercial, and institutional buildings that can support traditional CHP systems can also support micro-CHP systems, just at a smaller scale.

The project team assembled data and analyzed potential California CHP applications in the 10-50 kW size range using County Business Patterns data from the U.S. Census Bureau[49] and data on government facilities from the D&B Hoovers database.[50]

The number of employees for a given facility can be used to estimate the size of a building, and correspondingly, the on-site electric and thermal requirements. The project team used data on energy loads relative to the number of workers for each building type to estimate the total potential for 10-50 kW CHP systems in California, using the same methods that were applied to estimate the potential for applications larger than 50 kW. Overall, 2.5 GW of technical potential was found for California micro-CHP applications in the 10-50 kW size range. Figure 30 breaks down the technical potential by application.

**Figure 30: Technical Potential for 10-50 kW Micro-CHP in California, by Application**




Source: ICF analysis

The majority of technical potential for micro-CHP applications under 50 kW can be found in commercial establishments like restaurants, retail stores, commercial office

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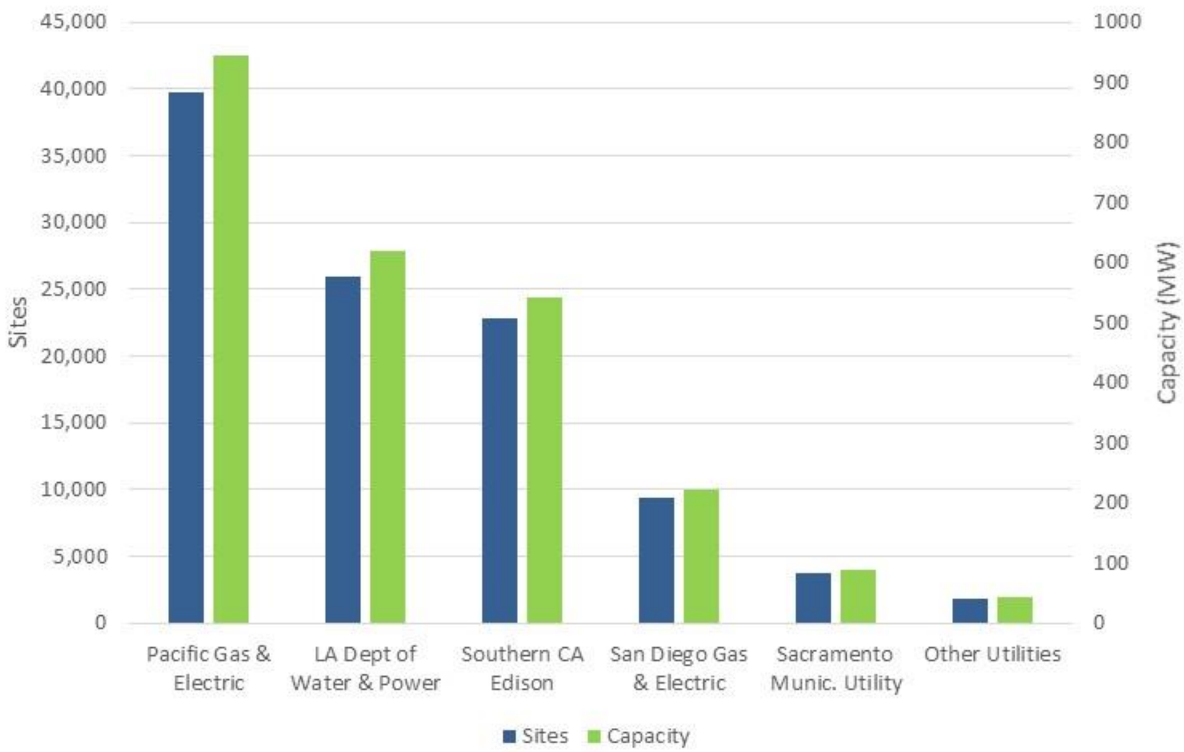
[49] United States Census Bureau, County Business Patterns. 2015. Retrieved from: https://www.census.gov/programs-surveys/cbp.html

[50] Dun & Bradstreet. D&B Hoovers Database. August 2017. http://www.hoovers.com.

buildings, and laundries. Accordingly, much of the technical potential is found in these applications. There is also technical potential in a wide range of institutional facilities, including government buildings and schools.

The technical potential for <50 kW CHP applications is concentrated in California's five major utility territories. Like the 50 kW – 5 MW technical potential, the PG&E utility territory contains much of the CHP technical potential sites and capacity. However, there is a much greater percentage of both sites and potential capacity in the LADWP territory for 10-50 kW applications compared to larger applications, with a corresponding drop in SCE technical potential. This is likely due to the high levels of commercial activity in Los Angeles County. Figure 31 displays the technical potential for micro-CHP applications by utility service territory.

**Figure 31: Technical Potential for 10-50 kW Micro-CHP in California, by Utility Service Territory**




Source: ICF analysis

## Micro-CHP for Single Family Homes

Micro-CHP systems need to be sized very small to efficiently serve most single family homes. Generally, homes sized 2,500-5,000 square feet will be able to efficiently use a 1-2 kW CHP system, using most of the available electricity and thermal energy. Night-time electric loads tend to fall below 1 kW, but net energy metering can allow systems to operate at full load 24/7. California's net metering rules include low-emission fuel cells, which are an emerging technology for residential micro-CHP applications.

Through the technical evaluation of CHP technologies described in CHAPTER 2, a promising 1.5 kW solid oxide fuel cell was identified, which could potentially be applied to single family homes. The fuel cell has a high electric efficiency, and correspondingly lower amount of available thermal energy. This is ideal for residential applications where thermal loads are relatively low, and hot water is typically the only output for a micro-CHP system.

There are approximately 9 million single family homes in California.[51] However, it is likely that only detached, owner-occupied homes will have the capability and incentive to install micro-CHP systems. When adjusting for percentages of detached, owner-occupied single family homes in California, the number of applicable homes drops to about 4.3 million homes that could be hosts for CHP.[52]

The EIA's *Residential Energy Consumption Survey (RECS)* provides representative samples of single family homes, including square foot size. The project team analyzed California RECS entries and found that 15 percent of detached single family homes are more than 3,000 square feet, while 11 percent range between 2,500-3,000 square feet. Applying these percentages, estimates for the total number of applicable detached, owner-occupied single family homes in each size category were developed:

- 645,000 homes more than 3,000 square feet (primary market)
- 473,000 homes between 2,500-3,000 square feet (secondary market)

Homes more than 3,000 square feet in size are seen as the primary market for residential micro-CHP. Homes in the 2,500-3,000 square feet range are viewed as a secondary market, with energy loads that are lower, and not as well-suited for a 1.5 kW CHP system.

EIA data for California's residential customers by utility territory were compared to the total number of California residential customers to develop a percentage of residential market share for each utility. The results of this analysis are provided in Table 38.[53]

[51] California Department of Housing and Community Development. California's Housing Future: Challenges and Opportunities. January 2017 Draft. Retrieved from: http://hcd.ca.gov/policy-research/plans-reports/docs/California's-Housing-Future-Full-Public-Draft.pdf

[52] Ibid.

[53] U.S. Department of Energy. Energy Information Administration. 2016 Utility Bundled Retail Sales – Residential (Data from forms EIA-861- schedules 4A & 4D and EIA-861S). 2016.

**Table 38: Residential Customers CHP by Utility Territory**

| Utility | Residential Customers | Percent of Market |
|---|---|---|
| Pacific Gas & Electric | 4,453,034 | 34.1% |
| Southern California Edison | 4,375,920 | 33.5% |
| Los Angeles Department of Water & Power | 1,315,413 | 10.1% |
| San Diego Gas & Electric | 1,264,642 | 9.7% |
| Sacramento Municipal Utility District | 546,155 | 4.2% |
| Other Utilities | 1,124,884 | 8.6% |
| Total | 13,080,048 | 100.0% |

These percentages were applied to the estimated total market sizes to develop technical potential estimates for 1.5 kW micro-CHP systems in the primary and secondary markets. The technical potential for single family home micro-CHP is shown by utility in Table 39.

**Table 39: Technical Potential for Single Family Home CHP by Utility Territory**

| Utility | Primary Market: >3,000 sq ft | | Secondary Market: 2,500-3,000 sq ft | |
|---|---|---|---|---|
| | Homes | Potential (MW) | Homes | Potential (MW) |
| Pacific Gas & Electric | 219,600 | 329 | 161,100 | 242 |
| Southern California Edison | 215,800 | 324 | 158,300 | 237 |
| Los Angeles Department of Water & Power | 64,900 | 97 | 47,600 | 71 |
| San Diego Gas & Electric | 62,400 | 94 | 45,700 | 69 |
| Sacramento Municipal Utility District | 26,900 | 40 | 19,800 | 30 |
| Other Utilities | 55,400 | 83 | 40,600 | 61 |
| Total | 645,000 | 968 | 473,000 | 710 |

Source: ICF Analysis

Overall, there is approximately 1.7 GW of technical potential for micro-CHP at single family homes, with close to 1 GW coming from homes more than 3,000 square feet.

## California Energy Rates for CHP

Prior to evaluating the economic potential for CHP in California, information on electric and gas utility rates was collected from the five major electric utilities and three major gas utilities in the state. For this exercise, the retail rates for typical customers *before* and *after* the CHP installation should be considered.

### Electric Rates

There are several components of electric rates, such as fixed charges, standby rates, and departing load charges, that cannot be avoided through on-site generation. Therefore, a CHP system is only able to avoid a portion of the electric retail rate, and the rate analysis performed for this assessment sought to determine the avoided electricity rate for each utility, for each CHP size class. The avoided electricity rate determines the potential for electric energy savings, and will most likely have the major effect on CHP economics.

For residential single family home customers, California's investor-owned utilities are in the process of shifting from zonal daily baseline charges – which penalize heavy electricity consumption – towards time-of-use charges. The new time-of-use rates are expected to take effect in 2019. This will have an unknown, but likely positive, effect on residential CHP as it expected to be built around solar PV generation profiles with less expensive afternoon rates and more expensive evening rates.

For the residential economic evaluation, due to the uncertainty in electric and gas rates for residential CHP, a detailed rate analysis was not performed. Project economics are calculated with the avoided electricity rate shown as a variable.

In Tables 40-44 the avoidable rates are presented for each of the five electric utilities, for two customer types: 1) high load factor (operating 24/7), and 2) low load factor (operating 14 hours/day). Due to higher time-of-use rates during daytime hours, the avoidable rate for low load factor customers tends to be higher than it is for high load factor customers.

**Table 40: Los Angeles Department of Water and Power**

| CHP Size Range (kW) | Applicable Electric Rates | Avoidable Rate - High Load Factor ($/kWh) | Avoidable Rate - Low Load Factor ($/kWh) |
|---|---|---|---|
| 10-999 | A-2/CG-2 | $0.129 | $0.135 |
| 1,000-5,000 | A-3/CG-3 | $0.127 | $0.133 |

Source: ICF Analysis

**Table 41: Pacific Gas and Electric**

| CHP Size Range (kW) | Applicable Electric Rates | Avoidable Rate - High Load Factor ($/kWh) | Avoidable Rate - Low Load Factor ($/kWh) |
|---|---|---|---|
| 10-49 | A-1 | $0.184 | $0.187 |
| 50-999 | A-10 | $0.132 | $0.148 |
| 500-999 | E-19 | $0.118 | $0.144 |
| 1,000-5,000 | E-20 | $0.107 | $0.132 |

Source: ICF Analysis

**Table 42: Sacramento Municipal Utility District**

| CHP Size Range (kW) | Applicable Electric Rates | Avoidable Rate - High Load Factor ($/kWh) | Avoidable Rate - Low Load Factor ($/kWh) |
|---|---|---|---|
| 10-249 | GS | $0.116 | $0.115 |
| 250-499 | GS-TOU3 | $0.087 | $0.087 |
| 500-999 | GS-TOU2 | $0.086 | $0.087 |
| 1,000-5,000 | GS-TOU1 | $0.077 | $0.074 |

Source: ICF Analysis

**Table 43: San Diego Gas & Electric**

| CHP Size Range (kW) | Applicable Electric Rates | Avoidable Rate - High Load Factor ($/kWh) | Avoidable Rate - Low Load Factor ($/kWh) |
|---|---|---|---|
| 10-999 | AL-TOU (secondary) | $0.114 | $0.141 |
| 1,000-5,000 | AL-TOU (primary) | $0.113 | $0.140 |

Source: ICF Analysis

**Table 44: Southern California Edison**

| CHP Size Range (kW) | Applicable Electric Rates | Avoidable Rate - High Load Factor ($/kWh) | Avoidable Rate - Low Load Factor ($/kWh) |
|---|---|---|---|
| 10-249 | TOU-GS-2 (A) | $0.082 | $0.104 |
| 250-500 | TOU-GS-3 | $0.084 | $0.104 |
| 500-1,000 | TOU-8/TOU-8-S-SEC | $0.083 | $0.101 |
| 1,000-5,000 | TOU-8/TOU-8-S-PRI | $0.077 | $0.095 |

Source: ICF Analysis

Overall, PG&E has the most favorable rates for CHP, followed by SDG&E and LADWP. SMUD's rates are less favorable, and SCE has the lowest avoidable electric rate in California of the privately held utilities, primarily due to high standby charges. Similar conclusions were drawn in the electric rate analysis performed for the 2012 Energy Commission market assessment. For this updated assessment focused on smaller CHP applications, electricity export via feed in tariffs are not considered, as this is not a common practice for CHP systems smaller than 5 MW.

Electric rates are forecasted to increase significantly for California over the next 20 years. The project team estimated electricity price escalation using the 2017 reference case scenario from the EIA *2017 Annual Energy Outlook (AEO).* Electricity price projections by Electricity Market Module (EMM) Region were used to develop a compound annual growth rate (CAGR) of 2.06% for California electricity rates through 2038.

### Gas Rates

In California, investor-owned gas utilities offer a special rate for customers with on-site electricity production. This lower rate for customers with on-site generation can greatly improve CHP economics. Additionally, CHP customers are able to avoid a substantial fuel purchases at higher retail rate, as thermal energy from the CHP system is applied to heating loads that were previously served by a boiler or water heater. In the rate analysis for this market assessment, the rates for boiler fuel and CHP fuel are calculated for each utility, for each CHP size class.

The gas cost data, representing bundled commodity and transportation prices, shows that the cost of gas changes with the size of the customer, and whether or not they are using the gas for CHP. It is assumed that LADWP and SCE customers obtain their natural gas from SoCalGas and SMUD customers obtain their natural gas from PG&E. PG&E and SDG&E are assumed to provide gas to their own electric customers (Tables 45-47).

**Table 45: PG&E Gas**

| CHP Size Range (kW) | Applicable Natural Gas Rates | Boiler Gas Rate ($/MMBtu) | Gas Rate for CHP Fuel ($/MMBtu) |
|---|---|---|---|
| 10-49 | G-NR1 | $10.02 | $4.02 |
| 50-249 | G-NR1 | $9.45 | $4.02 |
| 250-500 | G-NR1 | $7.93 | $3.82 |
| 500-1,000 | G-NT | $5.81 | $3.82 |
| 1,000-5,000 | G-NT | $5.63 | $3.82 |

Source: ICF Analysis

**Table 46: SDG&E Gas**

| CHP Size Range (kW) | Applicable Natural Gas Rates | Boiler Gas Rate ($/MMBtu) | Gas Rate for CHP Fuel ($/MMBtu) |
|---|---|---|---|
| 10-49 | GN-3 | $7.77 | $4.24 |
| 50-249 | GN-3 | $7.02 | $4.24 |
| 250-500 | GN-3 | $6.67 | $4.04 |
| 500-1,000 | GT-NC | $4.46 | $4.04 |
| 1,000-5,000 | GT-NC | $4.46 | $4.04 |

Source: ICF Analysis

**Table 47: SoCalGas**

| CHP Size Range (kW) | Applicable Natural Gas Rates | Boiler Gas Rate ($/MMBtu) | Gas Rate for CHP Fuel ($/MMBtu) |
|---|---|---|---|
| 10-49 | G-10 | $6.96 | $4.15 |
| 50-249 | G-10 | $6.20 | $4.15 |
| 250-500 | G-10 | $5.38 | $3.95 |
| 500-1,000 | GT-NC | $4.07 | $3.95 |
| 1,000-5,000 | GT-NC | $3.88 | $3.95 |

**SoCalGas rates for LADWP customers are slightly higher than SCE, due to a difference in the manner with which SoCalGas is expected to collect franchise fees within the city of Los Angeles.**

Source: ICF Analysis

Natural gas prices are expected to increase over the next 20 years, at a rate slightly higher than electricity prices. The project team estimated gas price escalation using the 2017 reference case scenario from the EIA *2017 AEO*. Natural gas price projections by Electricity Market Module (EMM) Region were used to develop a compound annual growth rate (CAGR) of 2.90% for California gas rates through 2038.

Compared to the 2012 Energy Commission market assessment, the gas rates for CHP customers in 2017 were found to be considerably lower. All three of California's major gas utilities now offer favorable gas rates for CHP customers through distributed generation tariffs. As a result, any locational differences in CHP economics are likely to depend on electric utility rates.

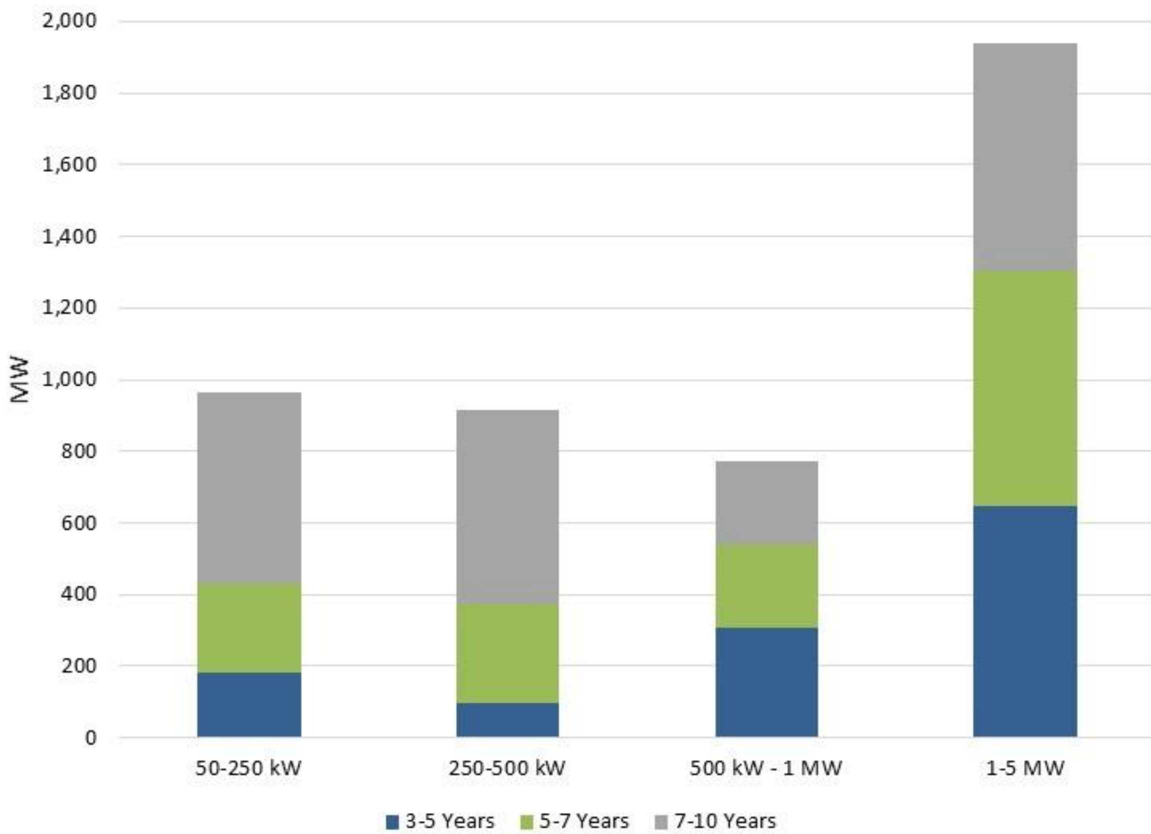
## Economic Potential for Small CHP Applications in California

Data collected for avoided electricity rates and CHP gas rates were applied to California sites with technical potential for CHP installations less than 5 MW. For each potential site, energy rates were combined with CHP sizing assumptions and operational characteristics, with associated capital and maintenance costs for CHP installations, to estimate the payback period. Sites with an estimated payback under 10 years were considered to have economic potential for CHP.

## Traditional CHP Applications: 50 kW to 5 MW

Evaluating economics for California sites with technical potential for 50 kW to 5 MW CHP systems resulted in more than 15,000 sites and 5 GW of economic potential. Figure 32 shows the total economic potential for traditional CHP installations in California by payback period and size range.

**Figure 32: Economic Potential for 50 kW to 5 MW CHP in California, by Size Range**

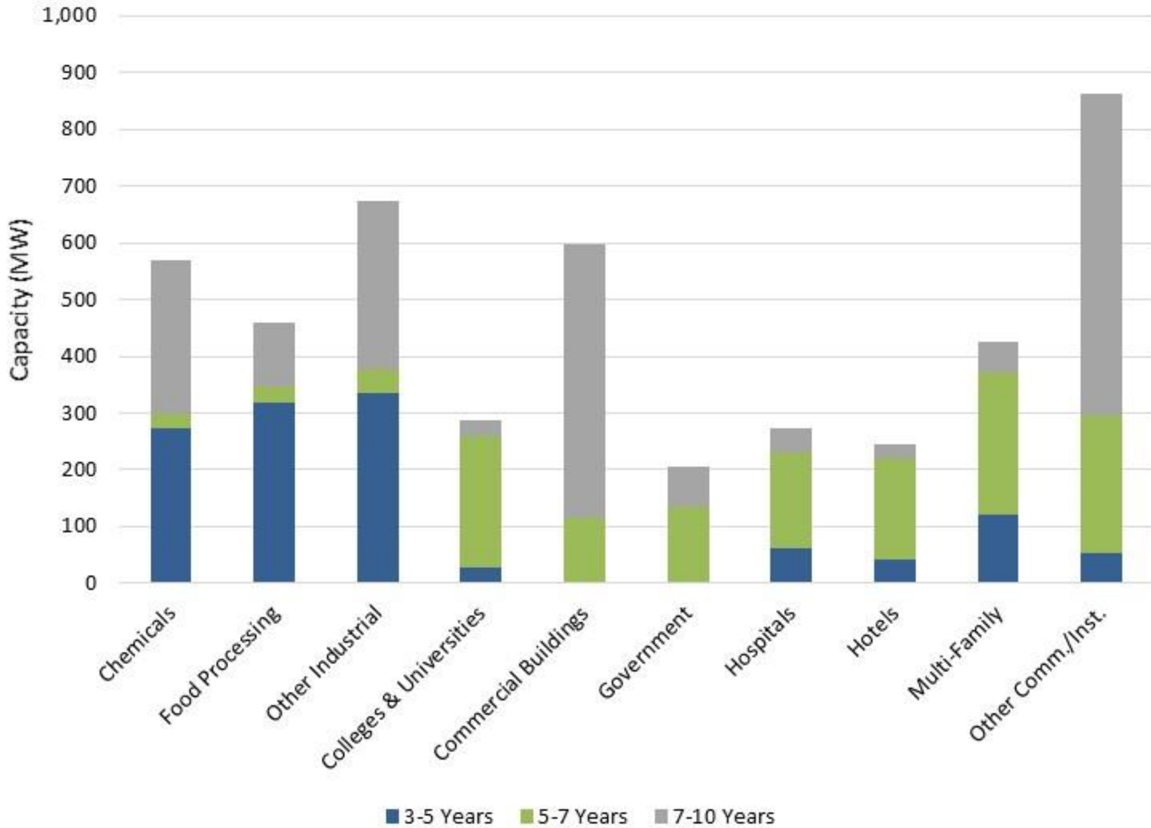



Source: ICF analysis

Larger sites capable of supporting 1-5 MW CHP systems contribute the most to the economic potential, with almost 2 GW of capacity, and over 600 MW at sites estimated to have payback periods under five years. Smaller sites were also found to have a large amount of economic potential, with nearly 1 GW from both the 50-250 kW and 250-500 kW size ranges. While economics may not be as favorable in these smaller size ranges, there are far more sites with CHP potential compared to the 1-5 MW size range.

Figure 33 shows the economic potential for traditional CHP installations in California by payback period and application.

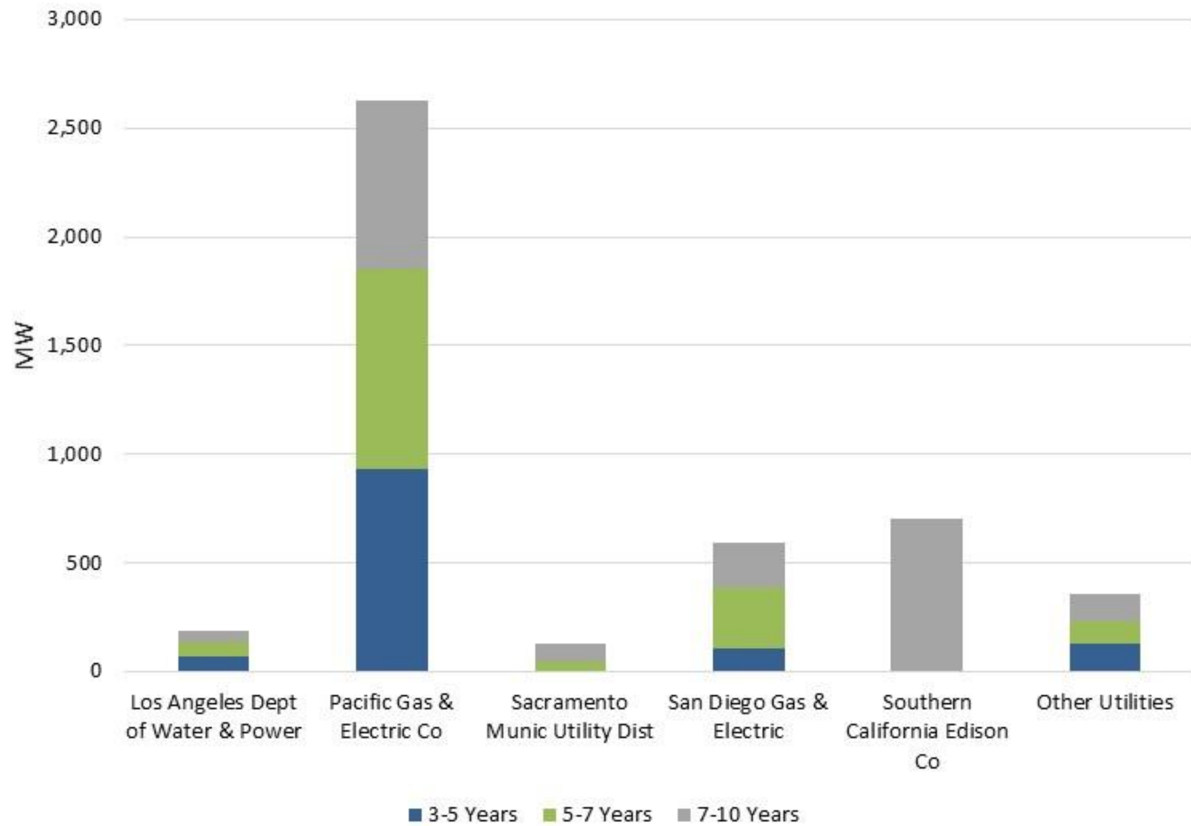
**Figure 33: Economic Potential for 50 kW to 5 MW CHP in California, by Application**




Source: ICF analysis

Economics for applications with limited hours of operation, such as commercial office buildings, government buildings, retail stores and K-12 schools, are less favorable then economics for applications with 24/7 operation, such as industrial facilities, colleges/universities, hospitals, hotels and multifamily buildings. For these high load factor applications, many buildings were able to achieve payback periods less than five years, especially in PG&E's utility territory. Figure 34 shows the economic potential for traditional CHP installations in California by payback period and utility territory.

**Figure 34: Economic Potential for 50 kW to 5 MW CHP in California, by Utility Territory**



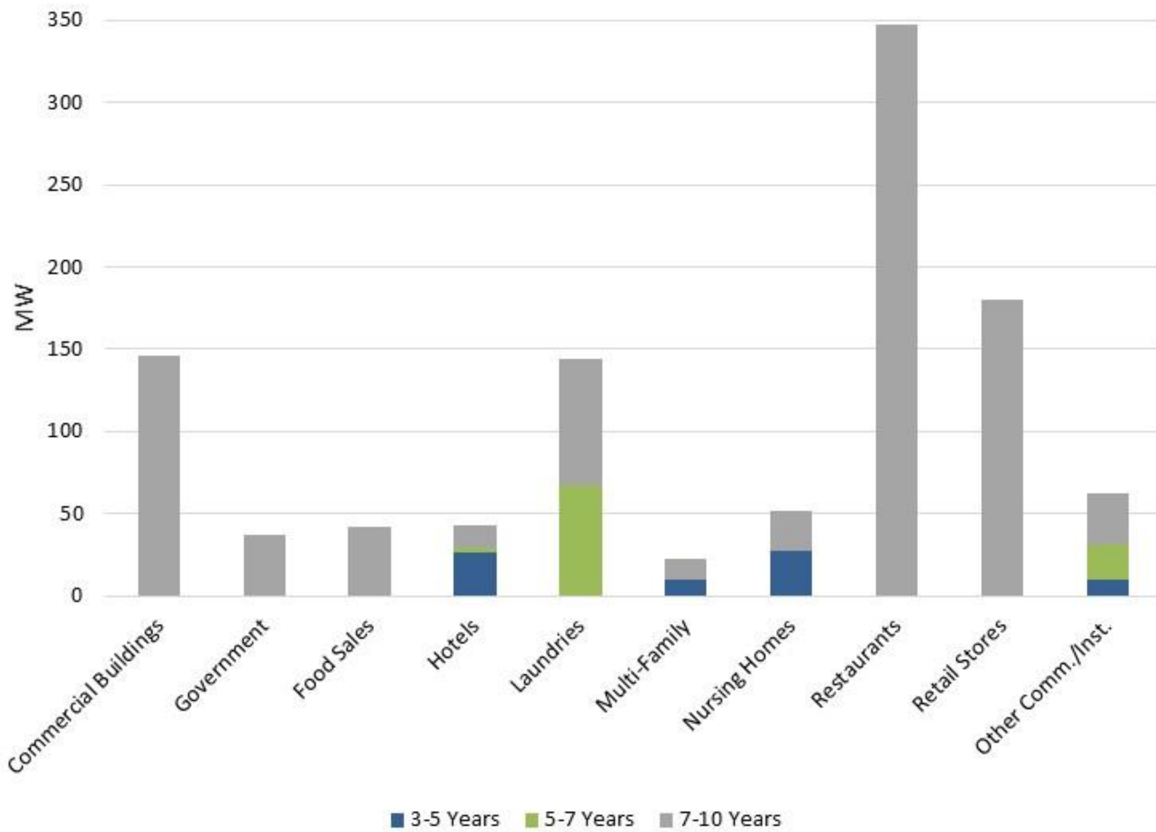

Source: ICF analysis

PG&E had the most favorable rates for CHP, with the highest avoidable electric rate and the lowest gas cost. As a result, PG&E showed the most economic potential, with over 1.5 GW of capacity estimated to have payback periods in the 3-5 year range. All of the sites that showed technical potential for CHP in PG&E's territory – 2.6 GW total – showed economic potential in the market assessment with payback periods under 10 years. Other California utilities also showed economic potential, including some 3-5 year payback periods in LADWP and SDG&E territories. However, economics for Southern California Edison were not as favorable, with economic potential only in the 7-10-year payback range, and limited to high load factor applications.

## Micro-CHP Applications: 10-50 kW

Although the market for micro-CHP in California is not as large as the market for traditional CHP, there is still more than 1 GW of economic potential for new CHP installations. Figure 35 shows the economic potential for micro-CHP installations in California by payback period and application.

**Figure 35: Economic Potential for 10-50 kW Micro-CHP in California, by Application**

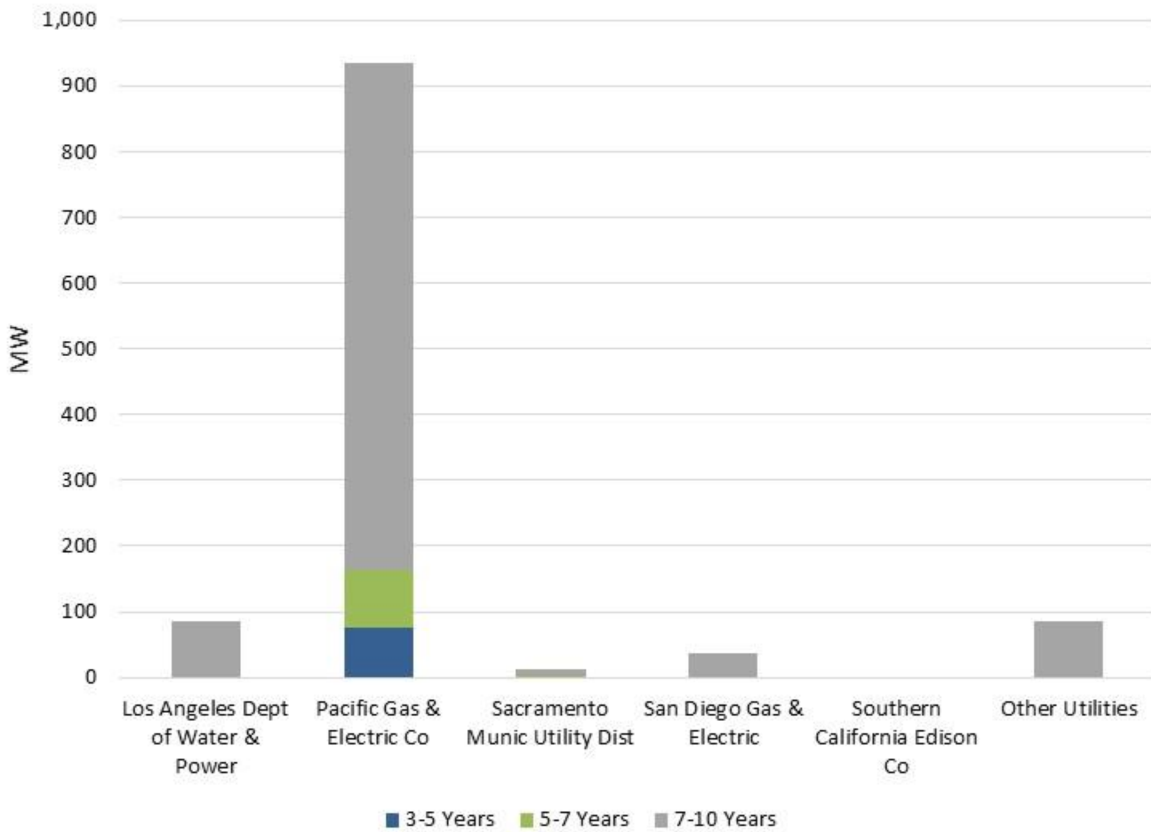



Source: ICF analysis

Most of the economic potential for sites 10-50 kW is found in commercial applications, especially at restaurants, retail stores, commercial office buildings, and laundries. These four applications make up more than 75% of all economic potential capacity for micro-CHP in California. Most of the micro-CHP potential sites with payback periods less than 5 years are found at sites with 24/7 operation, including hotels, nursing homes, correctional facilities and wastewater treatment plants.

Figure 36 shows the economic potential for CHP installations 10-50 kW in California by payback period and utility territory.

**Figure 36: Economic Potential for 10-50 kW Micro-CHP in California, by Utility Territory**




Source: ICF analysis

Nearly all of the economic potential for micro-CHP is located in the PG&E territory. Utilities outside of PG&E make up just over 10% of 10-50 kW CHP capacity, all with payback periods in the 7-10 year range. The SCE territory contains no micro-CHP sites with economic potential. This is largely due to less favorable electric rates for CHP, with a lower avoided cost compared to other utilities.

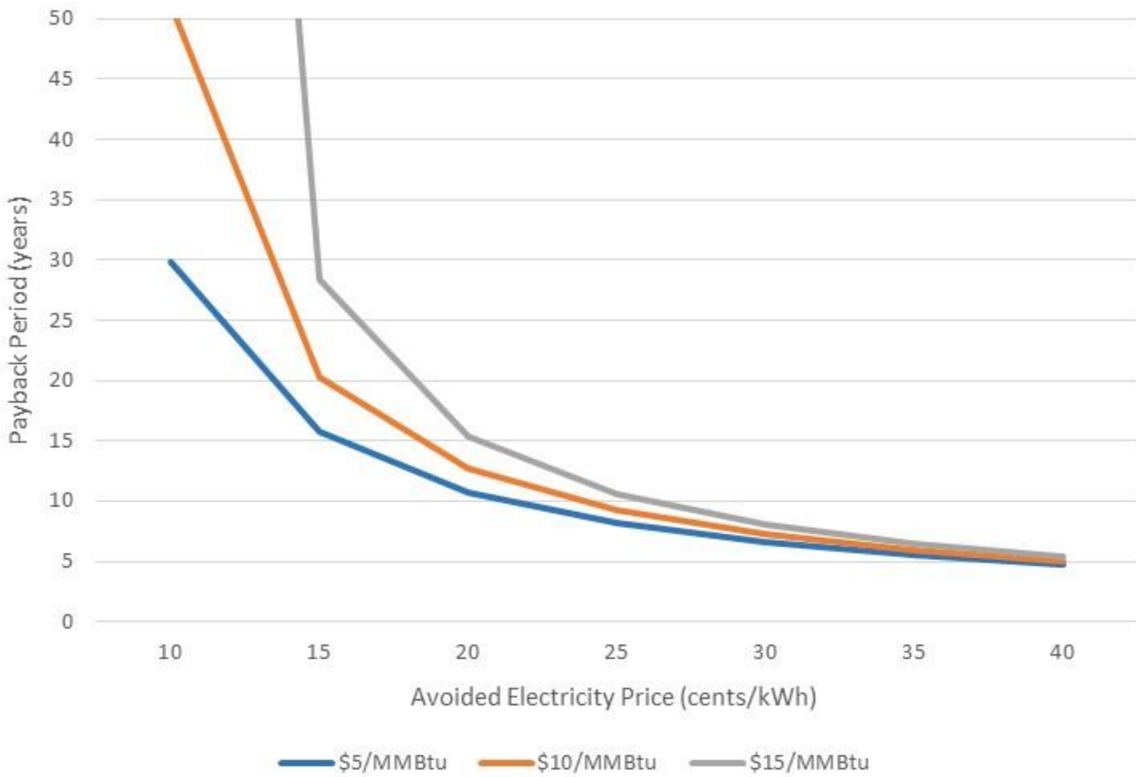
## Micro-CHP for Single Family Homes

The project team analyzed the economics for a single family home installing the 1.5 kW solid oxide fuel cell identified in the technology assessment described in CHAPTER 2. Although there is currently a lack of micro-CHP products for single family homes in the California market, this system was viewed as the most promising future technology. Economics were evaluated at different price points for residential gas rates and avoided electricity cost, followed by a sensitivity for a lower installed cost for the fuel cell.

Average electricity rates for California residences can range from 10-15 cents per kWh up to 30-40 cents per kWh depending on utility, location, level of daily consumption, and time of use. Residential gas rates in California tend to range from $9 to $17 per MMBtu. However, as they have with commercial and industrial rates, gas utilities may consider offering lower rates to residential customers that generate electricity with CHP, which could potentially bring the rates down to $5 per MMBtu.

The project team evaluated the payback period for a 1.5 kW fuel cell, assuming that electricity is net metered and all thermal energy is utilized, with 95% availability (8,322 hours of operation) throughout the year. The payback period depended on electricity rates and gas rates (Figure 37).

**Figure 37: Payback Period for Single Family Home CHP, by Avoided Electric Rate and CHP Gas Rate**

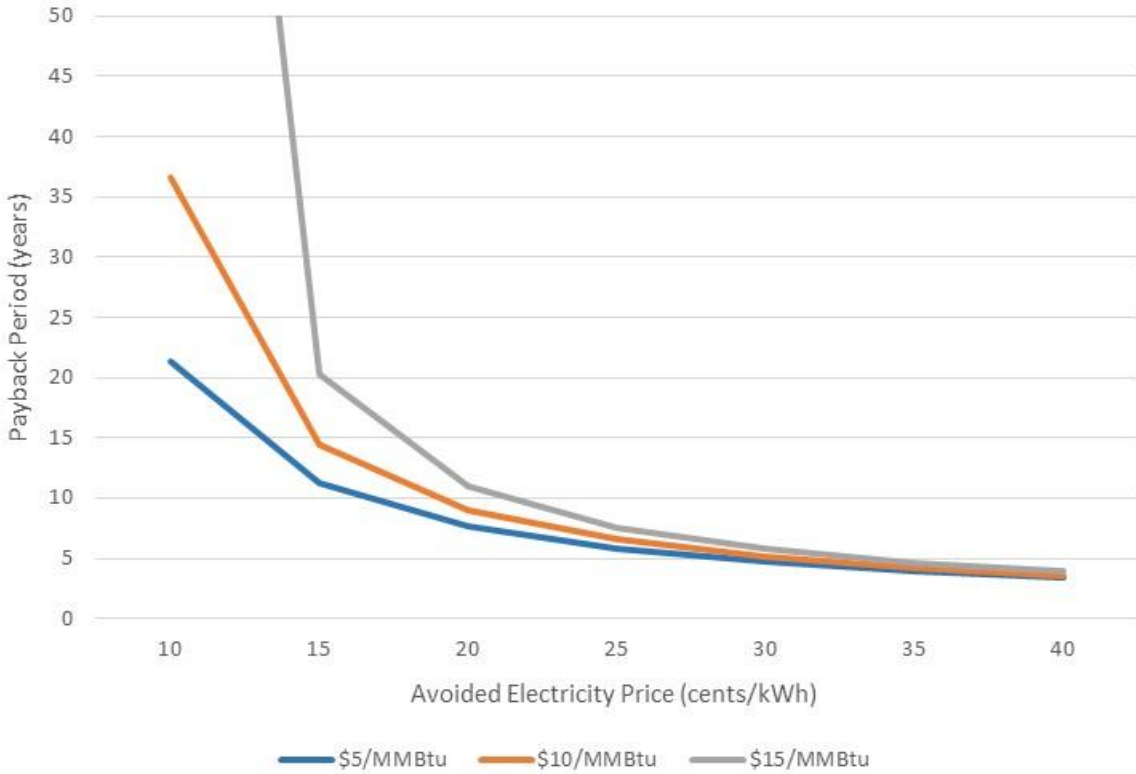



Source: ICF Analysis

The analysis showed that payback periods less than 10 years could be obtained with avoided electricity costs above 22.5 cents/kWh with gas at $5/MMBtu, or 27.0 cents/kWh with gas at $15/MMBtu. To achieve a payback period less than five years, the avoided electricity rate must exceed 40 cents/kWh. With these requirements, market adoption of residential CHP is expected to be very limited.

With economies of scale through increased production, the 1.5 kW fuel cell could potentially be installed for $10,000/kW, rather than $14,000/kW. The results are shown for this price point in Figure 38.

**Figure 38: Payback Period for Single Family Home CHP, by Avoided Electric Rate and CHP Gas Rate, with Reduced Installed Cost ($10,000/kW)**




Source: ICF Analysis

In this case, the analysis showed that payback periods less than 10 years could be obtained with avoided electricity costs above 17.5 cents/kWh with gas at $5/MMBtu, or 22.5 cents/kWh with gas at $15/MMBtu. To achieve a payback period less than five years, the avoided electricity rate must exceed 35 cents/kWh, which is possible for some California customers. Residential market adoption is likely to be considerably higher at this lower CHP price point. Of the major California utilities, PG&E has the highest residential electricity rates, and they are also the largest market. An analysis of technical potential for residential single family micro-CHP applications showed 571 MW of potential from over 380 thousand homes in their service territory.

## California CHP Market Adoption

The project team analyzed the expected market adoption for traditional CHP (50 kW – 5 MW) and micro-CHP applications 10-50 kW. The analysis was done over a 20 year period, using an annual growth rate of 1.36% for commercial and institutional applications, and 0.77% for industrial applications, based on 2017 EIA Annual Energy Outlook figures for energy consumption through 2037 for the Pacific Region.[54]

Estimates for CHP adoption are based on the market acceptance of CHP systems at different payback periods, and the expected penetration over time. After estimating the payback periods, the project team applied market acceptance percentages to each potential CHP installation based on the likelihood that an industrial or commercial customers would consider moving forward with a project. The sum represents the total market expected to adopt CHP over time, following a Bass diffusion curve. The adoption analysis is based on ICF's CHPower model, which was also used to estimate California CHP market adoption for the 2012 Energy Commission market assessment.[55]

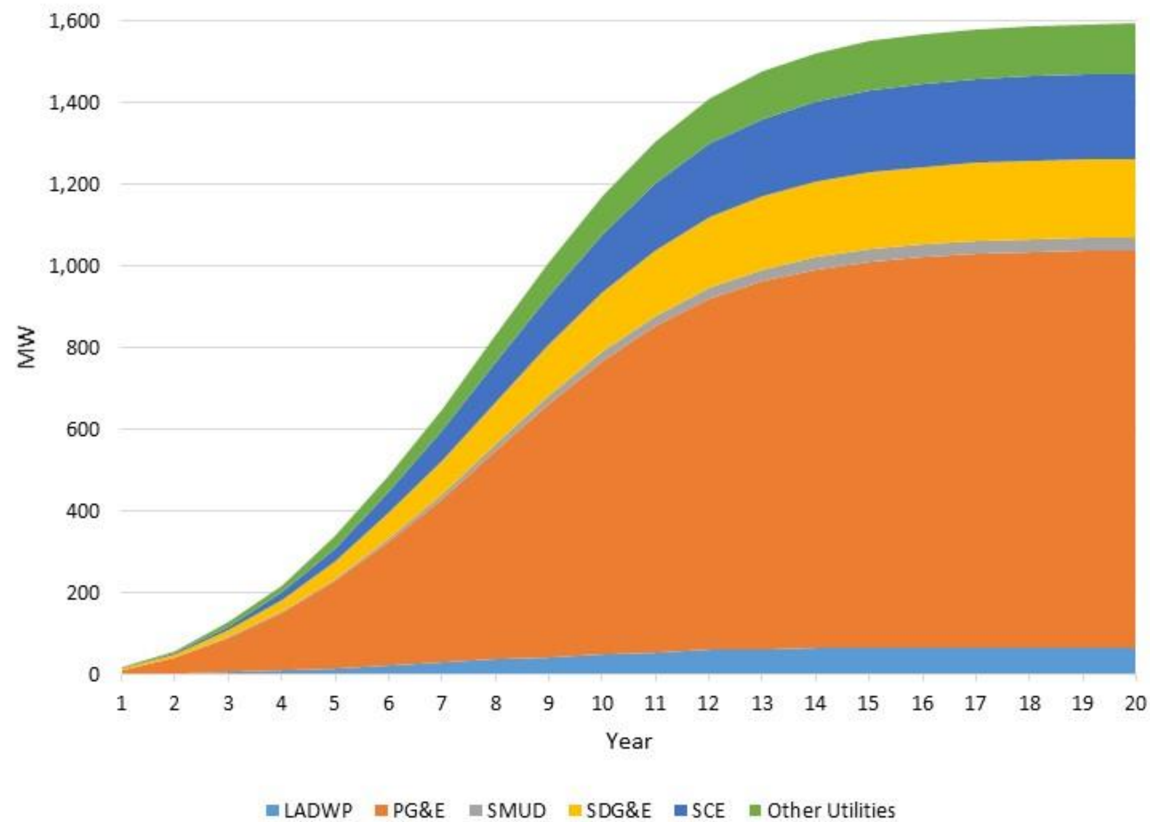
## Traditional CHP Applications: 50 kW to 5 MW

The market adoption analysis resulted in nearly 1.6 GW of expected adoption for traditional CHP applications in California. This figure can be compared with the 2.3 GW of adoption found in the base case of the 2012 Energy Commission market assessment. The previous assessment included larger applications over 5 MW in size, but market conditions were not quite as favorable as they are today, with lower gas rates and improvements in CHP equipment performance for smaller size ranges. Figure 39 shows the cumulative market adoption of traditional <5 MW CHP applications by year, broken down by utility territory.

[54] United States Department of Energy. Energy Information Administration. Annual Energy Outlook 2017. https://www.eia.gov/outlooks/aeo/

[55] California Energy Commission. Combined Heat and Power: Policy Analysis and 2011-2030 Market Assessment, prepared by ICF International. February 2012. http://www.energy.ca.gov/2012publications/CEC-200-2012-002/CEC-200-2012-002.pdf

**Figure 39: Cumulative Market Adoption for 50 kW to 5 MW CHP in California, by Year and Utility Territory**




Source: ICF analysis

A sizeable amount of new CHP capacity is expected in the SCE and SDG&E territories, with 207 MW and 193 MW, respectively, but the majority of projected market adoption – almost 1 GW – occurs in PG&E's territory. There are a large amount of potential CHP sites in PG&E's territory, and the energy rates are the most favorable in the state. Market adoption data for every five years can be found in APPENDIX C.

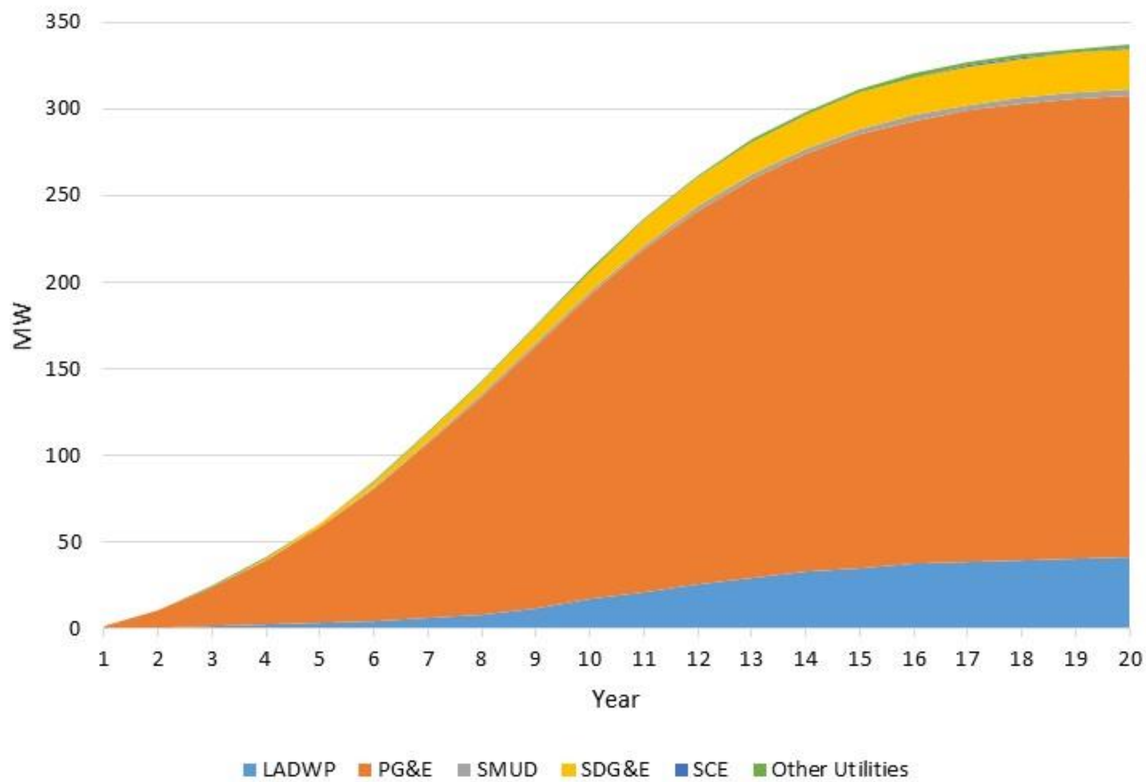
California's current installed base of CHP is only 662 MW, compared to the 1.6 GW of new capacity that is expected to come online during the next 20 years. Small CHP applications are poised for growth, with a large number of potential sites and favorable market conditions.

## Micro-CHP Applications: 10-50 kW

Compared to traditional CHP systems, the adoption of micro-CHP is expected to occur more gradually, as more product offerings come on the market and smaller customers become increasingly aware of CHP. Over the 20-year period, nearly 350 MW of micro-CHP capacity in the 10-50 kW range is expected to be adopted – about one third of the total economic potential – mostly in the PG&E territory.

Figure 40 shows the cumulative market adoption of micro-CHP applications by year and utility territory.

**Figure 40: Cumulative Market Adoption for 10-50 kW Micro-CHP in California, by Year and Utility Territory**




Source: ICF analysis

In the micro-CHP market, PG&E makes up almost 80% (270 MW) of projected adoption, attributed primarily to a high electricity rate for small commercial customers. LADWP and SDG&E comprise most of the rest of the projected adoption, with 41 MW and 24 MW respectively. More notably, SCE has almost no expected adoption for micro-CHP during the 20-year period. Tabulated market adoption data can be found in APPENDIX C.

## Potential Emissions Impacts

The adoption of 1.9 GW of CHP in California would save a significant amount of energy and reduce emissions compared to separate heat and utility purchased power. Baseload CHP systems would directly lead to a reduction in fossil fuel generation from the utility plants that serve CHP customers. The potential impact was measured using the Environmental Protection Agency's CHP Energy and Emissions Savings Calculator.[56]

The following assumptions were made to analyze the potential impact of small and micro CHP adoption:

- For 1.6 GW of traditional (50 kW – 5 MW) CHP, modeled performance and emissions characteristics of 820 kW reciprocating engine identified in CHAPTER 2 of this report to represent a typical installation in this size range;
- For 340 MW of micro (10-50 kW) CHP, modeled performance and emissions characteristics of 19.2 kW reciprocating engine identified in CHAPTER 2 of this report to represent a typical micro CHP installation;
- Assumed thermal energy from CHP is displacing an 80 percent boiler, and 80 percent of the recovered thermal energy is utilized for on-site heating loads on average;
- Assumed 7,000 full load equivalent hours of operation on average;
- Calculated NOx emissions using BACT and CARB standards for traditional CHP installations, and CARB standards for micro CHP installations; and
- Compared CHP emissions to utility fossil fuel emissions from the WECC California eGRID subregion, projected through 2037 using the Reference Case from the 2017 EIA Annual Energy Outlook, and average T&D losses from Western Interconnect region (2016 eGRID data, using calculated 2014 values).

The analysis showed that in 2037, with 1.9 GW of small and micro CHP adopted, there will be a significant amount of fuel savings and emissions reductions.

Overall, an estimated 39 million MMBtu/year of fuel (primarily natural gas) would be conserved, a savings of 23 percent compared to separate heat and utility power. Along with these energy savings, by 2037, 3,200 tons per year of NOx emissions would be avoided through small and micro CHP installations. Greenhouse gas emissions would also be reduced by more than 1 million tons of carbon dioxide (equivalent) on an annual basis.

## Alternative Scenarios

For this California CHP market assessment, two alternative scenarios were explored:

- A 10% reduction in installed cost, simulating the return of the Federal Investment Tax Credit, or an equivalent state incentive program, and

[56] United States Environmental Protection Agency. Combined Heat and Power Partnership. CHP Energy and Emissions Savings Calculator. Updated November 1, 2017. https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator

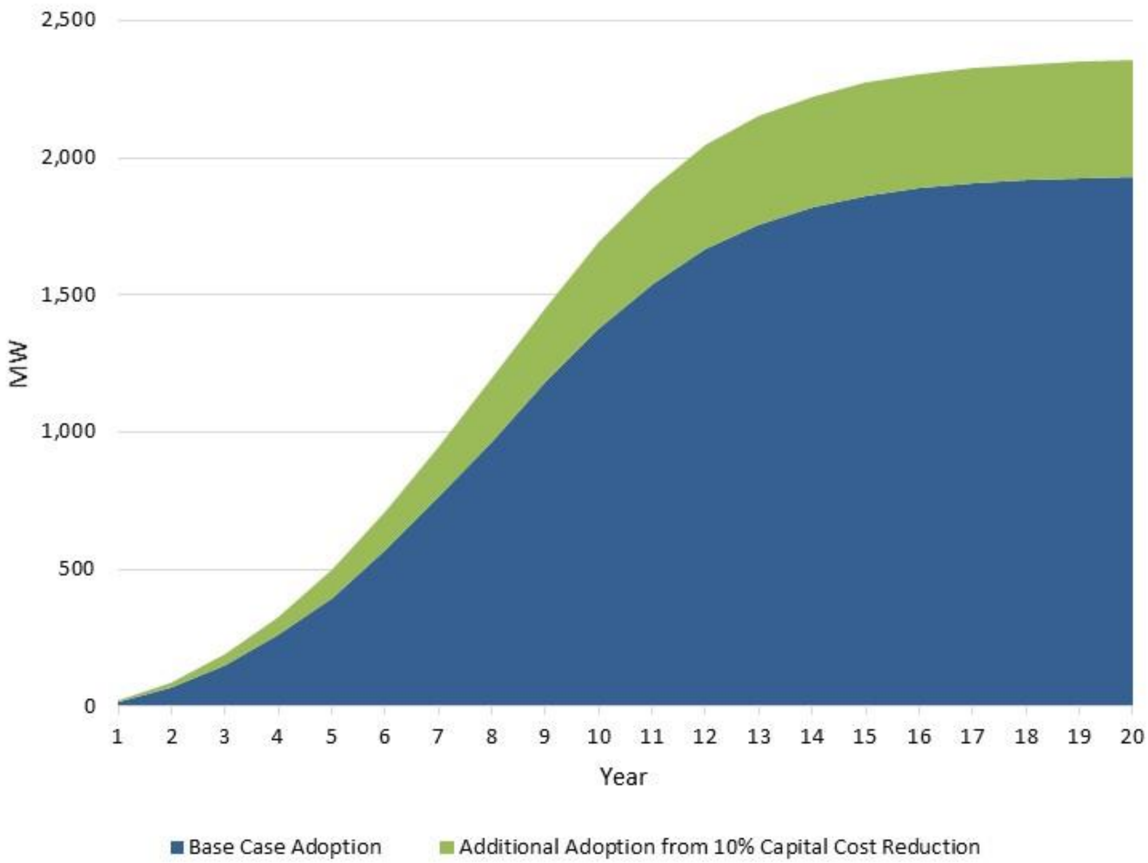
- An electric rate reform scenario, in which standby rates and departing load charges are eliminated.

## 10 Percent Reduction in Installed Cost

Reducing the installed cost of a CHP system by 10 percent typically has the effect of reducing the payback period by 10 percent. This can push sites from a 5.5 year payback down to below five years, or sites with an 11 year payback below 10 years. The benefit to economics is identical across the utility territories, and adoption patterns by utility remain similar, with PG&E accounting for the majority of expected adoption.

In total, accounting for traditional and micro-CHP applications, the expected 20 year adoption increases by 0.4 GW, with nearly 2.4 GW of installed capacity compared to 1.9 GW for the base case. This is illustrated in Figure 41.

**Figure 41: Total Market Adoption for 10% Capital Cost Reduction compared to Base Case**




Source: ICF Analysis

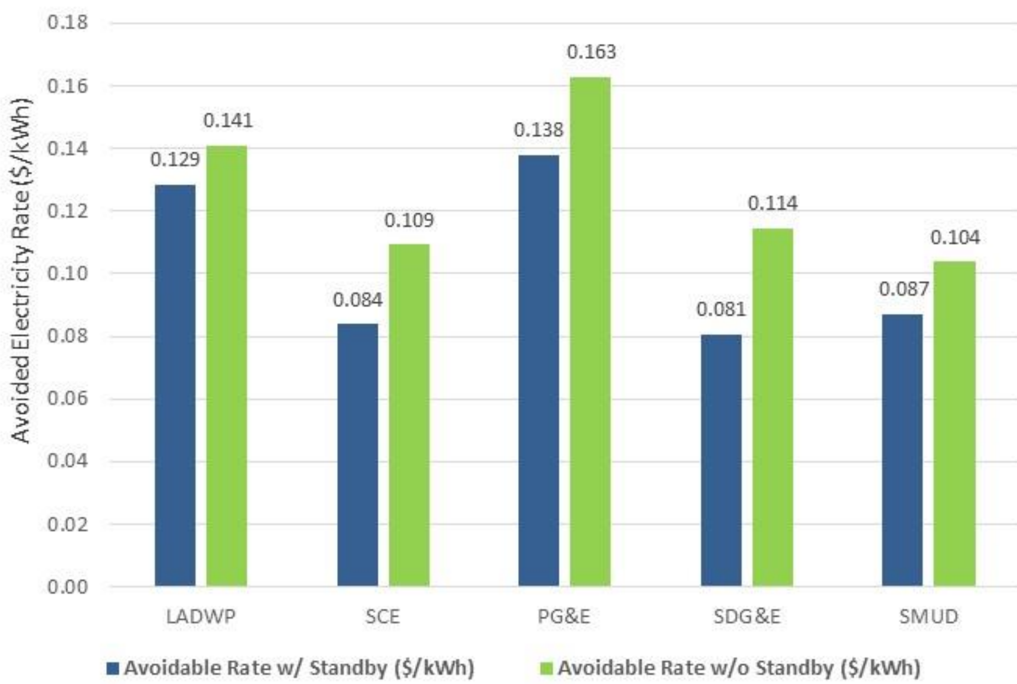
After the CHP adoption analysis was completed, the Federal Investment Tax Credit for CHP installations was reinstated, providing a 10 percent tax credit on the capital investment for efficient CHP systems.[57] With this incentive, future market adoption may be closer to this scenario compared to the base case.

## Electric Rate Reform

Standby rates and departing load charges are significant barriers to CHP in California. Standby rates are charged to customer-generators in order for the utility to reserve capacity in the event of on-site generator outages, but the charges are often considered to be significantly higher than actual utility costs. Departing load charges are typically on the order of 1 cent per kWh, intended to cover the loss of revenue from nuclear decommissioning and public purpose charges. California is one of the only locations in the country where departing load charges are applied.

With standby rates and departing load charges applied, the avoided electricity rate for CHP customers can be considerably lower than the retail rate. The effect of removing the charges can vary according to utility rate structure and the specific charges that are applied. Figure 42 shows the effect of removing standby rates and departing load charges on the avoided electricity rate for CHP applications in the 250-499 kW size range.

**Figure 42: Effect of Removing Standby Rates and Departing Load Charges on Avoided Electric Rate**




Source: ICF Analysis

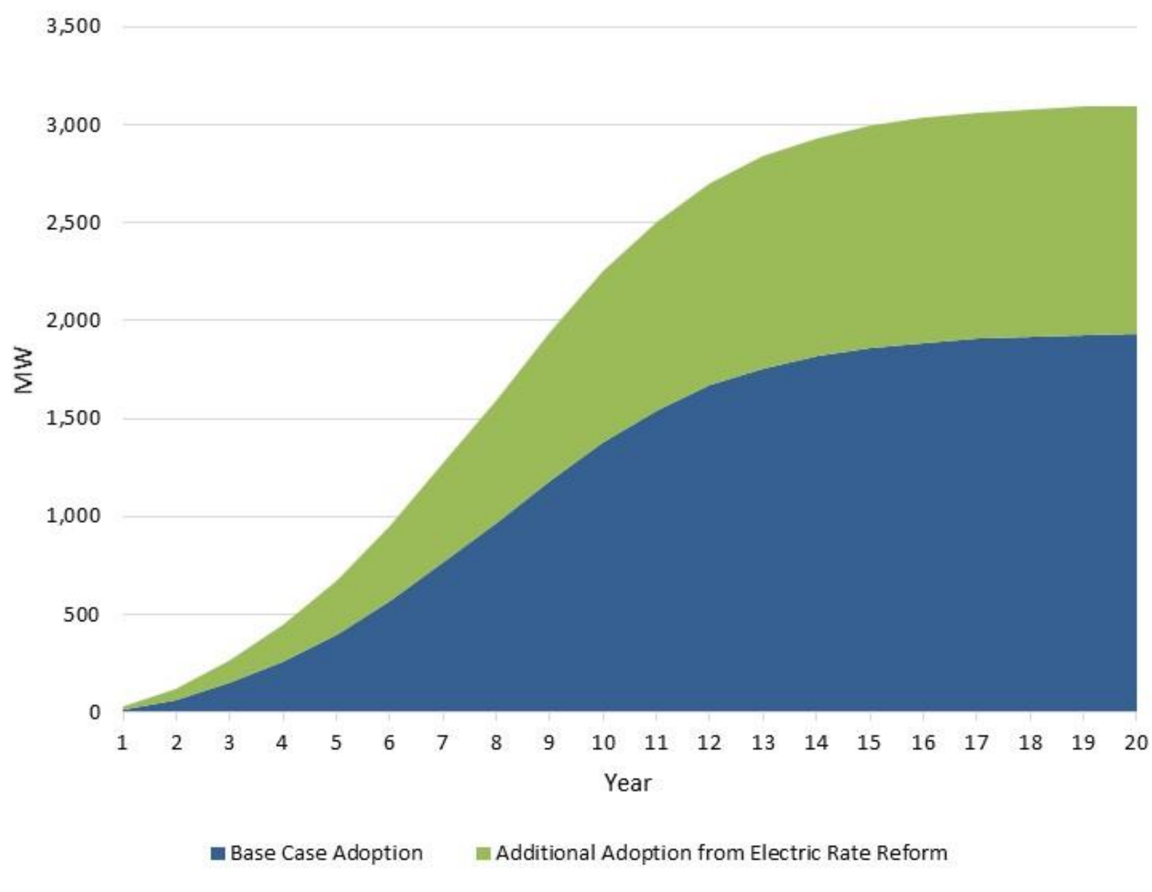
[57] More information available online at: https://www.energy.gov/savings/business-energy-investment-tax-credit-itc

The removal of standby rates and departing load charges would have the greatest effect on CHP applications located in the service territories of California's three investor-owned utilities (IOUs), with LADWP showing the smallest impact of the five major utilities.

Some form of standby service is required for electric utilities to reserve capacity for customer-generators, especially for unplanned generator outages. While the complete removal of standby rates is unlikely, this scenario considers the extreme case of removing all standby rates and departing load charges for CHP customers. This type of rate reform would have a large impact on CHP economics, especially for customers that purchase electricity from the IOUs. Compared to the base case (1.9 GW), an additional 1.2 GW of capacity would be expected to come online during the 20-years, resulting in 3.1 GW of total market adoption.

The total adoption for the base case and the electric rate reform scenario are compared in Figure 43.

**Figure 43: Total Market Adoption for Electric Rate Reform Scenario compared to Base Case**




Source: ICF Analysis

## Market Assessment Conclusions

There is a strong amount of potential for small CHP applications in California, from a technical and an economic perspective. While there is currently estimated to be 662 MW of existing capacity for CHP systems 5 MW or smaller, there is close to 10 GW of technical potential for CHP in this size range, or 11.6 GW when including potential single family home applications. Nearly half of this potential – 5.7 GW – is estimated to be economical, capable of obtaining a payback period less than 10 years.

When forecasting the market adoption of <5 MW CHP in California over the next 20 years, approximately 1.9 GW is expected to come online, which is more than three times the current installed capacity in this size range. The technical potential, economic potential, and expected market adoption for small CHP applications in California are summarized in Table 48.

**Table 48: Results of California <5 MW CHP Market Assessment**

| CHP Market | Total Capacity (GW) | | |
|---|---|---|---|
| | Technical Potential | Economic Potential | Market Adoption |
| Traditional CHP (50 kW – 5 MW) | 7.4 | 4.6 | 1.6 |
| Micro-CHP (10-50 kW) | 2.5 | 1.1 | 0.3 |
| Single Family Home Micro-CHP (1-2 kW) | 1.7 | n/a | n/a |
| **Total (<5 MW)** | **11.6** | **5.7** | **1.9** |

Source: ICF Analysis

A capital incentive program and utility electric rate reform measures could improve CHP economics and increase the level of CHP adoption. In particular, removing standby rates and departing load charges would lead to an increase of 1.2 GW over the base case scenario. Single family home CHP applications could also emerge and contribute to CHP adoption, but several uncertainties exist, including residential energy rates, available technology options, and installed cost of micro-CHP equipment in this size range.

# CHAPTER 4: Integration Issues, Barriers, and Recommendations

## Policy and Regulatory Considerations

California energy policy, legislation, regulations and consumer advocacy for sustainable energy practices over the last decade are substantially changing the behavior of utilities that generate and deliver energy. They are changing the behavior of energy consumers in the residential, commercial, institutional, and industrial sectors as well. Key legislation and regulations that are shaping California's energy future in general, and the role of distributed generation (DG) in particular, are summarized in Table 49.

**Table 49: Key Legislation and Regulations**

| Legislation and Regulations | Descriptions |
|---|---|
| AB 32 (2006) and SB 32 (2016) | Requires the State to cut GHG emissions to 1990 levels by 2020, and 40% below 1990 levels by 2030. |
| SB 350 (2015) | Increases the Renewable Portfolio Standard (RPS) to 50% by 2030. |
| AB 398 (2017) | Continues Cap-and-Trade Program through 2030. Although the legislation continued transitional support to many industrial segments competitively threatened by higher energy prices, a continuation of the transitional assistance for CHP through 2020 was not addressed in the October 2017 CARB[58] Final Regulation Order. A key consideration had been the exemption of a facility from Cap-and-Trade, should the addition of CHP trigger the covered entity threshold of 25,000 metric tonnes of $CO_2$ per year. Also, natural gas fuel cells lost their exemption from compliance obligations for GHG emissions. |
| AB 1637 (2016) | Makes qualifying natural gas fuel cell customer generators eligible for a Net Energy Metering (NEM) tariff that exempts the customer from departing load and standby charges on self-generated power. A 2017 bill (AB 36) that enabled all CHP technologies meeting the same qualifying criteria as fuel cells to be entitled to the same net metering benefits as fuel cells was |

[58] CARB - California Air Resources Board.

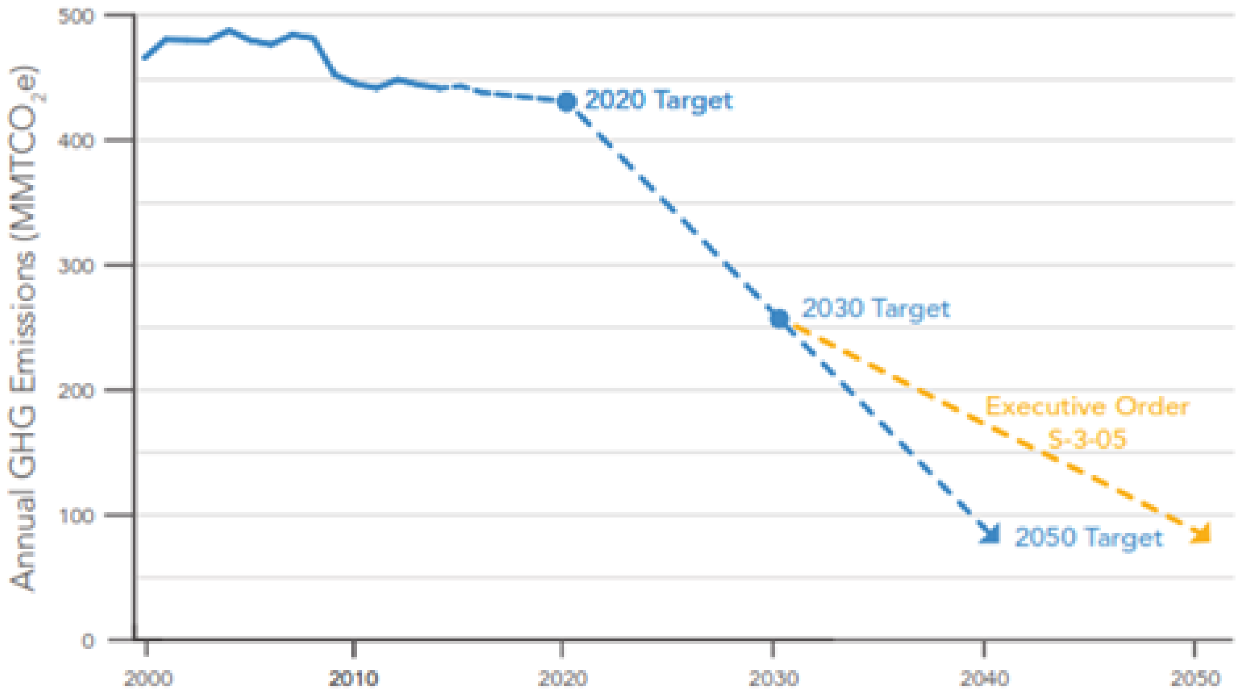
| Legislation and Regulations | Descriptions |
|---|---|
| | passed by the Assembly and Senate. However, this bill was vetoed by the Governor. |
| CARB Scoping Plan (2017) | Incorporates ongoing efforts and new actions to achieve 2030 GHG reduction goals and beyond. Unlike prior scoping plans, there was no mention of CHP. |
| CPUC Decision 16-06-055 (2016) | Revised the Self-Generation Incentive Program (SGIP) pursuant to SB 861 and AB 1478. The decision included a biogas blending requirement for all natural gas CHP projects that effectively excluded natural gas CHP projects from participation in SGIP, except for a few CHP sites that are co-located or in close proximity to a biogas source. Currently, directed biogas[59] is both scarce and too expensive to be considered for stationary CHP applications. |
| CPUC Decision 16-09-056 (2018) | Effective January 1, 2018, all DG technologies using diesel, natural gas, gasoline, propane, or liquefied petroleum gas (in CHP or non-CHP configurations) were prohibited for use during demand response events. |
| CEC Building Efficiency Standards (2015) | These standards, also referred to as “Title 24,” require all new residential buildings to be zero net energy (ZNE) beginning in 2020, and all new commercial buildings to be ZNE beginning in 2030. While natural gas appliances are exempt from the ZNE methodology, it is unclear how natural gas CHP will be treated in the ZNE methodology. |
| Federal Tax Incentives | Accelerated tax depreciation (MACRS) continues and the Investment Tax Credit (ITC) has been extended for five years in the 2018 budget bill. |
| Integrated Distributed Energy Resource Request for Offers (IDER RFOs) | California Investor Owned Utilities (IOUs) have been issuing IDER RFOs to defer the need for capital expenditures for traditional distribution infrastructure upgrades. Natural gas solutions are not allowed in some RFOs, while others do allow natural gas solutions if they meet the SGIP efficiency and environmental criteria. |

Source: ICF Analysis

[59] Directed biogas is biogas that has been processed to pipeline quality standards, is injected into the natural gas pipeline and nominated for use at a designated facility by the biogas owner.

Figure 44 illustrates the acceleration of the GHG emission reduction rate that is planned to begin in 2020. California's GHG target is to cut GHG emissions to 1990 levels by 2020 and 80% below 1990 GHG levels by 2050. This trajectory is illustrated by the blue dotted line in this figure, showing California can meet the 80% reduction target several years sooner than with the new intermediate SB32 target of 40% below 1990 levels by 2030.

**Figure 44: California GHG Emission Trajectory**




Source: CARB Scoping Plan, 2017

While the trend in California policies and regulations has made California more challenging for CHP, the CHP industry continues to advocate that CHP technologies offer a clean and economical solution with a small carbon footprint. The CHP industry believes that, collectively, California energy policies and regulations do not generally encourage natural gas CHP and CHP technologies are not eligible for meaningful support from state agencies, and endure harsh utility tariffs.

## The Role for CHP in the Transition to a Renewable Grid

Renewables will be an ever increasing part of California's energy mix; within the next decade a substantial number of energy users will meet a portion of their electricity requirements with solar photovoltaics (PV). As indicated in Table 49, Senate Bill 350 (DeLeon, 2015, Chapter 547) increases the Renewable Portfolio Standard (RPS) to 50% by 2030. However, due to intermittent generation and space limitations, PV can seldom meet the entire electricity load, making room for CHP to supply clean, low GHG electricity when PV electricity is insufficient or unavailable. In addition to providing electricity, CHP systems provide useful thermal energy for on-site needs.

Table 50 shows that natural gas generation will be a significant part of California's electricity mix for years to come. In 2016, 36.5% of California's generation mix was fueled by natural gas. In addition, a sizable portion of the out-of-state "unspecified" sources, which accounts for 14.4% of the state total, was derived from natural gas. In 2030, with a 50% RPS requirement on retail sales, California's electricity generation natural gas percentage is projected to decrease to a still significant 31.8% of the wholesale generation mix plus a portion of the 4.1% projected from "unspecified" out-of-state sources. Natural gas generation will still account for a significant portion of California's power mix in 2030 and beyond.

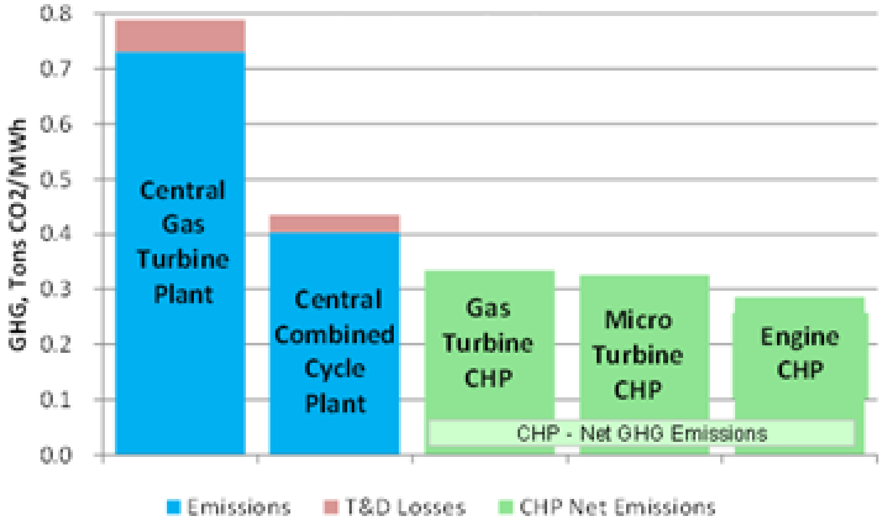
**Table 50: California Electric Generation Mix**

| California Total System Electric Generation Mix | | | | |
|---|---|---|---|---|
| Fuel Type | Energy Mix | | | |
| | 2016 | | 2030 | |
| | GWh | % | GWh | % |
| Coal | 12,006 | 4.1% | 0 | 0.0% |
| Large Hydro | 29,681 | 10.2% | 24,608 | 8.7% |
| **Natural Gas** | **105,992** | **36.5%** | **90,331** | **31.8%** |
| Renewables | 73,961 | 25.5% | 139,407 | 49.1% |
| Other | 27,101 | 9.3% | 18,077 | 6.4% |
| Unspecified | 41,825 | 14.4% | 11,760 | 4.1% |
| Total | 290,566 | 100.0% | 284,183 | 100.0% |

Sources: 2016 data from Energy Commission website; 2030 projection from 2017 IEPR mid-case forecast

To achieve GHG reduction goals in California, the efficiency with which natural gas is used to generate power should be a priority. Well-designed and operated CHP is more efficient and has a smaller carbon footprint than modern central station natural gas power plants. Figure **Error! Reference source not found.** compares net carbon emissions from on-site CHP against modern gas turbine peaker and combined cycle central station power plants. The value shown for CHP nets out emissions that would otherwise have been generated by a natural gas boiler. Even greater efficiency advantages for CHP can be achieved with enhanced heat recovery techniques, such as supplemental firing or condensing heat exchange. Because properly designed CHP systems operate at high efficiency, CHP systems can help accelerate the transition to the state's 2050 target to reduce GHG emissions by 80% below 1990 levels.

**Figure 45: CHP vs Central Plan GHG Emissions**




Source: Central Plant Data from E3 Avoided Cost Model

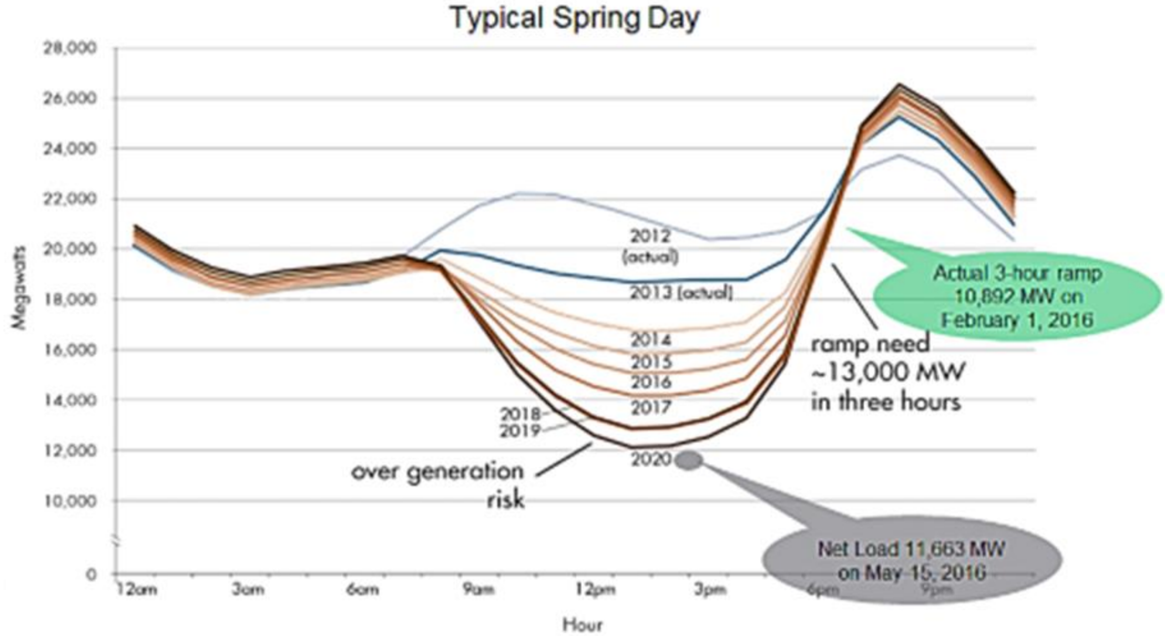
## Flexible CHP

The perceived concern with CHP is that it is a 24/7 "must run" resource that potentially displaces electricity generation from renewable resources. According to E3's Avoided Cost Model, there are projected to be 500 hours in 2020 where renewable energy is the marginal resource creating an excess renewable power generation risk.[60] Furthermore, the number of at-risk over-generation hours is estimated to increase each year beyond 2020. Figure 45, the Duck Curve illustrates this problem showing the steep ramping needs and over generation concern. According to the California Independent System Operator (California ISO), "… the ISO is collaborating on rules and new market mechanisms that support and encourage the development of flexible resources to ensure a reliable future grid."[61]

[60] California Public Utilities Commission. CPUC/E3 Avoided Cost Calculator. 2017. http://www.cpuc.ca.gov/General.aspx?id=5267

[61] California Independent System Operator, Fast Facts – Duck Curve, 2016.

**Figure 45: The Duck Curve**




Source: California Independent System Operator (CAISO)

Most CHP technologies can be curtailed or cycled on and off on a daily basis without compromising system life or reliability. During such curtailment, backup boilers or water heaters can be called upon to meet the thermal loads.[62] Market aggregators can coordinate with the California ISO and/or utilities to economically dispatch fleets of CHP units. Accretive market signals that properly motivate the CHP owner to operate in the best interests of the grid can be developed.

As mentioned in CHAPTER 3, there are 662 MW of installed CHP capacity in California for systems five MW and smaller. Based on information from the U.S. Department of Energy,[63] the total capacity for CHP systems of all sizes is approximately 8,500 MW at more than 1,200 sites located throughout the state. Looking to the future, there remains an untapped CHP potential in California of 11,000 MW, with 7,400 MW of this potential for CHP systems five MW and smaller.[64] CHP operators, if properly motivated to operate flexibly, can provide a sizeable resource to California ISO and the utilities with which to manage California's growing renewable grid.

[62] Usually on site as a result of their existence prior to the installation of new CHP systems.

[63] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Accessed February 2018. https://doe.icfwebservices.com/chpdb/.

[64] CHP systems with capacities of 50 kW to 5 MW.

## Capability of CHP Technologies to Operate Flexibly

The grid attribute focused on in this Flexible CHP study is an alternative to the energy time shift measure that storage technologies can address to manage the potential problem of renewable energy over-generation that will exacerbate over time as California decarbonizes the grid. Although not discussed in this study, many of these CHP technologies can provide other grid services including the lowest natural gas generating carbon footprint, transmission and distribution system support, backup power, and VAR adjustment. With the recent reductions in battery costs, attention is being given to its integration with CHP. Integrated CHP/battery systems can provide enhanced reliability, increased CHP capacity utilization, reduced grid backup charges, energy arbitrage and a number of ancillary grid services.

The intrinsic ability CHP has to support the grid in response to dispatch signals varies by technology type and application. Some technologies can be turned on and off daily without impacting life or reliability. Others can reduce output but are limited by efficiency degradation and/or application constraints. Some have little flexibility to adjust power output but can support the grid when integrated with storage technology. An evolving fuel cell technology will have the ability to switch from CHP mode to serve as an electrolyzer producing hydrogen when renewable generation is at the margin. Discussions on each of the CHP technologies follow. Note that we are only addressing technology suppliers who are active selling and servicing CHP equipment in California.[65]

### Internal Combustion Engines

Virtually all natural gas reciprocating Internal Combustion Engines (ICEs) less than 5 MW in size are capable of on/off operation on a daily basis without compromising life, reliability or maintenance expense. ICEs are also capable of good part-load performance down to about 50& of rated power. Maintenance contracts can be structured on an operating hour basis. [66]

ICE CHP sites retain boiler capacity for backup and supplemental heating demand so there is no impact to the operation of the facility should the units be dispatched off. ICE CHP systems can be started and brought back up to full load in less than 5 minutes, and some less than 3 minutes. Should a quicker startup time be an important attribute, ICE system suppliers felt there was room for further improvement. Most packaged ICE CHP systems come equipped with remote dispatch functionality.

### Industrial Gas Turbines

[65] The information provided herein was based on discussions with the following organizations: Western Energy Systems (Jenbacher Distributor), Tecogen, Solar Turbines, Capstone Turbine, Regatta Solutions (FlexEnergy Distributor), Doosan Fuel Cell, and Fuel Cell Energy.

[66] The maintenance cost for an hour of operation is fixed regardless of the power output.

Industrial gas turbines and aero-derivative gas turbines are capable of on/off operation on a daily basis without compromising longevity or reliability. However, most of the facilities do not keep their boilers operating or on hot standby as most turbines are equipped with supplemental firing so that all of the facility steam needs are met by the CHP system. Practically, the turbines can be turned down to 50% of rated power, decreasing electric efficiency somewhat but maintaining overall efficiency. The turbines remain in emission compliance at part-load and continues to serve the site thermal requirements with supplemental firing of the exhaust. A small percentage of gas turbine CHP units are capable of fresh-air firing which would enable shutting down the gas turbine without interrupting steam production.

Most gas turbines can be turned on and brought up to full power in less than 10 minutes. Gas turbines operating at part load can be brought back to full load in less than 10 seconds.

Remote dispatch is not an OEM supplied option on most gas turbines, but can be incorporated by the owner or operator as a custom feature.

**Microturbines**

Microturbines can be shut down and restarted daily without impacting reliability or equipment life. Owners and operators of microturbine CHP systems maintain boilers or hot water heaters for backup and supplemental thermal needs. Microturbines can be cycled off without impacting energy services to the facility.

Maintenance can be purchased on a run-hour basis. Remote dispatch functionality is a factory option so an after-market upgrade would be necessary for some of the systems operating in the field.

**Fuel Cells**

*Phosphoric Acid Fuel Cells*

The Phosphoric Acid Fuel Cell (PAFC) can operate at part load without impacting life or reliability. Shutting off the fuel cell on a daily basis, however, would negatively affect the life of the unit. PAFCs retain good electric efficiency down to 40% load, which represents a practical range for power flexibility. The ramp rate for the PAFC is 10 kW/second. All units have remote monitoring and control.

*Molten Carbonate Fuel Cells*

Molten Carbonate Fuel Cells (MCFCs) were designed for base-load operation and are not suited run at part-load or power off on a regular basis.

*Solid Oxide Fuel Cells*

A 200 kW Solid Oxide Fuel Cell (SOFC) is being readied for demonstration in the U.S. It’s much less material intensive than predecessor fuel cells providing significantly lower cost potential. This SOFC has a full-load electric efficiency of 61% LHV and a turndown ratio of 55%. Longer term, this fuel cell can switch functionality from power production to electrolyzer using solar power to generate hydrogen which can be stored for use when solar incidence is down or for transportation.

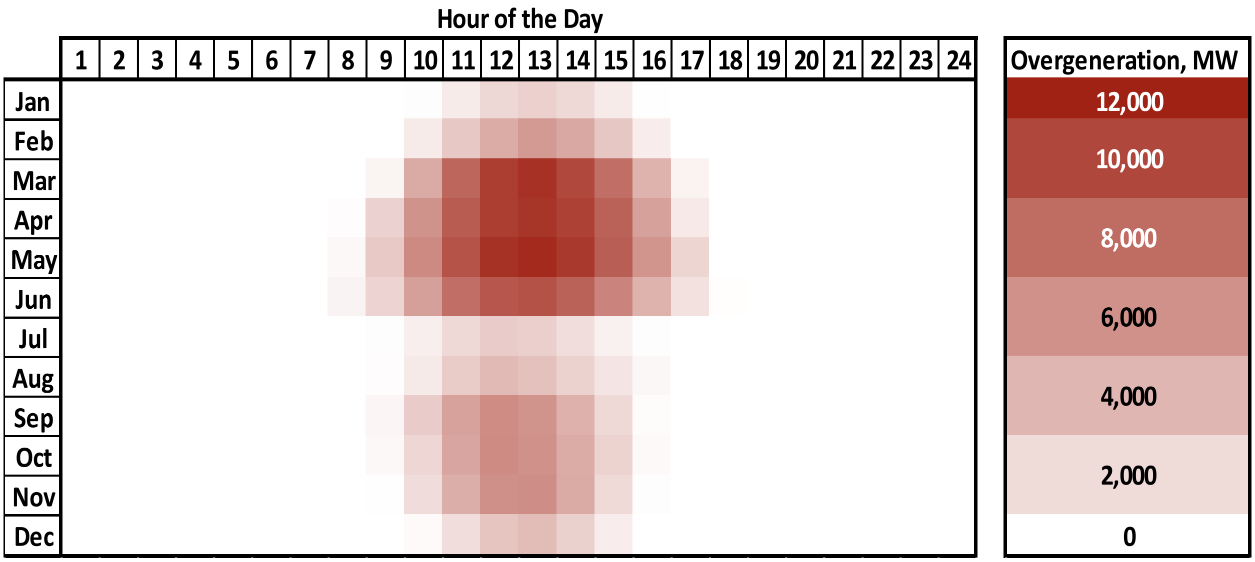
### Economics of Flexible CHP

Energy+Environmental Economics (E3) projects that the potential over-generation problem for a 50% RPS (2030 target) in the Large Solar case can span a 9 hour period and peak at 12,000 MW on some days.[67] Figure 46 illustrates the projected average over-generation by month and hour. The potential over-generation frequency occurs 20% of the time in 2030. There are many potential solutions to the problem, many or all of which will likely be deployed:

- Renewable resource diversity – Lesser dependence on solar in the renewable mix reduces the magnitude of the problem.
- Increased regional coordination – Renewable resource diversity increases if regional coordination can be expanded to neighboring states.
- Flexible loads – Shifting customer loads from one-time period to another.
- Energy storage – Can shift renewable resources to periods of the day where fossil generation is at the margin. Included in this category are batteries, pumped hydro, compressed air energy storage and thermal energy (chilled water and ice) storage.
- Flexible generation:
    - Central generation plants that can be ramped on as renewable generation decreases and ramps off as renewable generation increases.
    - Although not yet thoroughly considered, flexible generation can also include historically base loaded 24/7 CHP plants that can ramp down or off as renewables ramp up.

[67] California's 50% RPS – Lessons Learned and the Path Forward - Ana Mileva, Energy+Environmental Economics, Presentation at SoCalGas Distributed Energy Resources Seminar, March 10, 2016.

**Figure 46: Average Overgeneration by Month/Hour, 50% RPS Large Solar Case**




Source: Energy+Environmental Economics. Investing a Higher Renewables Portfolio Standard in California. January 2014

For context, the economics of flexible CHP are compared to battery storage, which is an accepted enabling technology for renewables in California's future energy landscape. To illustrate the flexible CHP approach, a 1.4 MW reciprocating engine CHP system operating in PGF&E's service territory is compared against a comparable capacity battery. The CHP performance specifications outlined in CHAPTER 2 for the 1.4 MW engine are shown again in Table 51.

**Table 51: Reciprocating Engine Performance Characteristics**

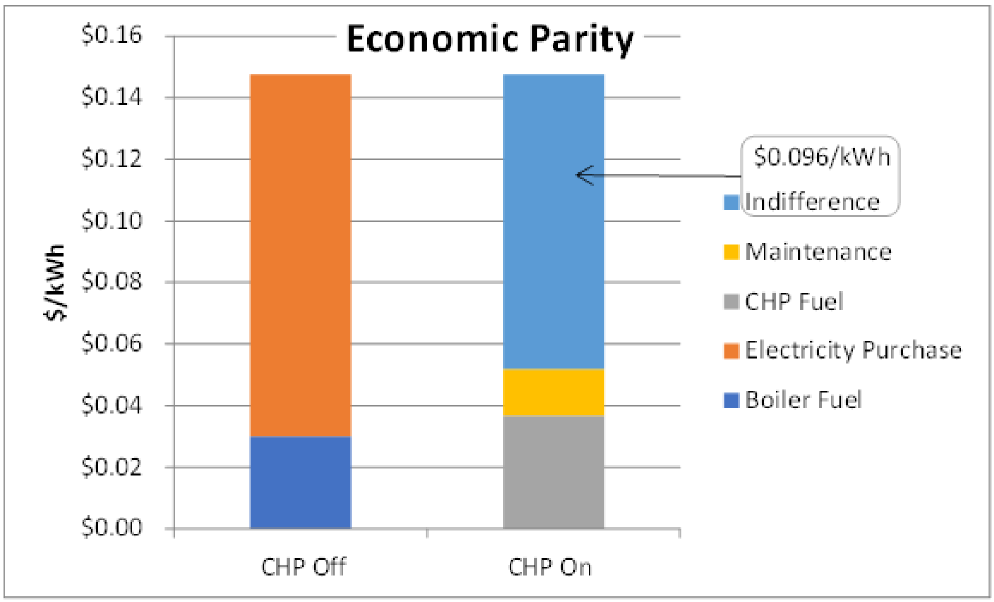
| Type | Lean-burn, Synchronous |
|---|---|
| Net Electric Power (kW) | 1,390 |
| Fuel Input (MMBtu/hr, HHV) | 13.41 |
| Useful Thermal (MMBtu/hr) | 5.76 |
| Electric Heat Rate (MMBtu/hr) | 9,630 |
| Electric Efficiency (%, HHV) | 35.4% |
| Thermal Efficiency (%, HHV) | 38.6% |
| Overall Efficiency (%, HHV) | 74.0% |

**Performance characteristics are average values and are not intended to represent a specific product.**

Source: Data based on discussions with equipment vendors and U.S. DOE fact sheets

PG&E's 2017 E-20 and S electric tariffs and the G-NR2 and G-EG gas tariffs were used in the analysis. Figure 47 puts the economic shortfall of turning the CHP system off into perspective. In this case, a CHP owner would require 9.6 ¢ for each kWh not generated during the dispatched shutdown period. This indifference value would make the CHP owner economically neutral while flexing off. It is assumed that the capital investment was justified without flexible operation in support of the grid, so no capital component was included in the analysis.

**Figure 47: Flex CHP – Economic Indifference**




Source: ICF Analysis

For battery storage, a five-hour storage system was selected. To compare flexible CHP against storage, nine scenarios were considered – installed battery system costs of 500, 400, and 300 $/kWh; a daily charge time of five hours and annual charge times of 500, 1,000 and 1,825 hours.[68] Other assumptions used in the analysis are listed in Table 52. Data on battery storage roundtrip efficiency vary widely.[69] For this study, with the battery being cycled on and off once a day, a roundtrip efficiency over the life of the battery of 90% was selected as a reasonable near-term target.

[68] 1,825 hours represents a five hour charge cycle 365 days of the year.

[69] 2016 SGIP Advanced Energy Storage Impact Evaluation. Prepared by Itron for SGIP Working Group. August 2017.

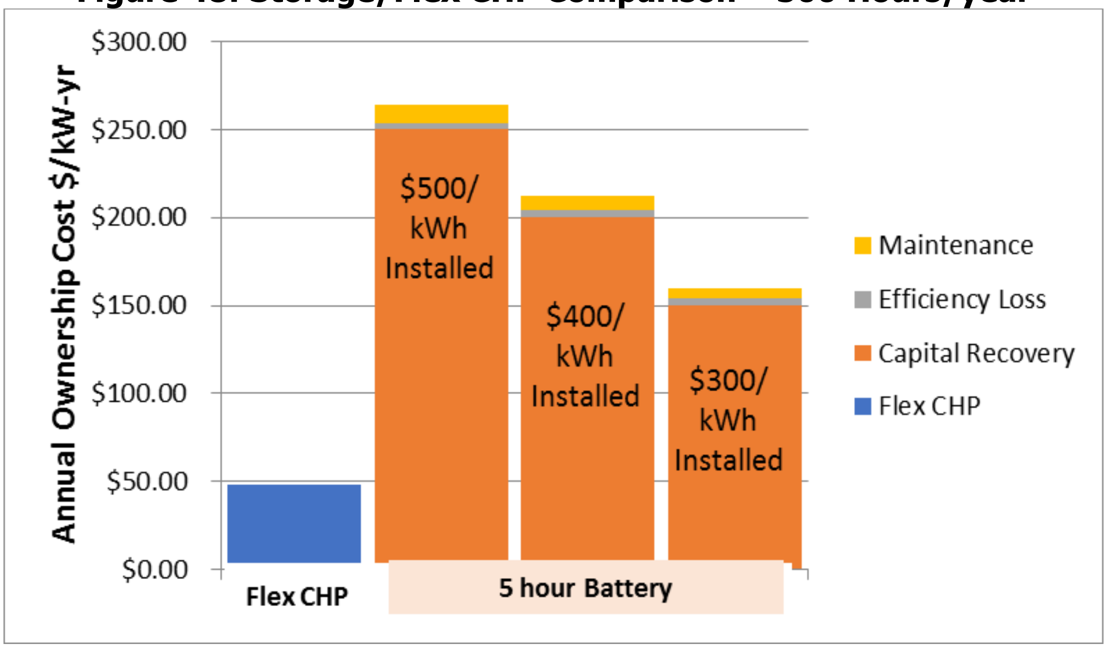
**Table 52: Battery Storage Analysis Assumptions**

| Characteristic | Assumption |
|---|---|
| Battery Capacity, MW/MWh | 1MW/5MWh |
| Annual Capital Recovery Factor, P&I | 10% |
| Roundtrip Efficiency | 90% |
| Maintenance, % Capital per yr. | 2% |
| Cost of inefficiency @ $0.08/kWh | $0.008/kWh |

Source: ICF Analysis

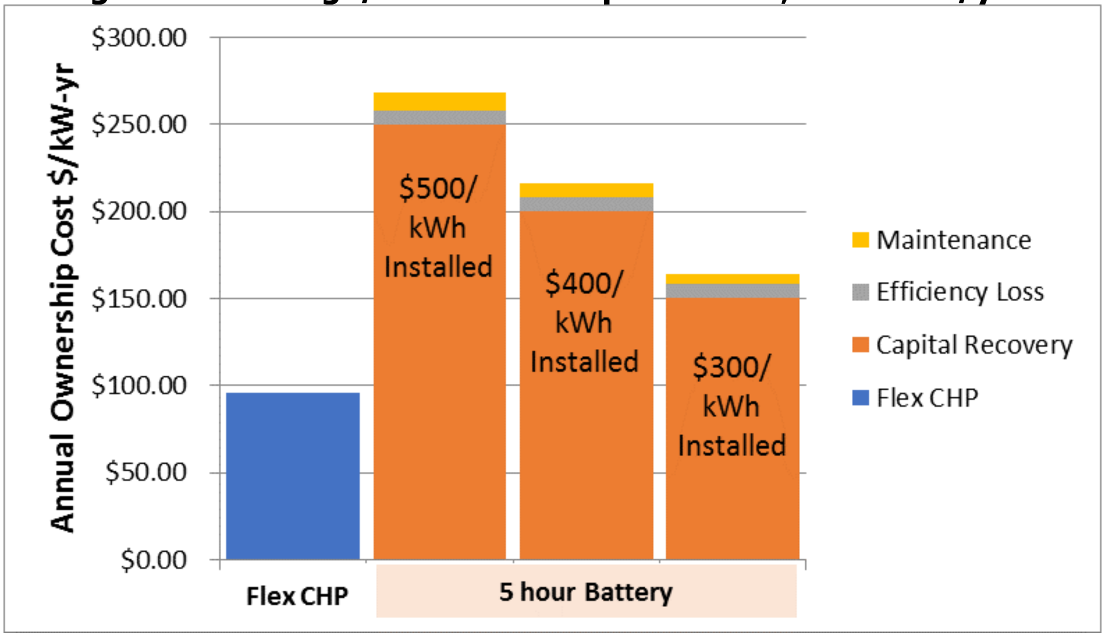
Figure 48, Figure 49, and Figure 50 illustrate the comparative economics for 500, 1,000 and 1,825 annual hours of storage and Flex CHP curtailment respectively.

**Figure 48: Storage/Flex CHP Comparison – 500 Hours/year**



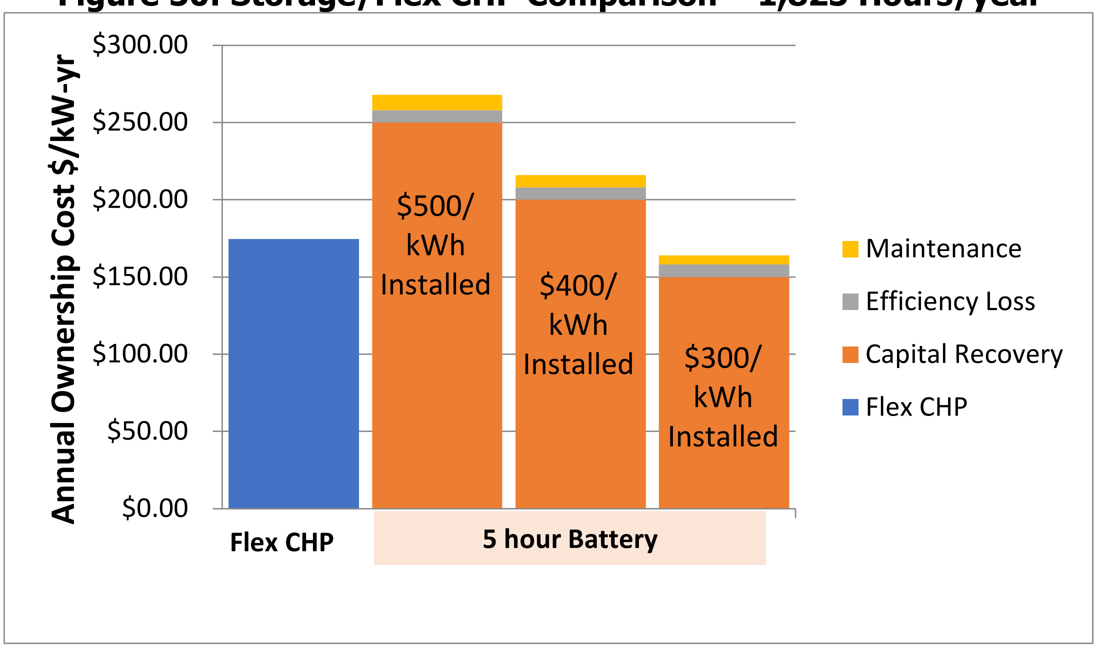

Source: ICF Analysis

**Figure 49: Storage/Flex CHP Comparison – 1,000 Hours/year**




Source: ICF Analysis

**Figure 50: Storage/Flex CHP Comparison – 1,825 Hours/year**




Source: ICF Analysis

These comparative charts are based on a simple economic analysis. An average electric tariff was used for the flexible CHP indifference calculation. The Capital Recovery Factor of 10% is a useful approximation. Currently available incentives, cost premiums to motivate owner participation, and aggregator and developer fees were not included in the calculation. Also not taken into account were other value-added grid services that

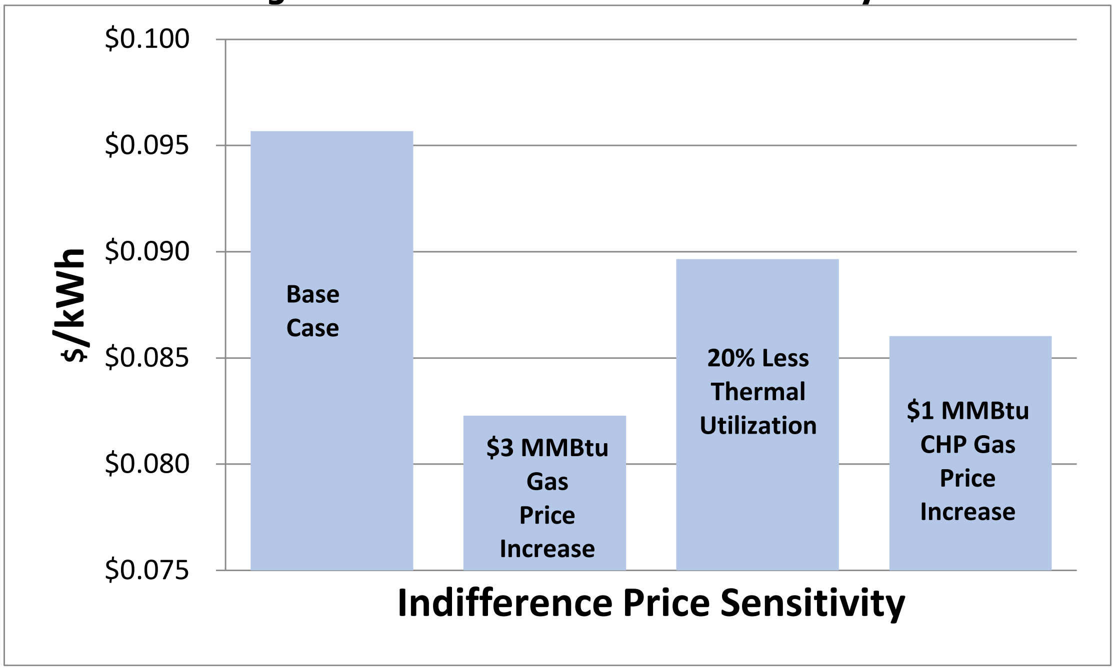
Flex CHP and battery storage can provide such as voltage support, enhanced reliability, transmission and distribution (T&D) deferral, and reserve capacity.[70]

With the right market signals, CHP *can* operate in a flexible manner and shut-down or curtail output during periods of threating over-generation threat of renewables. Flexible CHP offers some operational and economic advantages over batteries and can help the State balance supply and demand. The flexible CHP competitive advantage over batteries appears greatest for lower annual dispatch periods to handle the over-generation peak periods. Also, as the expenses are primarily operating and not capital in nature, the flexible CHP energy measure is not capacity or capital constrained and can be operated longer than a battery on a daily basis or less than a battery without duration limits or negative consequences of unused capital.

The sample Flex CHP system considered here probably represents the high end of the indifference price. Less efficient CHP systems, higher gas prices, and smaller spread between boiler fuel and CHP fuel prices all show lower indifference pricing as depicted in Figure 51. GHG emissions will be reduced during Flex CHP curtailments when renewables are at the margin. For this sample system, the GHG savings from CHP curtailment is 237 kg-$CO_2$/MWh or 433 tonnes $CO_2$/MW annually with 1,825 hours of curtailment with renewables at the margin. (Tonne is also called the British ton, based on the metric system and equals 2,200 pounds). When a natural gas combined cycle power plant is at the margin, running this CHP system for 6,500 hours per year will save 136 kg-$CO_2$/MWh or 880 tonnes $CO_2$ annually.

[70] Modelling the Impact of Flexible CHP on California's Future Electric Grid. U.S. Department of Energy. January 2018.

**Figure 51: Indifference Price Sensitivity**




There are a variety of ways Flex CHP benefits can be acquired:

- TOU rate tariffs with low prices during peak renewable hours for on-site CHP;
- Reverse Demand Response type tariff with capacity curtailment payments;
- Flex CHP eligibility for Utility Local Capacity resource RFOs; and
- A re-negotiated Power Purchase Agreement for larger CHP units that export electricity back to the grid.
- A combination of the above, where applicable.

Flexible CHP shows promise as a tool for helping California manage future electricity supply and demand in an economically and environmentally beneficial way. Additional analysis is needed to further quantify benefits and develop market procurement mechanisms.

### Microgrids – CHP, Solar, and Storage

Microgrids are electric generation and delivery platforms that can utilize a variety of generation and storage sources in a controlled manner to provide clean, resilient, and economic power to the end users on the microgrid. Early-on, microgrids were primarily associated with large campus facilities such as military bases, large universities, sprawling industrial/commercial complexes, and other district energy applications. But now, the concept is trickling down to smaller applications as well. Natural gas or biogas CHP is often thought as the foundation of the microgrid and is sized to fit the thermal load or in some cases sized for the biogas supply. Solar photovoltaics (PV) have become commonplace throughout California's commercial and industrial sectors and numerous sustainable-oriented businesses and organizations now have some level of solar PV on their premises, oftentimes limited by available space.

Battery storage is in its early adoption stage. Near term, batteries manage facility demand and can provide added resiliency for critical operations at the host site. Storage can also support CHP in applications with diurnal electricity swings by storing CHP power during periods of low electric demand and boosting onsite power during peak demand periods when supplemental electricity would otherwise be purchased from the grid. In addition, batteries can enhance CHP reliability and reduce demand and facility charges by producing power during short-term CHP outages. With an integrated CHP and battery storage system, onsite generation onsite power availability can be increased to 99% or higher, shaving fixed and demand expenses and reducing and possibly eliminating any support needed from the electric utility. An ever increasing role for electric storage will be to store PV electricity for use when the sun isn't shining. Storage can also be charged by the CHP system during periods of the day when demand is low and the solar incidence is low or zero. A battery like alternative that also complements CHP is chilled water storage using recovered heat in an absorption chiller to charge the chilled water tank during off-peak cooling hours and drawn down during high cooling load periods during the day. A microgrid management system capable of optimizing economic and environmental performance is essential.

As previously mentioned, though many of the microgrids operating today are in large campus settings such as large universities, military bases, and government campuses. However, there has been some recent small microgrid (< 5 MW CHP) implementation activity, examples of which are summarized in the next sections.

**Sierra Nevada Brewing Company**

Sierra Nevada Brewing Company was founded in 1980 in Chico, California and helped kick-start the American craft beer revolution. Dedicated to sustainability, the brewery installed four 250 kW fuel cells in 2005 and 2 megawatts of PV in 2007. In 2015, the fuel cells were retired and two 1 MW natural gas Capstone microturbine systems supplied by Regatta Solutions were installed in 2016 (Figure 53). In 2017, a 1 MW-hr. Tesla battery storage bank was added. The system is managed by an Agave energy management system to optimize financial and environmental performance in real-time. Parts of the microgrid are capable of running independent of the grid to provide energy resiliency to the brewery.

**Figure 52: Microturbines with Exhaust Heat Recovery**

Source: Regatta Solutions

### Stone Edge Farm

Stone Edge Farm (Farm) is a 16-acre estate in Sonoma, California that includes Bordeaux grape varieties, heirloom vegetables, olive groves, fruit trees, chickens and beehives. The Stone Edge microgrid encircles the Farm with a variety of interconnected electrical generation, storage and consumption devices. The Farm has seven electric meters that are interconnected with Automatic Transfer Switches (ATS) and a common trunk line. The microgrid includes a 65 kW natural gas Capstone microturbine, 300 kW of solar PV, multiple batteries of various types and manufacturers, a hydrogen generating electrolyzer, a hydrogen storage and fueling station for fuel cell cars, and three hydrogen fueled Plug Power fuel cells. A custom control system was designed to provide optimum performance of the entire 785 kW system and grid independent functionality for critical energy equipment.

### Princeton HealthCare System

The Princeton Medical Center (PMC) in Plainsboro, New Jersey has an operating microgrid that includes a 4.6 MW Mercury gas turbine supplied by Solar Turbines. Exhaust heat is used to generate steam for heating, chilled water and sterilization. The plant was designed, built and is operated by NRG. The CHP plant is integrated with a one million gallon chilled water storage tank that operates as a thermal battery that can be charged during off-peak hours and discharged during peak-demand periods. The PMC also includes a 200 kW solar array. Collectively, the microgrid is managed to operate at maximum efficiency and has the flexibility to export and import power from the grid when economically warranted or as needed. The microgrid enhances the hospital's energy reliability.

There are a growing number of new planned mixed-use communities where the high density portion of the development could be served with a CHP/PV/storage microgrid system connected to a thermal energy distribution loop that takes advantage of efficiency and economies of scale. Other small application clusters that are candidates for microgrids include smaller colleges and universities, K through 12 schools, health care, hotels, government campuses, light industrial, food processing, and multifamily.

## Renewable Gas

The availability of economical renewable gas (biogas, hydrogen) would enable CHP to partially or completely utilize renewable fuel either by piping non-pipeline quality biogas to the CHP site, using directed renewable gas, or purchasing pipeline gas that that has been blended with renewable gas. However, the market pricing for renewable natural gas is currently not economically viable for stationary generation.

### Energy Prices

There will be continuing upward pressure on retail electricity prices as utilities transition to a more robust T&D infrastructure to manage increased demand from electrification and the growth in distributed resources. PG&E projects electricity prices to increase 2% per year in real dollars. Non-bypassable surcharges will likely see increases to sufficiently incentivize electrification and less cost effective efficiency measures.

New York Mercantile Exchange (NYMEX) natural gas prices are projected to increase from $3 to $5/MMBtu over the next five years. California consumer gas prices will see further increases as a result of Cap-and-Trade allowance costs which have yet to be added to the price of gas for non-covered entities. Directed renewable gas will become more available for the transportation sector but may remain economically out of reach for CHP without a technology breakthrough.

As of the early 2018, the peak period for SDG&E customers on the time of use (TOU) rate has been shifted from the afternoon into the evening hours. SDG&E also extended the peak period from weekdays to include weekends and holidays. For PG&E and SCE, changes were only made to residential TOU customers. The summer weekday peak period was shifted to the evenings. Select evening hours in the winter and on summer weekends/holidays were designated partial peak or mid-peak periods. No other significant changes in response to the duck curve phenomena were noted.

According to the Advanced Energy Economy in their recent report *Rate Design for A DER Future*,[71] the US electricity system is transforming, powered by technological

[71] Rate Design for a DER Future. Prepared by Advanced Energy Economy. January 2018. Retrieved from: https://info.aee.net/hubfs/PDF/Rate-Design.pdf .

innovation, increased use of distributed energy resources (DER) and evolving customer needs and preferences. If properly integrated, DER can make the grid more efficient, flexible, resilient, reliable, and clean while giving customers greater choice and control. Future rates must compensate DER customers for the benefits provided and properly charge them for use of the grid. Utilities must be fairly compensated to maintain a system that provides safe, reliable, universal electricity service. But price signals need to motivate customers to act in ways that benefit themselves and the grid as a whole. For example, fixed charges and many demand based rates may be a preferred mechanism for utilities to be compensated for their services but they stifle customer flexibility to sustainably and economically manage their energy usage. The Advanced Energy Economy suggests that Time Varying Rates (TVR), bill minimums, and targeted demand charges over limited time periods would better enable customers to control their own energy destiny. Their report advocates a technology neutral approach to monetize value of all DER technologies and to encourage the integration of DG with other DER technologies such as "solar plus storage or CHP and demand management." The "value stack" framework being implemented in New York on a trial basis is used as an example solution, where the value is based on the utility's avoided cost plus other DER values including wholesale energy and capacity, distribution, ancillary services, and environmental attributes.

## Enhancing the CHP Value Proposition

### Technology Readiness

Perhaps the biggest market barrier confronting small CHP (< 5 MW) is high installed costs driven by site specific costs to retrofit the thermal and electric inter connections into the facility. The associated soft costs and time associated with design, Plan Check approval, the utility interconnect agreement, air permit, etc., can also debilitate these smaller projects. With cooperative government regulators and utilities, smart factory packaging and UL certifications, the time and cost to install and commission can be reduced considerably.

### System Packaging

Particularly for smaller CHP systems, factory assembly is cheaper and of higher quality and reliability than field erected systems. A portfolio of packaged CHP systems with integrated heat recovery, emission after-treatment, and controls is key to gaining traction in these smaller applications. Standardized off-the-shelf optional functionality can be made available including thermal energy storage (hot and cold), battery storage, microgrid compatibility and controls, PV interface, and multi-fuel capability.

### New and Retrofit Construction

CHP has typically been installed on a retrofit basis. The economies and efficiency can be maximized by integrating CHP into new construction or designing the facility for easy addition of CHP in the future. Demolition can be eliminated and supplemental heating and cooling equipment and emergency generators can be downsized or eliminated. Complicating the new construction benefit is the mandate for Zero Net Energy (ZNE) in new residential buildings in 2020 and new commercial buildings in 2030. For standardized building designs such as is practiced by a number of chain businesses, a standardized CHP package could be an optional system that makes sense for certain locations. Natural gas appliances have been excluded from the ZNE methodology but CHP has not been dealt with yet. Depending on the ZNE/CHP determination, CHP may have to be fueled with directed biogas (or less likely from a local biogas resource) or excess PV may be required to offset natural gas use for CHP.

## Barriers and Recommendations

Key barriers to the adoption of small and micro-scale CHP systems are summarized in Table 53.

Table 54 includes potential solutions identified to reduce these barriers.

**Table 53: Barriers to the Adoption of CHP Systems**

| Area | Barriers |
|---|---|
| State Policies, Legislation, and Regulations | • Natural gas CHP, even though it is the most efficient and cleanest fossil resource, is considered a baseload 24/7 technology and not a fit for California's energy future.<br>• Except for a few CHP sites in close proximity to a biogas source, the SGIP biogas minimum effectively eliminates CHP from eligibility.<br>• Cap-and-Trade allowance costs could seriously impact new CHP adoption despite its GHG benefits. The covered entity exclusion "But for CHP" in effect until 2020 was not renewed post 2020 putting CHP for many applications in jeopardy.<br>• NEM benefits have only been extended to one CHP technology regardless of performance attributes of others. |
| Electric Tariffs | • Non-bypassable surcharges (departing load charges) are selectively applied to generation from certain CHP technologies despite performance attributes. Most other customer measures are exempt from these punitive surcharges.<br>• High standby charges can deter new CHP and vary widely by utilities throughout the state. Again, only select CHP technologies pay these charges. Most DG technologies are exempt from standby tariffs.<br>• High demand charges, particularly non-coincident demand charges and ratchets, adversely affect natural gas DG. Renewable DG benefits from a special tariff where a large portion of these charges are converted to avoidable energy charges. |
| Interconnection | • Interconnection process time and cost has become long and costly, and is particularly damaging for smaller CHP systems. |
| Technology | • Smaller systems tend to have a higher capital cost burden for a number of reasons, including higher soft costs (permitting, interconnection agreements, and engineering), and installation costs.<br>• There is a lack of understanding of Flex CHP technology capabilities and market potential.<br>• There is no commercial micro-CHP (< 50 kW) technology option currently available in California. |

Source: Aggregate of expert stakeholder opinions gathered through TAC meetings, workshops, interviews, and phone calls.

**Table 54: Recommendations to Reduce the Identified Barriers**

| Area | Recommendations |
|---|---|
| State Policies, Legislation, and Regulations | • Recognize Flex CHP as a potentially cost-effective resource to manage electricity supply and demand. Thoroughly assess the potential, the benefits and implementation practicality of the concept. Consider a utility pilot to vet the concept in the field.<br>• Encourage DER solutions through policies, legislation, and regulations that are performance based and technology neutral.<br>• Help ensure flexible operation through electric utility owned CHP.<br>• Include flexible CHP in the utility integrated resource plans. |
| Electric Tariffs | • Eliminate non-bypassable surcharges on all efficient and clean customer DER measures.<br>• Recognize DG availability as a class when developing standby and demand charges for DG downtime, shifting a greater portion of the charges for backup power to energy vs demand.<br>• Reduce demand charges on short-term outages through a renewable tariff equivalent for CHP. |
| Interconnection | • Extend the fast track process to smaller CHP and reduce fees to very small CHP systems (< 200 kW). |
| Technology | • Reduce cost and time burdens for small scale CHP systems through smart factory packaging systems and UL certifications.<br>• Assess CHP technology capabilities and limitations to flexibly operate in support of economic, environmental and reliable grid performance. Assess other grid value-stacking benefits to be afforded a Flex CHP fleet. Explore methods for harnessing Flex CHP benefits and aggregating program participation. Consider demonstration and utility pilot projects.<br>• Seek innovative CHP demonstration projects in applications that provide co-benefits such as water purification or indoor farming.<br>• Develop and demonstrate near-zero emission, efficient small CHP (< 5 MW) and micro-CHP (<50 kW) for the large untapped market potential.<br>• Develop packaging solutions for small CHP that reduce installed costs, offer high overall efficiencies, provide high availability, and that can easily integrate with PV and storage.<br>• Help ease interconnection process via inverters on small CHP. |

Source: Aggregate of expert stakeholder opinions gathered through TAC meetings, workshops, interviews, and phone calls

# CHAPTER 5: Summary

While the trend in California policies and regulations has made California more challenging for CHP, the CHP industry continues to advocate that CHP technologies offer a clean and economical solution with a small carbon footprint. Due to intermittent generation, PVs can seldom meet the entire electricity load, making room for CHP to supply electricity when PV electricity is insufficient or unavailable. In addition to providing electricity, CHP systems provide useful thermal energy for site needs. Forecasts indicate that natural gas will continue to be prominent, with 32-36% of electricity consumption in California expected to be generated with natural gas in 2030.

To achieve GHG reduction goals in California, the efficiency of natural gas generators used for electricity production should be a priority. Well-designed CHP installations are more efficient and have a smaller carbon footprint than modern central station natural gas power plants. Because CHP systems operate at high efficiency, existing and new CHP systems can help the State reach GHG goals.

As CHAPTER 4 indicated, there are opportunities for CHP in microgrid applications and flexible CHP systems can support the grid while enabling further adoption of renewable energy resources. Hurdles will continue to prevent CHP adoption in California, including policy, electric tariffs, interconnection and technology. However, by implementing the recommendations included in this report, the state can encourage a growth in adoption rather than preclude.

## Technology Identification and Characterization

California accounts for 10% of the installed CHP capacity in the United States, with 8,600 MW of operational CHP systems. Large industrial and institutional CHP installations account for most of this capacity, with about 8% (663 MW) coming from systems under 5 MW in size.[72] There is a potential untapped opportunity for CHP in California, recently estimated at 8,000 MW for applications between 50 kW and 5 MW.[73] Additionally, new micro-CHP technologies could open the market to thousands of commercial applications and millions of residential applications under 50 kW in size.

This report characterizes CHP products commercially available, enabling technologies, and emerging micro-CHP systems in California.

[72] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Updated 2017. Available online: https://doe.icfwebservices.com/chpdb/

[73] Hedman, Bruce, Ken Darrow, Eric Wong, Anne Hampson. ICF International, Inc. 2012. *Combined Heat and Power: 2011-2030 Market Assessment, California Energy Commission, CEC-200-002.*

## Mature CHP Technologies

Simple cycle combustion turbines, are common for large industrial CHP applications, but they are not as economically viable in sizes under 5 MW. Combustion turbines can produce medium or high pressure steam, and when paired with supplemental exhaust firing, they can generate incremental steam at much higher efficiencies than a stand-alone boiler. Fitted with low-NOx combustors, selective catalytic reduction (SCR) and an oxidation catalyst, gas turbines can achieve very low emission levels, and they are capable of meeting the strictest emission standards in California.

Internal combustion engines (ICE) are the most common technology for small CHP installations, available in sizes from below 5 kW to 5 MW. ICEs tend to have higher electric efficiencies and lower installed costs than turbines and microturbines in this size range. However, they generally need more maintenance than competing CHP technologies, increasing operating costs and lowering system availability. ICEs have kept pace with California's ever tightening emission standards, the most notable of which is South Coast Air Quality Management District's (SCAQMD) Engine Rule.[74] ICEs may face additional technology challenges in the future should emission standards tighten even further.

Microturbines are small combustion turbines less than 350 kW in size, although multiple microturbines can be combined in a single container for larger systems. Microturbines are often equipped with recuperators to overcome the inherently low simple cycle efficiencies. Microturbines generally require infrequent maintenance and have high availability. Because they operate at modest combustor temperatures and pressures, these systems can meet California emission regulations with low NOx combustors and do not require exhaust after-treatment.

Fuel cells have relatively high electric efficiencies and inherently low emissions. Fuel cells have the highest capital costs of all the CHP technology options and generally have high availability with proper and well maintained fuel conditioning.

Table 55 provides an overview of the performance and cost characteristics of the mature market technologies in the 50 kW to 5 MW size range.

[74] SCAQMD Rule 1110.2: https://www.arb.ca.gov/energy/dg/dg.htm

**Table 55: Performance and Cost Characteristics (50 kW – 5 MW)**

| Metric | Gas Turbine | Engine | Microturbine | Fuel Cell |
|---|---|---|---|---|
| Size kW | 3,300 – 5,200 | 75 – 4,300 | 62 – 1,000 | 440 – 2,800 |
| Elec Eff HHV | 24 – 34% | 27 – 40% | 24 – 30% | 40 – 43 |
| Total Eff HHV | 64 – 76% | 74 – 81% | 67 – 73% | 76 – 81% |
| Heat Quality | 150 psig steam | 180°F+ HW | 140°F HW | 140°F HW |
| Emissions | SCAQMD | SCAQMD | SCAQMD/ CARB | CARB |
| Capital Cost ($/KW) | 2,430 – 3,580 | 2,100 – 3,750 | 2,950 – 3,550 | 3,600 – 6,700 |
| Maintenance (¢/KWh) | 1.4 – 1.9 | 1.4 – 2.4 | 1.8 – 2.0 | 2.6 – 3.2 |
| Availability | 97 – 98% | 94 – 96% | 97 – 98% | 95 – 97% |

Source: Obtained by surveying active California CHP product suppliers

## Micro-CHP

Micro-CHP products, defined to have a capacity smaller than 50 kW for purposes of this assessment, have emerged in recent years. Micro-CHP technology options include fuel cells, Stirling engines, internal combustion engines and microturbines. Micro-CHP products are designed for residential and small commercial markets. These markets are driven by relatively high energy prices and incentives such as tax credits, capital cost subsidies, NEM, and low interest loans. Worldwide, there are more than twenty micro-CHP products that are available or emerging in the market.

Micro-CHP equipment has been commercially available for well over a decade, and worldwide sales have approached 300,000 units. Japan accounts for 80% of the volume, Europe accounts for 15%, and the U.S. only accounts for 0.2% of micro-CHP sales.[75] There are some micro-CHP products currently available in North America (NA) and several other manufacturers are in the process of certifying their products for the NA market.

Micro-CHP products currently available in NA include the Marathon 4.4 kW ICE, the Yanmar 5 kW and 10 kW ICE units, the EC Power 19 kW ICE module, the Tedom 35 kW ICE package and the Capstone 30 kW microturbine. In some cases, manufacturers are

[75] MicroCogen Partners LLC. Current Economic Outlook for mCHP. Technology to Policy mCHP "Status" Workshop. Philadelphia, PA. June 2017.

seeking volume commitments in NA to justify start-up expenses. These manufacturers include Solid Power (1.5 kW, 6 kW and 12 kW BlueGen solid oxide fuel cells (SOFC)) and Ametek (1 kW Sunpower Stirling engine).

Micro-CHP products that could serve California are shown in Table 56 with their performance and cost characteristics. They all employ condensing heat recovery which produces hot water at temperatures around 140°F, and all achieve high overall efficiencies. Although none have obtained CARB DG[76] certification to-date, they are all considered capable of acquiring the certification, with emission control technologies required for some technologies.

**Table 56: Representative Micro-CHP Technologies**

| Description | SOFC[a] | Stirling Engine[b] | Rich-Burn ICE | Rich-Burn ICE | Microturbine |
|---|---|---|---|---|---|
| Net Electric Power (kW) | 1.5 | 1.0 | 4.4 | 19.2 | 28 |
| Fuel Input (Btu/hr, HHV) | 9,426 | 9,425 | 71,800 | 233,100 | 420,000 |
| Useful Thermal (Btu/hr) | 2,356 | 3,412 | 42,200 | 130,000 | 210,000 |
| Heat Quality | 140°F HW | 140°F HW | 140°F HW | 140°F HW | 140°F HW |
| Electric Efficiency (%, HHV) | 54.3% | 36.2% | 20.9 | 28.1% | 22.7% |
| Overall Efficiency (%, HHV) | 79.3% | 72.4% | 79.7% | 83.9% | 72.7% |
| Installed Cost ($/kW) | $14,000 | $7,000 | $9,000 | $5,300 | $5,025 |
| Maintenance Cost (¢/kWh) | 3.0 | 1.0 | 3.0 | 2.5 | 2.3 |

**a: With signed deployment agreements totaling 5,000 units/yr, a $4,000 module price is projected, reducing installed cost to approximately $8,000.**

**b: ARPA-E development project – Prices based on production of 100,000 units.**

Source: Obtained by surveying active California CHP product suppliers.

[76] CARB 2007 DG Standards: https://www.arb.ca.gov/energy/dg/dg.htm

## Enabling Technologies

Enabling technologies are supplemental technologies that can improve CHP heat use, which would otherwise constrain system size and/or capacity factor of the system. This is a particularly important issue for California with its moderate climate and short space heating season. Also, because of California's unique and aggressive emission regulations, affordable emission control technology is a must.

The three enabling technologies addressed in this report are absorption cooling, thermal energy storage, and emission control technology.

### Absorption Chillers

Absorption chillers use heat to generate chilled water. This heat can come directly from a fueled burner or the recovered thermal energy from the operation of a prime mover such as reciprocating engines, combustion turbines or fuel cells. Hot exhaust gases, medium pressure steam (greater than 100 psig), low pressure steam (15 psig or greater) and hot water (200 - 240°F) can all provide heat to an absorption chiller. Absorbers are characterized as single effect or double effect. Single effect absorption chillers take low quality heat such as low-pressure steam or hot water and produce chilled water. Double effect machines require higher quality heat but can also use lower temperature sources of thermal energy to produce chilled water more efficiently than single effect machines.

Table 57 provides a summary of cost and performance characteristics for absorption chillers matched with CHP products up to 5 MW in size. Absorption chillers sized from 5 to 3,100 refrigeration tons as depicted.

**Table 57: Absorber Performance and Cost Summary**

| Description | System | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Design | Single Effect | | | | Double Effect | | | |
| Heat Source | Hot Water | | | Low Press Steam | High Pressure Steam | | Exhaust Fired | |
| Nominal Capacity (Tons) | 5 | 50 | 440 | 1,320 | 330 | 1,320 | 120 | 3,100 |
| Cooling COP (Full Load) | 0.70 | 0.70 | 0.74 | 0.79 | 1.42 | 1.42 | 1.26 | 1.37 |
| Installed Cost ($/ton) | 16,800 | 6,000 | 2,300 | 1,800 | 3,000 | 2,200 | 5,100 | 1,600 |
| O&M Cost (¢/ton-hr) | 1.7 | 0.6 | 0.2 | 0.1 | 0.3 | 0.1 | 0.3 | 0.1 |

Source: Adapted from U.S. DOE Absorption Chillers for CHP Systems Technology Fact Sheet. May 2017

### Thermal Storage

Small and micro-CHP systems often serve residential and light commercial applications that have highly variable diurnal thermal demands driven by domestic hot water (DHW) usage patterns. Hot water storage and/or thermal load following is essential to achieve high thermal heat utilization from many of these smaller CHP systems. Sizing of the thermal storage systems can vary considerably from site to site.

Hot water storage tanks are off-the-shelf equipment. A double wall heat exchanger generally separates the prime mover heat recovery loop from the domestic hot water (DHW) tank. The heat exchanger can be immersed in the hot water tank or it can be located external to the tank. Installed costs for a thermal storage system are in the $20 – $35/gallon range.

Chilled water storage systems can add significant economic value to a facility's energy system. They can peak-shave, participate in utility demand response programs, reduce the amount of chiller equipment, and serve the facility during grid outages reducing the amount of backup generator sets on-site. When used in conjunction with CHP and an absorption chiller, excess chilled water can be produced and stored at night at relatively low cost, and then dispatched during the day during peak demand periods when the value of chilled water is relatively high.

### Emission Control

The air criteria pollutant regulations for CHP in California are among the toughest in the world. South Coast Air Quality Management District (SCAQMD) is recognized as the most challenged air district in the nation by the EPA and houses about 40% of California's population. There are three primary sets of regulations that have shaped CHP emission requirements in California: Best Available Control Technology (BACT), California Air Resources Board Distributed Generation (CARB DG) Certification and SCAQMD Engine Rule 1110.2.

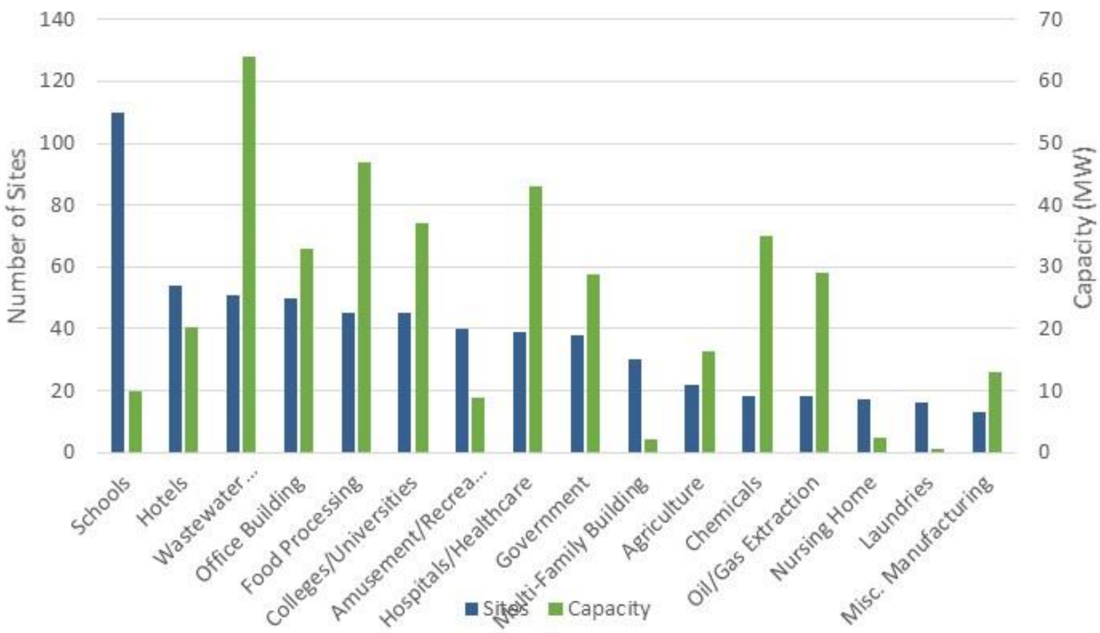
Recent ICE, combustion turbine, microturbine and fuel cell installations have either received SCAQMD permits or have been CARB DG certified. CARB DG certification, the standard with the lowest emission requirements, is not applicable for current ICE and combustion turbine products. But a new DG incentive under consideration includes CARB DG standards as an eligibility requirement. The CHP product suppliers presently active in California's CHP market have indicated that they will be able to comply with the incentive requirement.

## CHP Applications

Potential applications for CHP consist of industrial, institutional, commercial, and residential buildings with coincident power and thermal loads. Facilities with 24/7 electric and thermal requirements, such as industrial manufacturing plants, colleges, and hospitals, are ideal hosts for CHP and have historically been the most prevalent applications for CHP installations. However, any site with coincident power and thermal loads with a significant percentage of operational time is a potential CHP candidate.

Industrial CHP applications represent 75% of California’s current installed capacity. However, industrial facilities only represent 25% of the installed capacity for CHP applications smaller than 5 MW. The remaining CHP capacity in the <5 MW size range – close to 75% of this market – primarily consists of buildings in the commercial and institutional sectors, led by wastewater treatment plants, hospitals, and colleges/universities. Figure 53 shows the top applications for California CHP installations by number of sites and total CHP capacity.

**Figure 53: Number of Sites and Installed Capacity (MW) for <5 MW CHP: Top Applications**




Source: U.S. DOE CHP Installation Database, July 2017

The complete list of applications from current California CHP installations is shown in Table 58. Several of these applications can be consolidated with others based on similar building load profiles and functionality.

**Table 58: CHP Applications Identified From Existing California Installations**

| Industrial | Commercial, Institutional, and Residential | |
|---|---|---|
| Agriculture | Air Transportation | Laundries |
| Chemicals | Amusement/Recreation | Military/National Security |
| Electronics | Automotive Services | Misc. Services |
| Fabricated Metals | Banks | Motion Pictures |
| Food Processing | Car Washes | Multi-Family Building |
| Instruments | Colleges/Universities | Museums/Zoos |
| Machinery | Commodity Brokers | Assisted Living |
| Misc. Manufacturing | Communications | Office Building |
| Oil/Gas Extraction | Community Services | Postal Service |
| Primary Metals | Construction | Private Household |
| Printing/Publishing | Data Centers | Restaurants |
| Pulp and Paper | District Energy | Schools |
| Refining | Energy Management Services | Solid Waste Facilities |
| Rubber/Plastics | Food Stores | Space Research and Technology |
| Stone/Clay/Glass | General Merch. Stores | Utilities |
| Textiles | Government | Warehouses |
| Transportation Equipment | Hospitals/Healthcare | Wastewater Treatment |
| Wood Products | Hotels | Wholesale Trade |
| | Justice/Public Order | |

Source: U.S. DOE, CHP Installation Database, July 2017

CHP is well-suited for industrial facilities[77] with consistent electric and thermal loads. Most industrial manufacturing plants are sized relatively large for economies of scale, and they have a strong demand for electricity and thermal energy as steam or process heating. The high-temperature output of combustion turbines makes them ideal for many industrial manufacturing CHP applications. While many of the potential CHP applications are significantly larger than 5 MW, there are some industrial manufacturing plants with baseload electricity requirements below 5 MW, where smaller CHP systems can be used.

Commercial and institutional buildings, including hotels, office buildings, hospitals, and schools, tend to have smaller electric and thermal demands compared to industrial facilities. Additionally, commercial buildings tend to have lower load factors, with larger differences between peak and average loads, and more seasonal variation in their energy requirements. CHP installations are most ideal for commercial and institutional buildings with consistent electric and thermal loads that operate 24 hours a day, 7 days

[77] Industrial facilities consist primarily of those in the manufacturing industries (SIC 20-39, NAICS 311-339) as well as agriculture, oil and gas extraction, and gas processing facilities.

a week. However, applications such as office buildings and retail establishments with low nighttime loads have the potential to economically and efficiently use CHP during operational hours.

To date, residential CHP applications in California have been limited, with 30 installations in multifamily buildings and 12 in private residences. There is a significant amount of potential for CHP applications at large high-rise multifamily buildings in urban areas, like Los Angeles and San Francisco, but the majority of California's potential for multi-family and single-family residential applications falls in the micro-CHP category. The potential market for CHP in California's residential sector will depend on future advancements in micro-CHP technologies and their availability in the state.

## Technical Potential for Small CHP Applications

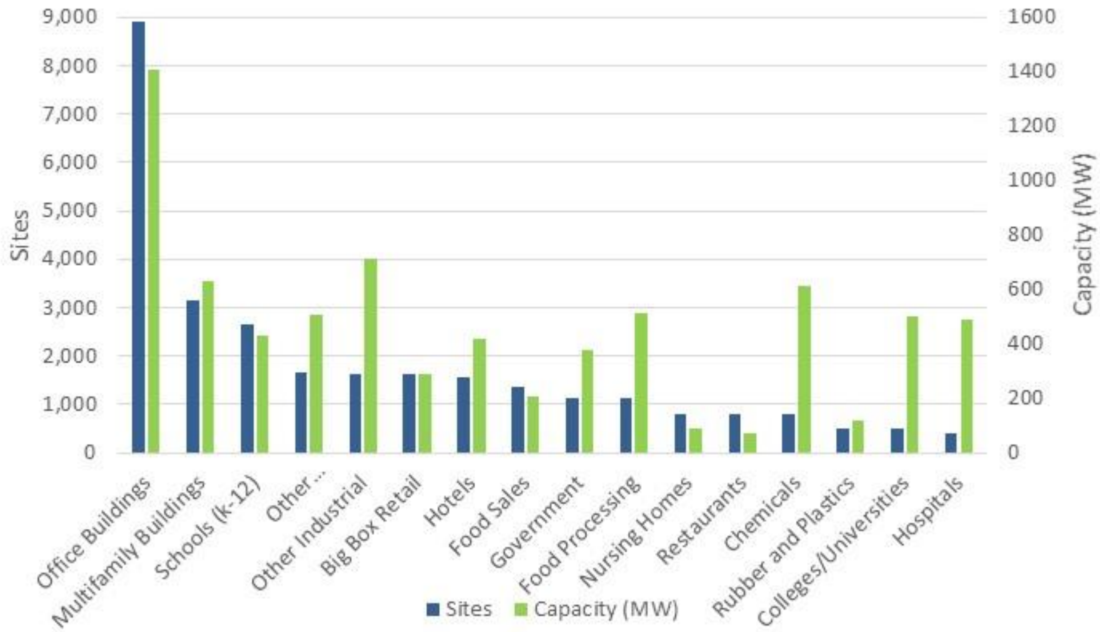
To evaluate the technical potential for new California CHP installations as a part of this assessment, the installed base of current CHP systems was first identified. The Department of Energy's CHP Installation Database shows that there is 662 MW of CHP capacity in California for systems 5 MW or smaller in size, at a total of 1,036 sites.[78] Facilities with existing CHP installations were removed from the pool of California sites with technical potential for CHP.

Data for California sites capable of installing new CHP systems between 50 kW and 5 MW was assembled, including potential applications in the industrial, commercial, institutional and residential (multifamily) sectors. Overall, there is an estimated 7.4 GW of technical potential across more 28,600 sites for California CHP applications sized 50 kW to 5 MW.

For traditional CHP applications 50 kW to 5 MW in size, commercial office buildings have the most technical potential for the number of sites and total capacity. California facilities with technical potential for CHP systems in the range of 50 kW to 5 MW are broken down by application type in Figure 54.

[78] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Data retrieved Dec 31, 2016. https://doe.icfwebservices.com/chpdb/

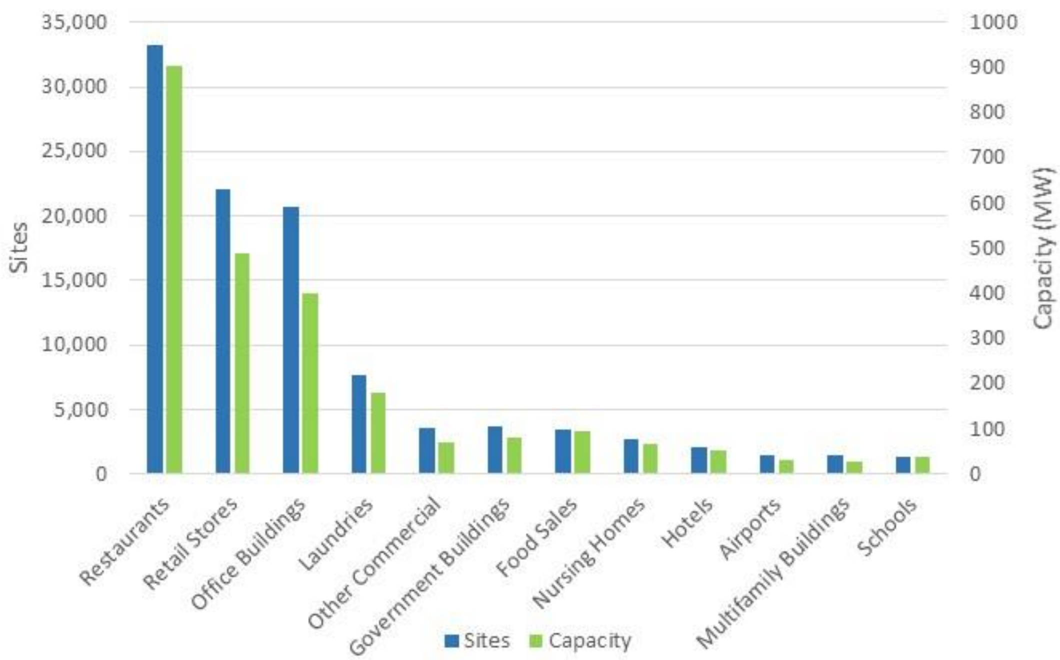
**Figure 54: Technical Potential for Micro-CHP Applications 50 kW – 5 MW**




Source: ICF Analysis

For micro-CHP applications, excluding single family homes, the technical potential (2.5 GW total) is led by restaurants, retail stores and office buildings. The potential sites and capacity for 10-50 kW micro-CHP applications are shown in Figure 55.

**Figure 55: Technical Potential for Micro-CHP Applications, 10-50 kW**




Source: ICF Analysis

Technical potential for residential single family home CHP applications was also considered in this market assessment. Based on the estimated number of single family homes over 3,000 square feet in size (considered to be the primary market for residential micro-CHP) and 2,500-3,000 square feet (considered to be the secondary market), the technical potential for micro-CHP applications with a 1.5 kW fuel cell (proxy residential CHP unit) is estimated to be 1.7 GW for the entire state.

The potential markets are broken down by utility service territory in Table 59.

**Table 59: Technical Potential for Single Family Home CHP by Utility Territory**

| Utility | Primary Market: >3,000 sq ft | | Secondary Market: 2,500-3,000 sq ft | |
|---|---|---|---|---|
| | Homes | Potential (MW) | Homes | Potential (MW) |
| Pacific Gas & Electric | 219,600 | 329 | 161,100 | 242 |
| Southern California Edison | 215,800 | 324 | 158,300 | 237 |
| Los Angeles Department of Water & Power | 64,900 | 97 | 47,600 | 71 |
| San Diego Gas & Electric | 62,400 | 94 | 45,700 | 69 |
| Sacramento Municipal Utility District | 26,900 | 40 | 19,800 | 30 |
| Other Utilities | 55,400 | 83 | 40,600 | 61 |
| Total | 645,000 | 968 | 473,000 | 710 |

Source: ICF Analysis

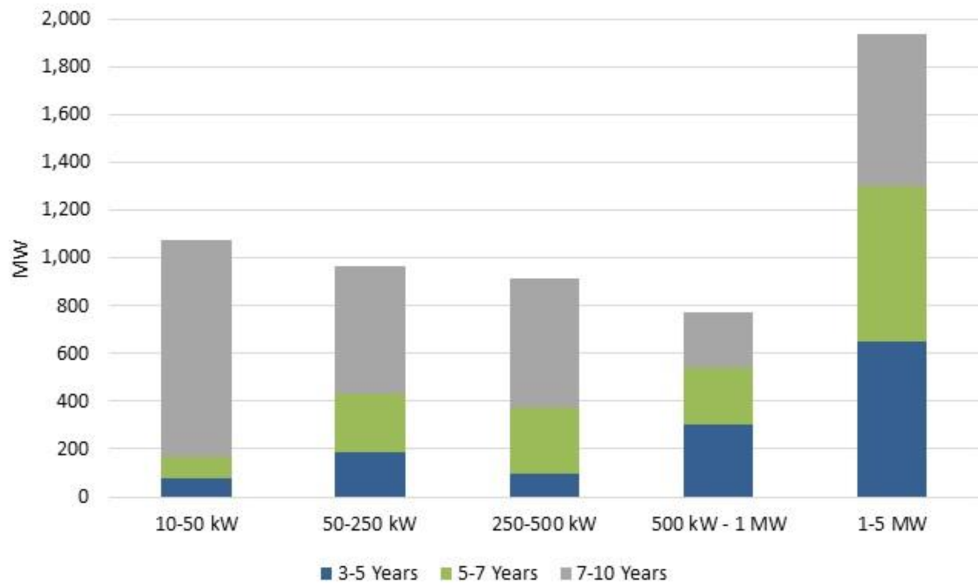
When combining the technical potential for micro-CHP and traditional CHP applications up to 5 MW, there is approximately 11.5 GW of total technical potential in California.

## Economic Potential for Small CHP Applications

The economic potential for CHP was estimated by evaluating electricity and gas rates for major California utilities, and applying them to the operational performance of CHP systems by application, using the equipment cost and performance characteristics identified in CHAPTER 2. Sites that could achieve a payback period of less than 10 years were considered to have economic potential. Overall, approximately 5.7 GW of economic potential was found for California CHP applications, including 10-50 kW micro-CHP and traditional CHP installations 50 kW to 5 MW in size.

In Figure 56, the economic potential is shown by CHP size range and payback period range.

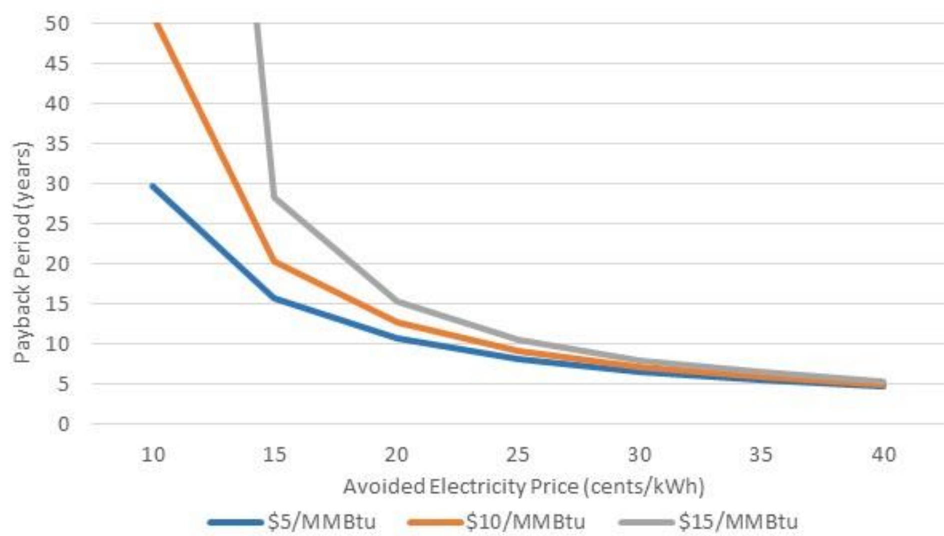
**Figure 56: Economic Potential for Small CHP Applications in California, by Size Range**




Source:ICF Analysis

Economics for single family home CHP applications were also considered, using an emerging 1.5 kW solid oxide fuel cell identified in the analysis described in CHAPTER 2. Payback periods for net metering applications were calculated using different electricity and gas prices to determine where residential micro-CHP could be successful. At the current installed cost of $14,000 per kW ($21,000 total), the avoided electricity cost must be close to 25 cents/kWh or higher for a 10 year payback, or more than 40 cents/kWh for a 5 year payback (Figure 57).

**Figure 57: Economics for Single Family Home CHP by Electricity and Gas Price**




Source: ICF Analysis

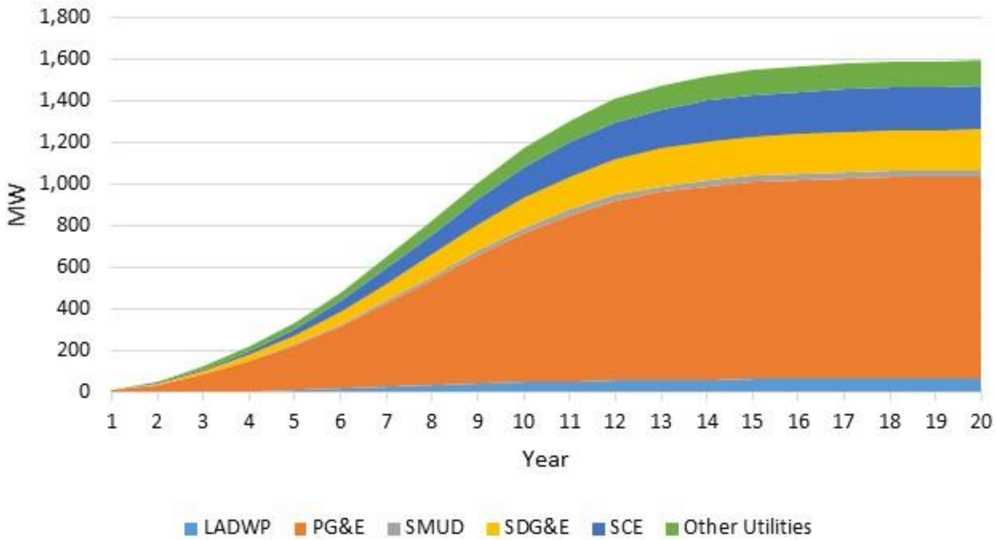
While the avoided electricity cost must be relatively high for single family home micro-CHP applications to be successful, average residential rates are in the vicinity of 20 cents/kWh, and some California residences can pay 40 cents/kWh for peak usage. If 1-2 kW micro-CHP systems become commercially available, and if product demand reaches a certain threshold level, installed costs could fall to $10,000/kW or below, creating a viable California residential market.

Due to variation and uncertainty with residential energy rates, and the lack of available systems, the economic potential for residential micro-CHP applications was not calculated for this market assessment. However, the analysis showed that customers with avoided electricity costs over 25 cents/kWh could achieve a payback period under 10 years with a 1.5 kW fuel cell installation. Of the major California utilities, PG&E has the highest residential electricity rates and the largest potential market for residential micro CHP, estimated at 571 MW from over 380 thousand homes in their service territory. New residential time-of-use rates being adopted by California IOUs in 2019 have the potential to improve CHP economics and enable emerging micro-CHP technologies to penetrate the market.

## California CHP Market Adoption

The results of the economic analysis were applied to ICF's CHPower adoption model to estimate the 20-year market penetration of new CHP installations for traditional CHP applications up to 5 MW in size and micro-CHP applications in the 10-50 kW size range. For both markets, the majority of CHP adoption is expected to take place in PG&E's utility territory, which has the most favorable electricity and gas rates for CHP applications. SCE has the least favorable energy rates for CHP, resulting in significantly less forecasted adoption despite its large customer base. The market adoption forecast for traditional CHP applications 50 kW to 5 MW in size is shown in Figure 58**.**

**Figure 58: Market Adoption Forecast for Traditional 50 kW – 5 MW CHP Applications by Utility**

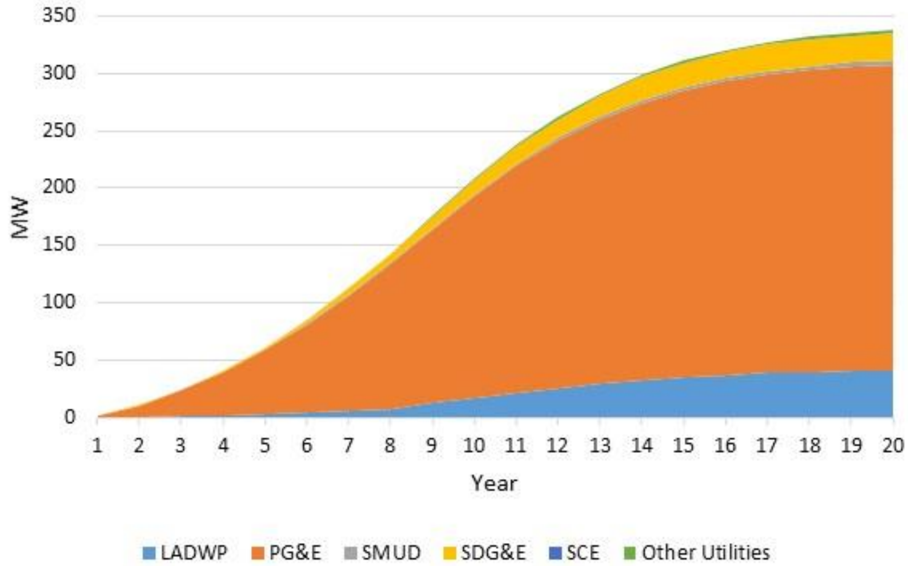



Source: ICF Analysis

Overall, nearly 1.6 GW of new CHP capacity is expected in this size range to be adopted in California over the next 20 years, with almost 1 GW coming from PG&E customers. California's current installed base of CHP in this size range is only 662 MW, so CHP is poised for growth with a large number of potential sites and favorable market conditions.

The micro-CHP market is also expected to grow, although adoption will occur more slowly compared to traditional CHP applications. For 10-50 kW CHP installations, close to 340 MW of adoption is anticipated over the next 20 years, with over 80 percent coming from Pacific Gas & Electric customers with the most favorable rates for CHP. The market adoption forecast for 10-50 kW micro-CHP applications is shown in Figure 59. In total, more than 1.9 GW of <5 MW CHP adoption is expected over the next 20 years, which is three times the current installed capacity in this size range.

**Figure 59: Market Adoption Forecast for 10-50 kW Micro-CHP Applications by Utility**




Source: ICF Analysis

## Potential Emissions Impacts

The analysis showed that in 2037, with 1.9 GW of small and micro CHP adopted, there will be a significant amount of fuel savings and emissions reductions. Fuel requirements and emissions for CHP systems with market potential were compared to projected 2037 utility grid fossil fuel emissions, which would be displaced by baseload CHP.

Overall, an estimated 39 million MMBtu/year of fuel (primarily natural gas) would be conserved, a savings of 23 percent compared to separate heat and utility power. Along with these energy savings, by 2037, 3,200 tons per year of NOx emissions would be avoided through small and micro CHP installations. Greenhouse gas emissions would also be reduced by over 1 million tons of carbon dioxide (equivalent) on an annual basis.

## Alternative Scenarios

For this California CHP market assessment, two alternative scenarios were explored. The first scenario was the reduction of installed costs by 10 percent. Reducing the installed cost of a CHP system by 10 percent typically has the effect of reducing the payback period by 10 percent. This can push sites from a 5.5 year payback to below 5 years, or sites with an 11 year payback below 10 years. The economic benefit is identical across the utility territories, and adoption patterns by utility remain similar, with PG&E accounting for the majority of expected adoption. In total, accounting for both traditional and micro-CHP applications, the expected 20-year adoption increases by 0.4 GW, with nearly 2.4 GW of installed capacity compared to 1.9 GW for the base case. Note that since this analysis was completed, the Federal Investment Tax Credit was restored for CHP, providing a 10 percent tax credit for efficient CHP installations.[79]

The second scenario was an electric rate reform scenario, in which standby rates and departing load charges are eliminated. With these charges, the avoided electricity rate can be considerably lower than the retail rate, but the effect varies depending on utility rate structures and specific charges. While some form of compensation for standby service is required for utilities, a scenario was evaluated in which electric rate reform leads to the effective removal of standby rates and departing load charges in California, often considered significant barriers to CHP. This would have a large impact on CHP economics. Compared to the base case, an additional 1.2 GW of capacity would be expected to come online over the 20-year period in this scenario, resulting in 3.1 GW of total market adoption.

## Conclusions

The technical and economic potential and expected market adoption for small CHP applications in California resulting from this Energy Commission market assessment are summarized in Table 60.

**Table 60: Results of California <5 MW CHP Market Assessment**

| CHP Market | Total Capacity (GW) | | |
|---|---|---|---|
| | Technical Potential | Economic Potential | Market Adoption |
| Traditional CHP (50 kW – 5 MW) | 7.4 | 4.6 | 1.6 |
| Micro-CHP (10 – 50 kW) | 2.5 | 1.1 | 0.3 |
| Single Family Home Micro-CHP (1 – 2 kW) | 1.7 | n/a | n/a |
| **Total (<5 MW)** | **11.6** | **5.7** | **1.9** |

Source: ICF Analysis

Based on this market assessment, there is technical potential of 11.6 GW for CHP systems 5 MW or smaller, including potential single family home applications. Almost 50% of this potential, or 5.7 GW, is estimated to be economical, capable of obtaining a payback period under 10 years. Three times the current installed capacity of <5 MW CHP in California is expected to come online over the next 20 years. This means market adoption is forecasted to be about 2 GW of CHP capacity. CHP is the cleanest and most efficient way to convert fossil fuels into energy, and it will continue to play an important role in the California energy market.

[79] Additional information can be found online at: https://www.energy.gov/savings/business-energy-investment-tax-credit-itc.

# LIST OF ACROYNMS

| Terms | Definition |
|---|---|
| AC | Alternating Current |
| AFC | Alkaline Fuel Cell |
| AEO | Annual Energy Outlook |
| ATS | Automatic transfer switches |
| BACT | Best Available Control Technology |
| Brayton Cycle | In the Brayton Cycle, atmospheric air is compressed, heated by burning fuel (such as natural gas), and then used to drive an expansion turbine that in turn drives both the inlet compressor and a drive shaft connected to an electrical power generator. |
| Btu/kWh | British thermal unit per kilowatt hour |
| California ISO | California Independent System Operator |
| CARB DG | California Air Resources Board Distributed Generation |
| CHP | Combined Heat and Power |
| CCHP | Combined Cooling, Heat and Power |
| $CO_2$ | Carbon dioxide |
| $CO_2$/MW | Carbon dioxide per Megawatt |
| CPUC | California Public Utilities Commission |
| CRV | Capital Recovery Factor |
| D&B | Dun & Bradstreet |
| DER | Distributed Energy Resources which include |
| DC | District Current |
| DG | Distributed Generation |
| DMFC | Direct Methanol Fuel Cell |
| DOE-OE | Department of Energy Office of Electricity |
| EIA | Energy Information Administration |
| Energy Commission | California Energy Commission |

| Terms | Definition |
|---|---|
| EPA | Environmental Protection Agency |
| EPIC | Electric Program Investment Charge |
| EPRI | Electric Power Research Institute |
| FITC | Federal Investment Tax Credit |
| GHG | Greenhouse gas |
| GTI | Gas Technology Institute |
| HHV | Higher heating value |
| HPNG | High Pressure Natural Gas available at or above 75 psig |
| IOUs | Investor owned utilities |
| ICE | Internal combustion engines |
| ITC | Income tax credit |
| Kg/MWh | Kilogram per megawatt hour |
| kW | Kilowatt |
| kWh | Kilowatt hour |
| LADWP | Los Angeles Department of Water and Power |
| Lb/MWh | Pound per megawatt hour |
| LHV | Lower heating value |
| LPNG | Low Pressure Natural Gas necessitates the addition of a gas compressor |
| MACRS | Modified Accelerated Cost Recovery System |
| Micro-CHP | Micro-CHP technologies are defined for this assessment to have a capacity <5 kW. Micro-CHP technology options include fuel cells, Stirling engines, ICE, microturbines, and ORC. Micro-CHP products are designed for residential and small commercial markets. |
| MCFC | Molten carbonate fuel cell |
| MMBtu | Million British thermal unities |
| MW | Megawatt |
| MWh | Megawatt hour |

| Terms | Definition |
|---|---|
| NAICS | North American Industry Classification System |
| $NO_x$ | Nitrogen oxides |
| O&M | Operation and maintenance |
| ORC | Organic Rankine Cycles |
| PAFC | Phosphoric Acid Fuel Cell |
| PEMPFC | Proton Exchange Membrane Fuel Cell |
| PG&E | Pacific Gas and Electric Company |
| PIER | Public Interest Energy Research |
| PMC | Princeton Medical Center |
| PV | Solar photovoltaics |
| RFO | Request for offers |
| RECS | Residential Energy Consumption Survey |
| RPS | Renewables Portfolio Standard |
| SCAQMD | South Coast Air Quality Management District |
| SCE | Southern California Edison |
| SCR | Selective catalytic reduction |
| SDG&E | San Diego Gas & Electric Company |
| SGIP | Self-Generation Incentive Program |
| SIC | Standard Industrial Classification |
| Smart Grid | Smart Grid is the thoughtful integration of intelligent technologies and innovative services that produce a more efficient, sustainable, economic, and secure electrical supply for California communities. |
| SMUD | Sacramento Municipal Utility District |
| SOFC | Solid Oxide Fuel Cell |
| T&D | Transmission and Distribution |
| TOU | Time of use |

| Terms | Definition |
|---|---|
| Tonne | British ton also called long ton based on metric system and equal<br><br>2,200 pounds |
| TVR | Time varying rates |
| ZNE | Zero Net Energy |
| $/kWh | Dollar per kilowatt hour |

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# APPENDIX A: Existing California CHP Installation Data

**Table 61: Number of Sites and Installed Capacity (MW) for <5 MW CHP, by Size Range**

| Size Range | Sites | Capacity (MW) |
|---|---|---|
| <50 kW | 96 | 1.8 |
| 50-249 kW | 415 | 46.0 |
| 250-499 kW | 150 | 51.6 |
| 500-999 kW | 152 | 107.4 |
| 1-5 MW | 223 | 456.0 |
| Total | 1,036 | 662.8 |

Source: ICF

**Table 62: Number of Sites and Installed Capacity (MW) for <5 MW CHP: Top Applications**

| Application | Sites | Capacity (MW) |
|---|---|---|
| Schools | 110 | 10 |
| Hotels | 54 | 20 |
| Wastewater Treatment | 51 | 64 |
| Office Buildings | 50 | 33 |
| Food Processing | 45 | 47 |
| Colleges/Univ. | 45 | 37 |
| Amusement/Recreation | 40 | 9 |
| Hospitals/Healthcare | 39 | 43 |
| Government | 38 | 29 |
| Multi-Family | 30 | 2 |
| Agriculture | 22 | 16 |
| Chemicals | 18 | 35 |
| Oil/Gas Extraction | 18 | 29 |
| Nursing Homes | 17 | 2 |
| Laundries | 16 | 1 |
| Misc. Manufacturing | 13 | 13 |

Source: ICF

**Table 63: Number of Sites Installed Capacity (kW) for <50 kW micro-CHP: Top Applications**

| Application | Sites | Capacity (MW) |
|---|---|---|
| Laundries | 13 | 160 |
| Private Homes | 11 | 107 |
| Hotels | 9 | 259 |
| Amusement/Recreation | 8 | 164 |
| Multi-Family | 8 | 134 |
| Misc. Services | 7 | 127 |
| Office Buildings | 5 | 130 |
| Schools | 4 | 101 |
| Restaurants | 3 | 43 |
| Justice/Public Order | 2 | 60 |
| Agriculture | 2 | 55 |
| Retail Stores | 1 | 40 |
| Nursing Homes | 1 | 35 |
| Car Washes | 1 | 30 |

Source: ICF

# APPENDIX B: California CHP Technical Potential Data

**Table 64: Technical Potential for 50 kW to 5 MW CHP in California, by Size Range**

| Size Range | Sites | Capacity (MW) |
|---|---|---|
| 50-249 kW | 20,859 | 1,845 |
| 250-499 kW | 2,127 | 758 |
| 500-999 kW | 3,822 | 1,823 |
| 1-5 MW | 1,826 | 2,952 |
| **Total** | 28,634 | 7,378 |

Source: ICF

**Table B-2: Technical Potential for 50 kW to 5 MW CHP in California, by Application**

| Application | Sites | Capacity(MW) |
|---|---|---|
| Office Buildings | 8,904 | 1,410 |
| Multi-Family | 3,140 | 629 |
| Schools (k-12) | 2,668 | 430 |
| Other Commercial | 2,571 | 1,492 |
| Other Industrial | 2,156 | 831 |
| Big Box Retail | 1,624 | 292 |
| Hotels | 1,546 | 416 |
| Food Sales | 1,358 | 208 |
| Government | 1,130 | 378 |
| Food Processing | 1,115 | 515 |
| Nursing Homes | 813 | 90 |
| Restaurants | 813 | 74 |
| Chemicals | 796 | 615 |
| Rubber and Plastics | 516 | 117 |
| Colleges/Universities | 509 | 498 |
| Hospitals | 398 | 489 |

Source: ICF

**Table B-3: Technical Potential for 50 kW to 5 MW in California, by Utility Territory**

| Electric Utility | Sites | Capacity (MW) |
|---|---|---|
| Southern California Edison Co | 11,198 | 3,047 |
| Pacific Gas & Electric Co | 10,383 | 2,629 |
| San Diego Gas & Electric | 2,121 | 590 |
| LADWP | 1,556 | 305 |
| Sacramento Munic Utility Dist | 926 | 257 |
| Other | 2,450 | 550 |

Source: ICF

**Table B-4: Technical Potential for 10-50 kW Micro-CHP in California, by Application**

| Application | Sites | Capacity (MW) |
|---|---|---|
| Restaurants | 33,297 | 905 |
| Retail Stores | 22,105 | 489 |
| Office Buildings | 20,745 | 400 |
| Laundries | 7,675 | 181 |
| Other Commercial/Institutional | 3,619 | 69 |
| Government | 3,736 | 81 |
| Food Sales | 3,483 | 96 |
| Nursing Homes | 2,723 | 66 |
| Hotels | 2,136 | 54 |
| Airports | 1,511 | 33 |
| Multi-Family | 1,398 | 29 |
| Schools | 1,326 | 38 |

Source: ICF

**Table B-5: Technical Potential for 10-50 kW Micro-CHP in California, by Utility Service Territory**

| Electric Utility | Sites | Capacity (MW) |
|---|---|---|
| Pacific Gas & Electric Co | 39,739 | 944 |
| LADWP | 25,999 | 618 |
| Southern California Edison | 22,885 | 543 |
| San Diego Gas & Electric | 9,395 | 222 |
| Sacramento Munic Utility Dist | 3,726 | 89 |
| Other | 1,886 | 45 |

Source: ICF

# APPENDIX C: Expected California CHP Market Adoption Data

**Table C-1: Cumulative Market Adoption for 50 kW to 5 MW CHP in California, by Year and Utility Territory**

| Utility | 2022 | 2027 | 2032 | 2037 |
|---|---|---|---|---|
| LADWP | 15.3 | 48.9 | 64.5 | 66.4 |
| PG&E | 212.3 | 717.9 | 944.8 | 970.8 |
| SMUD | 6.4 | 22.6 | 30.3 | 31.3 |
| SDG&E | 42.6 | 144.2 | 188.4 | 193.3 |
| SCE | 32.3 | 143.8 | 199.8 | 207.3 |
| Other Utilities | 28.3 | 92.5 | 120.7 | 124.1 |

Source: ICF

**Table C-2: Cumulative Market Adoption for 10-50 kW Micro-CHP in California, by Year and Utility Territory**

| Utility | 2022 | 2027 | 2032 | 2037 |
|---|---|---|---|---|
| LADWP | 3.1 | 16.9 | 35.2 | 41.1 |
| PG&E | 55.6 | 175.9 | 250.0 | 266.7 |
| SMUD | 0.6 | 1.9 | 3.0 | 3.5 |
| SDG&E | 1.3 | 11.8 | 21.0 | 23.5 |
| SCE | 0.0 | 0.0 | 0.0 | 0.2 |
| Other Utilities | 0.3 | 1.1 | 1.9 | 2.2 |

Source: ICF

# APPENDIX D: Project Technology and Knowledge Transfer Activities

## Overview

The target audience of the results of this project are regulators, hardware vendors, project developers, technology RD&D professionals, utility account representatives, and policy analysts. This report provides the project team's dissemination activities of the results to the broader public. In summary, the project team shared results of the project through the following venues during the course of the project:

- Two stakeholder workshops
- Two Technical Advisory Committee (TAC) meetings
- Speaking opportunities at outside conferences
- Published documents prepared for public dissemination
- Presentation materials
- Photographs
- Technology and Knowledge Transfer Final Report

During the project, the technology transfer activities in accordance with the Technology and Knowledge Transfer Plan were reported in the monthly progress reports.

## Stakeholder Workshops

The project team held two workshops hosted by SoCalGas at the Energy Resource Center (ERC) in Downey, California, open to the general public between 2017 and 2018. Objectives of the workshops included sharing results of the technology and market assessment and obtaining feedback from the public, key decision-makers, and other interested stakeholders on project efforts.

- Workshop #1 was held on August 21, 2017 in Downey, California.
- Workshop #2 was held on March 21, 2018 in Downey, California.

## Technical Advisory Committee

Technical Advisory Committee (TAC) members provided guidance on the direction of the project, provided input on the draft written reports and stakeholder workshop material, and were notified when final reports are released. In addition to periodic phone calls, TAC members were engaged through two in-person meetings following the two stakeholder workshops:

- TAC Meeting #1 was held on August 21, 2017 in Downey, California in conjunction with the first stakeholder workshop on the same day.
- TAC Meeting #2 was held on March 21, 2018 in Downey, California in conjunction with the second stakeholder workshop on the same day.

The TAC is made up of 10 individuals (Table D-1).

**Table D-1: Technical Advisory Committee**

| TAC Member | Organization |
|---|---|
| Adam Robinson | Solar Turbines |
| Bill Martini | Tecogen |
| Brittany Westlake | EPRI |
| Carol Denning | NRG |
| Hugh Merriam | PG&E |
| Paul Fukumoto | Fuel Cell Energy |
| Shawn Jones | Center for Sustainable Energy |
| Steven Acevedo | Regatta Solutions |
| Steve Hall | Western Energy (GE Jenbacher) |
| Tim Kingston | Gas Technology Institute |

Source: ICF Analysis

## Speaking Opportunities at Outside Conferences

During this project, the project team took advantage of opportunities while presenting at different conferences to share results of the project and announce the dates of the stakeholder workshops. These conference speaking opportunities included the following:

- ICF presentation at the CHP Association 2017 CHP Policy Forum, October 11, 2017.
- Cogeneration Day 2017, November 2, 2017.
- PowerGen 2017, December 6, 2017.
- Energy Solutions Center, Technology and Market Forum, March 1, 2017.
- Project team presentations at the SoCalGas Distributed Generation / Combined Heat & Power Seminar, March 20, 2018.
- California Clean DG Coalition (CCDC) is planning to include Flex CHP on its advocacy agenda for 2018.

## Published Documents Prepared for Public Dissemination

Project Fact Sheets were developed to describe the project issues and benefits and ultimately the results of the project analysis.

- The project team completed an initial Project Fact Sheet in April 2017 that described the project.
- The project team completed a final Project Fact Sheet in May 2018 that discussed the results of the project.
- The project team created three additional Fact Sheets in June 2018 that summarize the key project results included in the Final Project Report.

Final Project Report

- The project team completed a Final Report in June 2018 to disseminate the results of the project, to be released by the California Energy Commission.

## Presentation Materials

The presentation materials for the two stakeholder workshops were shared with attending and interested stakeholders, as well as submitted to the project CAM, for their records. The titles of the workshop presentations are below:

- CHP Workshop 21 Aug 2017.pdf
- CHP Workshop 21 March 2018 Presentation Slides.pdf

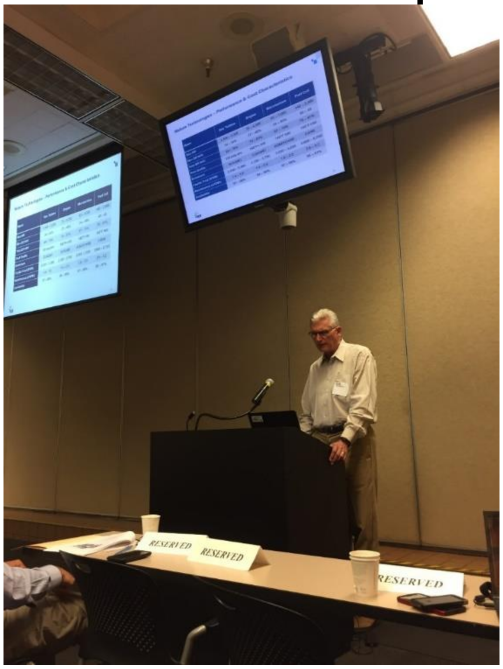
## Photographs

On September 29, 2017, the project team submitted eight photographs from the August 2017 stakeholder session and figures developed for the Final Task 2 Technologies and Applications Report.

The eight images on the following pages include:

- Figure D-1 – Stakeholder Workshop (presentation)
- Figure D-2 – Stakeholder workshop (panel discussion)
- Figure D-3 – Stakeholder workshop (audience)
- Figure D-4 – Mature CHP Technologies
- Figure D-5 – Micro-CHP Technologies
- Figure D-6 – Micro-CHP Commercial and Emerging Products
- Figure D-7 – Exhaust Fired Double-Effect Absorption Chiller
- Figure D-8 – Single Stage Absorption Chiller

**Figure D-1: Stakeholder Workshop - Presenter**




**Keith Davidson – Presenter**

Source: ICF

**Figure D-2: Stakeholder Workshop – Panel Discussion**

Source: ICF

## Figure D-3: Stakeholder Workshop – Audience


Source: ICF

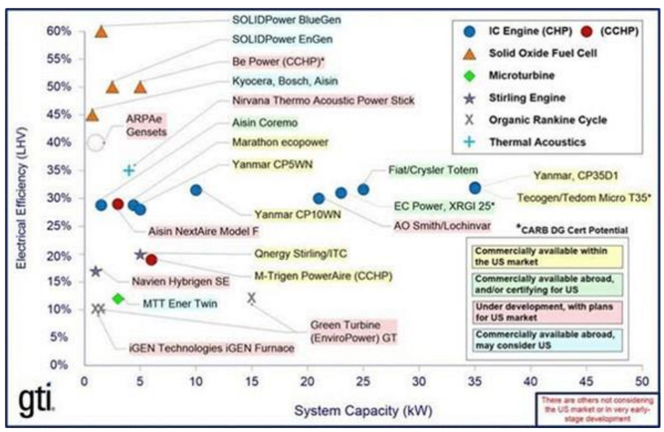
## Figure D-4: Mature CHP Technologies


Source: ICF

## Figure D-5: Micro-CHP Technologies


Source: ICF

## Figure D-6: Micro-CHP Commercial and Emerging Products

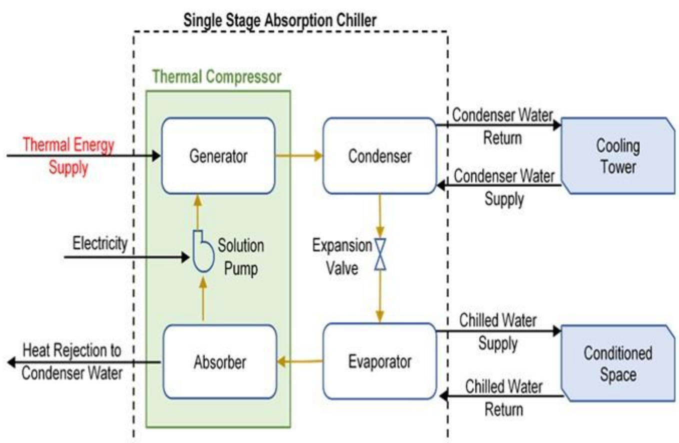



Source: GTI

**Figure D-7: Exhaust Fired Double-Effect Absorption Chiller**

Source: ICF

**Figure D-8: Single Stage Absorption Chiller**




Source: ICF

# Technology and Knowledge Transfer Plan Schedule

## Table D-1: Activities and Deliverables

| Activities and Deliverables | 2017 | | | | | | | | | | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J |
| Stakeholder Workshops | | | | | | ★ | | | | | | | ★ | | | |
| Fact Sheets | | ★ | | | | | | | | | | | | | ★ | |
| Final Report | | | | | | | | | | | | | | | | ★ |
| TAC Meetings | | | | | | ★ | | | | | | | ★ | | | |
| Conference Speaking Opportunities | | | | | | | | ★ | ★ | ★ | | | ★ | | | |
| Presentation Materials | | | | | | ★ | | | | | | | ★ | | | |
| Photographs | | | | | | | ★ | | | | | | | | | |
| Technology & Knowledge Transfer Report | | | | | | | | | | | | | | | | ★ |

Source: ICF

# APPENDIX E:
# Workshop Summaries

## Purpose of Workshops

Two CHP stakeholder workshops were held on Monday, August 21, 2017 and Wednesday, March 21, 2018 in Downey, California. The purpose of the workshops was to highlight the scope of the project, disseminate project results, and solicit input from a broader stakeholder group. This document includes the agendas of workshop topics, participants who attended the meetings in-person and virtually, and a summary of stakeholder questions and feedback received.

## August 21, 2017

### Agenda

| Time | Topic | Speaker |
|---|---|---|
| 8:30 | Check-in | --- |
| 9:00 | Welcome | Gabe Olson, SoCalGas |
| 9:05 | Perspective on Small CHP | Kevin Uy, Energy Commission |
| 9:10 | Workshop Goals and Project Overview | Rick Tidball, ICF |
| 9:30 | Overview of Small and Micro CHP Technologies | Keith Davidson, DE Solutions |
| 10:00 | Break | --- |
| 10:45 | Small and Micro CHP Technologies | Keith Davidson, DE Solutions |
| 11:15 | Applications for Small and Micro CHP | Anne Hampson, ICF |
| 12:00 | Lunch | --- |
| 12:45 | Technical and Economic Potential Estimates | David Jones, ICF |
| 1:15 | Regulations, Policies, and Barriers | Carol Denning, NRG<br>Mark Gilbreth, Regatta Solutions<br>George Simons, Itron<br>Kris Jorgensen, Al Smith Corporation |

| Time | Topic | Speaker |
|---|---|---|
| | | Keith Davidson, DE Solutions |
| 2:15 | Next Steps and Closing Remarks | Rick Tidball, ICF |
| 2:30 | Adjourn | --- |

## Summary of Stakeholder Feedback during the Q&A Sessions

The following provides a summary of the Q&A sessions with stakeholders following the presentations. The questions are recorded without attribution.

*Applications for Small and Micro CHP*

- Q: When discussing the potential in office buildings, is that assuming cooling with absorption chillers?
    - A: The project team is assuming that cooling is being used. It is especially important for office buildings and data centers. When the project team looks at economics later in the study, it may change the results on the potential.
- Q: For market segment micro-CHP, what are the key barriers from the policy/market perspective of the technologies presented? For the sectors the project team analyzed, what is the payback/break even for Southern California?
    - A: Economics due to high system cost are the primary barrier to micro-CHP. Unless there is equipment progress, micro-CHP will always be difficult. Interconnection is also a barrier for all CHP. As for payback, there is a large variation in what folks will accept. For industrial CHP, you want a quick payback period, 3 to 5 or even below 3 years. Hospitals/Universities are more willing to accept longer payback, (i.e., about 7 to 10 years). Other reasons, like desiring reliability or sustainability, will allow for acceptance at a lower return on investment (ROI).
- Q: Has there been any work been done regarding incentives in CA, specifically to level the playing field against solar?
    - A: Solar incentives get a large range of buy-in from stakeholders. CHP does not get as heavily subsidized as solar for that reason. California has good interconnection standards, up to 20 MW. California also has SGIP and feed-in tariff for CHP. Policy considerations will be considered further later in the study.

*Technical and Economic Potential Estimates*

- Q: Will the project team capture multi-family residential and zero net energy (ZNE) goals, and how they will affect CHP going forward?
    - A: Yes, the project team plans to look at both multi-family residential and ZNE goals.
- Q: Did the project team consider cooling and thermal storage in your analysis?
    - A: The analysis will be done at a pretty high level in how CHP can be applied to different applications, operating hours, and thermal/electric requirements. Individual site load profiles are where you would apply storage considerations, but it is not part of this market analysis.
- Q: Regarding adoption rates based on payback periods, how did the project team develop the adoption rate for the Base model?
    - A: The numbers were originally derived from databases. The curves were modified based on feedback and interviews from manufacturers.
- Q: How would residential economics be affected by time-of-use rates, which are becoming standard in 2019?
    - A: The project team hasn't gotten into the rate analysis part of the study yet, that will come from the economic potential estimates. The project team will definitely take a look at changing the rates, and residential rates will be considered. Time of use (TOU) will improve economics for CHP. A lot of different rates could affect residential rates.
- Q: Did the project team look at volume production rates versus cost for a baseline?
    - A: That has not factored into the Bass curves at this point. The project team is willing to discuss further offline.
- Q: Will the project team look at actually turning devices on and off, and how the cycles affect the CHP system maintenance/lifetime?
    - A: Maintenance costs are based on per kWh operation. The project team could take a deeper look into those that shut down at night, and determine if $/kWh should be adjusted for maintenance. As the project team moves into the market assessment part of the analysis, the team can look into making that adjustment.

*Regulations, Policies and Barriers*

The following are key takeaways from the panel discussion on regulations, policies, and barriers.

- Some stakeholders feel that policy incentives are not supportive of CHP in California, and the industry needs to work towards increasing CHP adoption without incentives.
- Some stakeholders agreed that the number one barrier is departing load charge and discussed ways the industry can work together to get rid of this barrier that results in a lack of incentives and a penalty.
- Stakeholders discussed the potential for biogas CHP projects and examples of successful projects in the state.
- NYSERDA's programs for CHP were referenced by multiple stakeholders as being a successful for California. NYSERDA provides a catalog of CHP technologies where manpower does not need to be dedicated to screening the technologies. This helps to streamline the interconnection process.
- The group discussed how the California Energy Commission is considering adding CHP back into Title 24 standards. It was discussed that there is a need to educate the governor's office on the value of CHP.
- Stakeholders discussed the potential of CHP to reduce CHG emissions.

## Next Steps

- The next CHP stakeholder workshop will be scheduled around March 2018 when the project team will present modeling results.
- Stakeholders were invited to contact the project team with any remaining questions or comments regarding the project.

## March 21, 2018

### Agenda

| Time | Topic | Speaker |
|---|---|---|
| 8:30 | Check-in | --- |
| 9:00 | Welcome | Rosalinda Magana, SoCalGas |
| 9:10 | Update on California Energy Commission Micro-CHP Research Portfolio | Kevin Uy, Energy Commission |
| 9:20 | Workshop Goals and Project Overview | Rick Tidball, ICF |
| 9:30 | California Market Assessment for Small and Micro-CHP Technologies | Anne Hampson & David Jones, ICF |
| 10:30 | Break | --- |
| 10:40 | Perspective on Micro-CHP Technologies | Tim Kingston, GTI |
| 11:20 | Perspective on CHP Applications | Carol Denning, NRG |
| 12:00 | Lunch | --- |
| 12:15 | CHP Integration Issues and Barriers | Keith Davidson, DE Solutions |
| 1:15 | Open Discussion | --- |
| 1:45 | Next Steps | Rick Tidball, ICF |
| 1:50 | Closing Remarks | Rizaldo Aldas, Energy Commission |
| 2:00 | Adjourn | --- |

### Summary of Stakeholder Feedback during the Q&A Sessions

The following provides a summary of the Q&A sessions with stakeholders following the presentations. The questions are recorded without attribution.

*Update on California Energy Commission Micro-CHP Research Portfolio*

- **Q**: Where are the majority of the Energy Commission projects?
  - **A**: The preference has been in Southern California for the last couple of solicitations.

*California Market Assessment for Small and Micro-CHP Technologies*

- **Q**: What is the cost of the 1.5 kW CHP system used in the analysis?
    - **A**: $14,000 dollars/kW installed for 1.5kW SOFC ($21k total) based on what the project team found in the Task 2 analysis.
- **Q**: What were the assumptions used for this analysis?
    - **A**: The project team outlined some of them in the Task 3 Report and will provide a more detailed list in the Final Report.
- **Q**: What work has been done on CHP with PV/Storage where the daily usage is <5 kWh electricity per day?
    - **A:** There has been no work done as <5 kWh has been too small. The Final Report will have a chart with the technology breakdown for existing <5 MW CHP (chart currently available in Task 3 Report)
- **Q**: What is the penetration of turbines verses engine based technologies in the <5 MW range, and how does that compare with the larger MW size range?
    - **A**: >5 MW would be nearly all gas and steam turbines, with a small percentage of engines.

*Perspective on Micro-CHP Technologies*

- **Q**: Are there other <10 kW systems GTI is missing? Have you spoken with people at places like Achates Power, Qnergy, ITC, etc.?
    - **A**: Yes, GTI has collaborated with others on projects and will continue to do so.
- **Q**: Do any of the CHP systems have cooling?
    - **A**: M-Trigen 6 kW engine (health clubs or full restaurants)
- **Q**: Is energy storage integration in any of the GTI projects?
    - **Q**: GTI intends to test storage at the micro-CHP test lab at GTI Illinois. GTI has not spent extensive time researching storage scenarios, but is interested in understanding how CHP can be used in a PV and storage system.

- **Q**: $14,000 dollars/kW was thrown out for a fuel cell during the previous presentation. Is that what GTI is presenting here? This is for the residential market? $14k seems a bit steep.
  - **A**: An established market will drive value. GTI understands the economic challenges and believes costs will become cheaper, just as PV became cheaper.

*Perspective on CHP Applications*

- **Q**: For the Princeton Medical Center mentioned as the case study during the presentation, can you talk more about how the system is optimized?
  - CHP cuts new building's costs by 25%, reduced GHGs by 50%
  - Offers ancillary services – frequency response
  - CHP ramps down depending on grid needs – load following
  - Has >1 million gallon thermal energy storage
  - Even though the parking lot is covered with storage, it is a minor amount of what we are producing
  - As with all projects, NRG sizes to the thermal load (steam, hot/chilled water)

*CHP Integration Issues and Barriers*

- **Q**: Power quality and power reliability are missing in the analysis, but why isn't SoCalGas lobbying more for CHP?
  - **A**: Reliability is included in the analysis. The California Clean DG Coalition is active in legislative affairs in Sacramento and many audience members are active in the Coalition. SoCalGas supports CHP but has political and economic limitations.
- **Q**: Is there a reactive power tariff in California?
  - **A**: There is not an established tariff. There was an LADWP project where 25 MW of generators provided VARs, but this was a one-off.
- **Q**: Does flexible (flex) CHP imply engines or turbines that can turn on and off pretty efficiently?
  - **A**: Some of the older, larger ones would have trouble turning on and off, but they all have the ability to be turned on and off, when needed.

- **Q**: What are good resources for how CHP can operate flexibly? Will the project team's analysis include addressing the duck curve?
  - **A**: There is a storage analysis from CAISO; the StorageVET tool from EPRI; PG&E has RFOs where CHP could bid in and be eligible which some have done; US DOE did analysis in 2017 on CHP flex analysis which started with California. A lot more work still needs to be done to address the duck curve and flex CHP.
- **Q**: **1)** Will biomethane and CHP be eligible RPS generation? **2)** How much biomethane is produced to power CHP or is it all spoken for? **3)** Is CHP an unlikely renewable?
  - **A1**: Yes, renewable energy under RPS
  - **A2**: Biomethane is primarily being used for transportation
  - **A3**: Biomethane for CHP is limited by availability through the pipes. On-site renewable generation is very common, especially with municipalities.

*Open Discussion Feedback*

- **Q:** What technology advancements would help with new CHP?
  - Flexible operation of CHP, as mentioned previously
  - Emission reduction technologies
  - Standard form factor, modular CHP in units of 500 watts could be promising for flexibility
  - (Policy) Applying the same treatment as fuel cells – net energy metering for 5 MW and below
  - (Policy) SGIP needs to de-emphasize storage or re-evaluate the program, as it can be an effective storage mechanism if used properly
  - (Policy) SGIP needs to come back with a biogas adder, instead of a requirement
  - (Policy) Carbon tax credits should apply to CHP for when it displaces GHGs (i.e. when you replace a boiler with CHP)
- **Q:** What applications for CHP are under served in California (hospitals mentioned previously)?

- There is an opportunity to convert wastewater to clean water applications to be used for irrigation for golf courses

- **Q**: What projects could the California Energy Commission fund that could have the greatest impact on CHP?
    - (Policy) Increase AB 1613 rates as they are too low to justify very many projects being built ($0.04 to $0.08/kWh swing)
    - (Policy) Make all energy policy technology neutral and incentivize based on lowest emissions level for a given technology, allowing the industry to determine which technologies to use
    - (Policy) Tariff 1613 would be better if it considered CHP "green energy"
    - (Policy) Biogas is all going to renewable fuels; those that aren't are going straight to electricity to the grid for BioMAT – not much available for CHP
    - (Policy) Should use a BioMAT-like pricing model
    - Feedback from manufacturers – afraid CARB might change DG certification regulations after they (manufacturers) have invested in meeting the standards.

## Next Steps

- Stakeholders were invited to contact the project team with any remaining questions or comments regarding the project.
- The project is set to conclude in May 2018 with a Final Report.

## Participants

The following documents the participants captured through Skype and sign-in sheets at the Energy Resource Center in Downey, California for the two workshops (Table E-1).[80]

**Table E-1: Workshop Participants**

| Participant | Organization | Attendance 8/21/17 | Attendance 3/21/18 |
|---|---|---|---|
| McKinley Addy | AdTra | Phone | |
| Nick Connell | Advanced Microgrid Solutions | In-person | |
| Kris Jorgensen | A.O. Smith Corporate Technology Center | Phone | Phone |
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[80] Additional unidentified callers may have participated but did not identify themselves.

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| TAC Members | Organization | Attendance/Alternate | |
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| Bill Martini | Tecogen | | In-person |
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| Project Team | Organization | Attendance | |
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| Dale Fontanez | SoCalGas | In-person | In-person |
| Cherif Youssef | SoCalGas | In-person | In-person |
| Jim Kerrigan | SoCalGas | In-person | In-person |
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| Rod Hite | ICF | In-person | In-person |
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| David Jones | ICF | Phone | Phone |

# APPENDIX F: Recommended Resources

To advance discussions around increasing adoption of small CHP systems in California, the project team encourages collaboration between all parties. Listed are useful resources to advance the discussions.

California Energy Commission. Combined Heat and Power website. http://www.energy.ca.gov/chp/

California Energy Commission. Co*mbined Heat and Power: Policy Analysis and 2011-2030 Market Assessment.* Prepared by ICF International. February 2012. CEC-200-2012-002. http://www.energy.ca.gov/2012publications/CEC-200-2012-002/CEC-200-2012-002.pdf

Hedman, Bruce, Ken Darrow, Eric Wong, Anne Hampson. ICF International, Inc. 2012. *Combined Heat and power: 2011-2030 Market Assessment.* California Energy Commission, CEC-200-2012-002. 2012.

Jones, David, and Meegan Kelly. ICF. Supporting Grid Modernization with Flexible CHP Systems. November 30, 2017. https://www.icf.com/resources/white-papers/2017/supporting-grid-modernization-with-flexible-chp-systems

Jones, David and Rick Tidball, ICF. *CHP for Microgrids: Resiliency Opportunities Through Locational Analysis.* June 2016. https://www.icf.com/resources/white-papers/2016/chp-for-microgrids-resiliency-opportunities-through-locational-analysis

U.S. Department of Energy. Combined Heat and Power. Website: https://betterbuildingssolutioncenter.energy.gov/chp

U.S. Environmental Protection Agency. *Catalog of CHP Technologies.* September 2017. https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf

U.S. Department of Energy. *Combined Heat and Power: A Clean Energy Solution.* August 2012. https://www.energy.gov/sites/prod/files/2013/11/f4/chp_clean_energy_solution.pdf

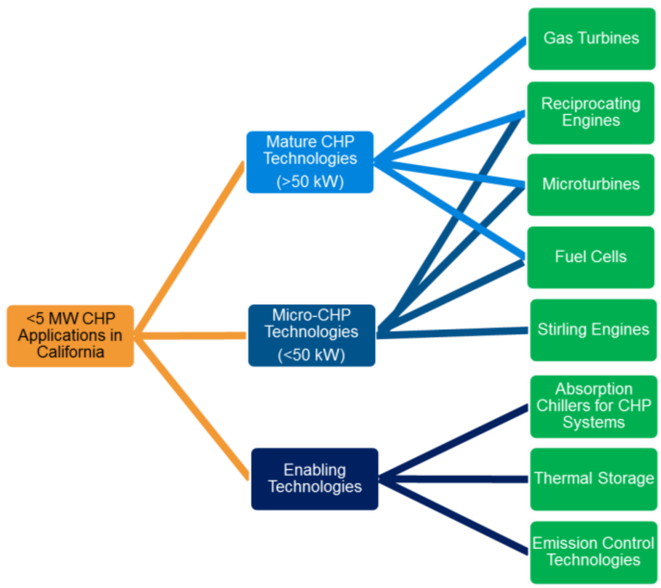
U.S. Department of Energy. *Combined Heat and Power (CHP) Technical Potential in the United States*. March 2016. https://doe.icfwebservices.com/chpdb/

U.S. Department of Energy. *Modeling the Impact of Flexible CHP on California's Future Electric Grid.* January 2018. https://www.energy.gov/sites/prod/files/2018/01/f47/CHP%20for%20CA%20Grid%201-18-2018_compliant.pdf

# APPENDIX G:
# Fact Sheets

This appendix provides summary fact sheets which condense the findings of the report chapters into four fact sheets: 1) Identifying and Characterizing Small CHP Technologies, 2) Technical, Economic, and Market Potential for CHP Applications in CA, 3) Integration Issues, Barriers, and Recommendations, and 4) Combined Heat and Power Technology Recommendations.

**Figure G-60: CHP Technology Categories**




## Identifying and Characterizing Small CHP Technologies

The *Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California* identifies, characterizes, and assesses combined heat and power (CHP) technologies and applications under 5 MW in size for residential, commercial, and light industrial markets in California. In this Fact Sheet, cost and performance data are presented for mature (>50 kW) CHP technologies, enabling technologies for CHP systems, and emerging micro-CHP technology options for potential <5 MW CHP applications I the California market.

## CHP Technologies: <5 MW

California accounts for 10% of the United States' installed CHP capacity, with 8,500 MW of operational CHP systems. While large industrial and institutional CHP installations account for most of this capacity, about 8% (663 MW) of the installed capacity comes from systems under 5 MW in size.[81] Yet approximately 7,000 MW out of the remaining 11,500 MW of remaining technical potential for CHP in California reside in applications less than 5 MW in size.

## Mature CHP Technologies

**Gas turbines** are available in sizes ranging from 3 MW to more than 300 MW and are used to meet diverse power needs, including propulsion (e.g., aircraft, ships, and trains), direct drive (e.g., pumps and compressors) and stationary electricity generation. Simple cycle combustion turbines are common for large industrial CHP applications, but they are not as economically viable in sizes under 5 MW. Combustion turbines can produce medium or high pressure steam, and when paired with supplemental exhaust firing, they can generate incremental steam at much higher efficiencies than a stand-alone boiler. Fitted with low-NOx combustors, selective catalytic reduction (SCR) and an oxidation catalyst, gas turbines can achieve very low emission levels, and they are capable of meeting the strictest emission standards in California.

**Reciprocating internal combustion engines (ICE)** are a mature technology used for power generation, transportation, and many other purposes. Reciprocating internal combustion engines (ICE) are the most common technology for small CHP installations, available in sizes from below 5 kW to over 5 MW. Most commercially available ICEs fall in the range of 100 kW to 2 MW. ICEs tend to have higher electric efficiencies and lower installed costs than turbines and microturbines. However, they generally require more maintenance than competing CHP technologies, which increases operating costs and lowers system availability. With emission control technologies, ICEs have kept pace with California's ever tightening emission standards, the most notable of which is South Coast Air Quality Management District's (SCAQMD) Engine Rule.[82]

**Microturbines** are small single-stage combustion turbines under 350 kW in size, although multiple microturbines can be combined in a single container for larger systems. Microturbines are typically equipped with recuperators to overcome the inherently low simple cycle efficiencies in small sizes. Microturbines generally require infrequent maintenance and have high availability. Because they operate at modest combustor temperatures and pressures, these systems can meet California emission regulations with low NOx combustors and usually do not require exhaust after-treatment.

**Fuel cells** use an electrochemical process to convert the chemical energy in a fuel to electricity. In contrast to reciprocating engines and gas turbines, fuel cells generate electricity without combusting the fuel and have relatively high electric efficiencies and inherently low emissions. Fuel cells have the highest capital and maintenance costs of

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[81] U.S. DOE Combined Heat and Power Installation Data Base, https://doe.icfwebservices.com/chpdb/

[82] SCAQMD Rule 1110.2: https://www.arb.ca.gov/energy/dg/dg.htm

all the CHP technology options and generally have high availability with proper and well maintained fuel conditioning.

Table 55 provides an overview of the performance and cost characteristics of the mature market technologies in the 50 kW to 5 MW size range.

**Table G-65: Performance and Cost Characteristics (50 kW – 5 MW)**

| Metric | Gas Turbine | Engine | Microturbine | Fuel Cell |
|---|---|---|---|---|
| Size kW | 3,300 – 5,200 | 75 – 4,300 | 62 – 1,000 | 440 – 2,800 |
| Elec Eff HHV[83] | 24 – 34% | 28 – 40% | 24 – 30% | 40 – 43 |
| Total Eff HHV | 64 – 76% | 74 – 81% | 67 – 73% | 76 – 81% |
| Heat Quality | 150 psig steam | 180°F+ HW[84] | 140°F HW | 140°F HW |
| Emissions | SCAQMD | SCAQMD | SCAQMD/ CARB | CARB |
| Capital Cost ($/KW) | 2,430 – 3,580 | 2,100 – 3,750 | 2,950 – 3,550 | 3,600 – 6,700 |
| Maintenance (¢/KW | 1.4 – 1.9 | 1.4 – 2.4 | 1.8 – 2.0 | 2.6 – 3.2 |
| Availability | 97 – 98% | 94 – 96% | 97 – 98% | 95 – 97% |

Source: Obtained by surveying active California CHP product suppliers

## Enabling Technologies

Enabling technologies are supplemental technologies that can improve CHP heat utilization, which would otherwise constrain system size and/or capacity factor of the system.  This is a particularly important issue for California with its moderate climate and short space heating season.  Also, because of California's unique and aggressive emission regulations, affordable emission control technologies are critical for CHP.

**Absorption Cooling.** Absorption chillers use heat to generate chilled water.  This heat can come directly from a fueled burner or the recovered thermal energy from the operation of a prime mover such as reciprocating engines, combustion turbines or fuel cells.  Hot exhaust gases, medium pressure steam (greater than 100 psig), low pressure steam (15 psig or greater) and hot water (200 - 240°F) can all provide heat to an absorption chiller.  Absorbers are characterized as single effect or double effect.  Single effect absorption chillers take lower quality heat such as low-pressure steam or hot water and produce chilled water.  Double effect machines require higher quality heat to produce chilled water more efficiently than single effect machines.

**Thermal Storage**.  Small and micro-CHP systems often serve residential and light commercial applications that have highly variable thermal demands driven by domestic

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[83] HHV – Higher Heating Value of natural gas

[84] HW – Hot Water

hot water (DHW) usage patterns. Hot water storage and/or thermal load following is essential to achieve high thermal heat utilization from many of these smaller CHP systems. Sizing of the thermal storage systems can vary considerably from site to site. Hot water storage tanks are typically off-the-shelf equipment. A double wall heat exchanger generally separates the prime mover heat recovery loop from the domestic hot water (DHW) tank. The heat exchanger can be immersed in the hot water tank or it can be located external to the tank. Installed costs for a thermal storage system are in the $20 – $35/gallon range.

Chilled water storage systems can add significant economic value to a facility's energy system. They can reduce peak electric demand, participate in utility demand response programs, reduce the amount of chiller equipment, and serve the facility during grid outages. When used in conjunction with CHP and an absorption chiller, excess chilled water can be produced and stored at night at relatively low cost, and then dispatched during during peak demand periods when the value of chilled water is relatively high.

**Emission Control Technologies.** There are three primary sets of regulations that have shaped CHP emission requirements in California: Best Available Control Technology (BACT), California Air Resources Board Distributed Generation (CARB DG) Certification and South Coast Air Quality Management District (SCAQMD) Engine Rule 1110.2. Recent ICE, combustion turbine, microturbine and fuel cell installations have either received SCAQMD permits or have been CARB DG certified. CARB DG certification, the standard with the lowest emission requirements, is not applicable for current ICE and combustion turbine products as they are permitted by the local air pollution control districts.

## Micro-CHP

**Micro-CHP products**, defined to have a capacity smaller than 50 kW for purposes of this assessment, have emerged in recent years. Micro-CHP technology options include ICEs, microturbines, fuel cells, Stirling engines, and other emerging technologies. Micro-CHP products are designed for residential and small commercial markets. These markets are driven by relatively high energy prices and some benefits from incentives such as tax credits, capital cost subsidies, net energy metering, and low interest loans. Worldwide, there are more than twenty micro-CHP products that are available or emerging in the market.

Micro-CHP equipment has been commercially available for well over a decade, and worldwide sales have approached 300,000 units. Japan accounts for 80% of the volume, Europe accounts for 15%, and the U.S. only accounts for 0.2% of micro-CHP sales.[85] There are some micro-CHP products currently available in North America and several other manufacturers are in the process of certifying their products for the

[85] MicroCogen Partners LLC. Current Economic Outlook for mCHP. Technology to Policy mCHP "Status" Workshop. Philadelphia, PA. June 2017.

market. Micro-CHP products currently available in North America include the Marathon 4.4 kW ICE, the Yanmar 5 kW and 10 kW ICE units, the EC Power 19 kW ICE module, the Tedom 35 kW ICE package and the Capstone 30 kW microturbine. In some cases, manufacturers are seeking volume commitments in North America to justify start-up expenses. These manufacturers include Solid Power (1.5 kW, 6 kW and 12 kW BlueGen solid oxide fuel cells (SOFC)) and Ametek (1 kW Sunpower Stirling engine).

Representative micro-CHP products that could serve California are shown in Table 56 along with their performance and cost characteristics. They all employ condensing heat recovery which produces hot water at temperatures around 140°F, and all achieve high overall efficiencies. Although none have obtained CARB DG[86] certification to-date, they are all considered capable of acquiring the certification, with emission control technologies required for some technologies.

**Table G-66: Representative Micro-CHP Technologies**

| Description | SOFC[87] | Stirling Engine[88] | Rich-Burn ICE | Rich-Burn ICE | Microturbine |
|---|---|---|---|---|---|
| Net Electric Power (kW) | 1.5 | 1.0 | 4.4 | 19.2 | 28 |
| Fuel Input (Btu/hr, HHV) | 9,426 | 9,425 | 71,800 | 233,100 | 420,000 |
| Useful Thermal (Btu/hr) | 2,356 | 3,412 | 42,200 | 130,000 | 210,000 |
| Heat Quality | 140°F HW | 140°F HW | 140°F HW | 140°F HW | 140°F HW |
| Electric Efficiency (%, HI | 54.3% | 36.2% | 20.9 | 28.1% | 22.7% |
| Overall Efficiency (%, HH | 79.3% | 72.4% | 79.7% | 83.9% | 72.7% |
| Installed Cost ($/kW) | $14,000 | $7,000 | $9,000 | $5,300 | $5,025 |
| Maintenance Cost (¢/kW | 3.0 | 1.0 | 3.0 | 2.5 | 2.3 |

Source: Obtained by surveying active California CHP product suppliers

The performance and cost characteristics of both mature and micro-CHP prime mover technologies were used to perform a technical and market analysis for new CHP installations under 5 MW in size.

Additional details can be found in the following report:

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[86] California Air Resources Board (CARB) 2007 Distributed Generation (DG) Standards: https://www.arb.ca.gov/energy/dg/dg.htm

[87] With signed deployment agreements totaling 5,000 units/yr, a $4,000 module price is projected, reducing installed cost to approximately $8,000.

[88] ARPA-E development project – Prices based on production of 100,000 units.

Jones, David, Keith Davidson, Rod Hite, and Annie Howley. 2018. *A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California*. California Energy Commission. Publication Number: CEC-500-2019-030.



## Technical, Economic, and Market Potential for CHP Applications in CA

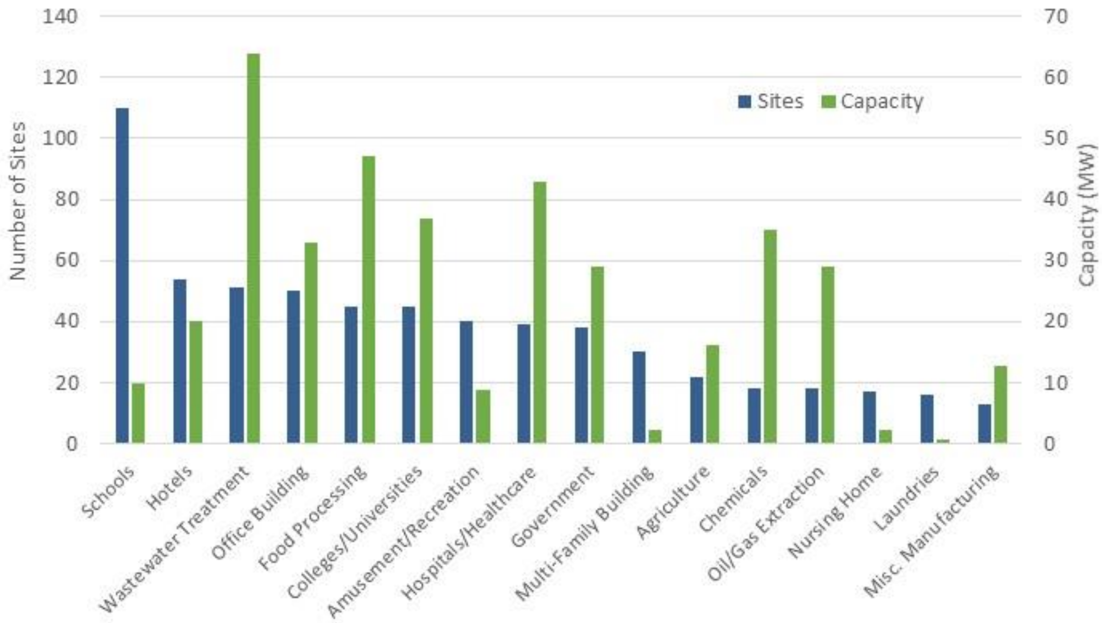
The *Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California* identifies, characterizes, and assesses combined heat and power (CHP) technologies and applications under 5 MW in size for residential, commercial, and light industrial markets in California. This Fact Sheet reviews the technical, economic, and market potential for CHP systems in California.

## CHP Applications

Potential applications for CHP consist of industrial, institutional, commercial, and residential buildings with coincident requirements for electric power and thermal energy. Industrial CHP applications represent 75% of California's current installed capacity. However, industrial facilities[89] only represent 25% of the 662 MW of installed capacity for CHP applications smaller than 5 MW. The remaining CHP capacity in the <5 MW size range primarily consists of buildings in the commercial and institutional sectors, led by wastewater treatment plants, hospitals, and colleges/universities. Figure G-2 shows the top applications for small California CHP installations by number of sites and total CHP capacity.

[89] Industrial facilities consist primarily of those in the manufacturing industries (SIC 20-39, NAICS 311-339) as well as agriculture, oil and gas extraction, and gas processing facilities.

**Figure G-2: Number of Sites and Installed Capacity (MW) for <5 MW CHP: Top Applications**




Source: U.S. DOE CHP Installation Database, July 2017

Commercial and institutional buildings, including hotels, office buildings, hospitals, and schools, tend to have smaller electric and thermal demands compared to industrial facilities. Additionally, commercial buildings tend to have lower load factors, with larger differences between peak and average loads, and more seasonal variation in their energy requirements. CHP installations are most ideal for commercial and institutional buildings with consistent electric and thermal loads that operate 24 hours a day, 7 days a week. However, applications such as office buildings and retail establishments with low nighttime loads have the potential to economically and efficiently utilize CHP during operational hours.

To date, residential CHP applications in California have been limited, with 30 installations in multifamily buildings and 12 in private residences. There is a significant amount of potential for CHP applications at large high-rise multifamily buildings in urban areas, like Los Angeles and San Francisco, but the majority of California's potential for multi-family and single-family residential applications falls in the micro-CHP category. The potential market for CHP in California's residential sector will depend on future advancements in micro-CHP technologies and their availability in the state.

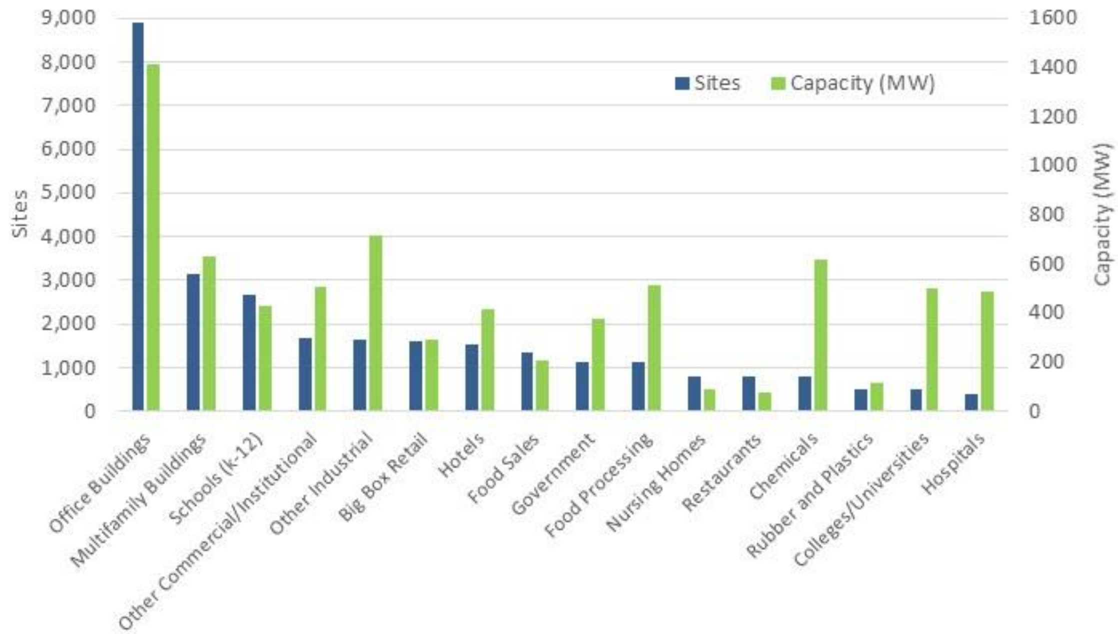
## Technical Potential for Small CHP Applications

Technical potential refers to all sites that are capable of installing new CHP systems between 50 kW and 5 MW (mature CHP technologies). Data for California sites was assembled for this analysis, including buildings in the industrial, commercial, institutional, and residential (multifamily) sectors. Overall, there is an estimated 7.4 GW of technical potential across more 28,600 sites for California CHP applications sized

50 kW to 5 MW. For traditional CHP applications 50 kW to 5 MW in size, commercial office buildings have the most technical potential in terms of both number of sites and total capacity.

California facilities with technical potential for CHP systems in the range of 50 kW to 5 MW are broken down by application type in Figure G-3.

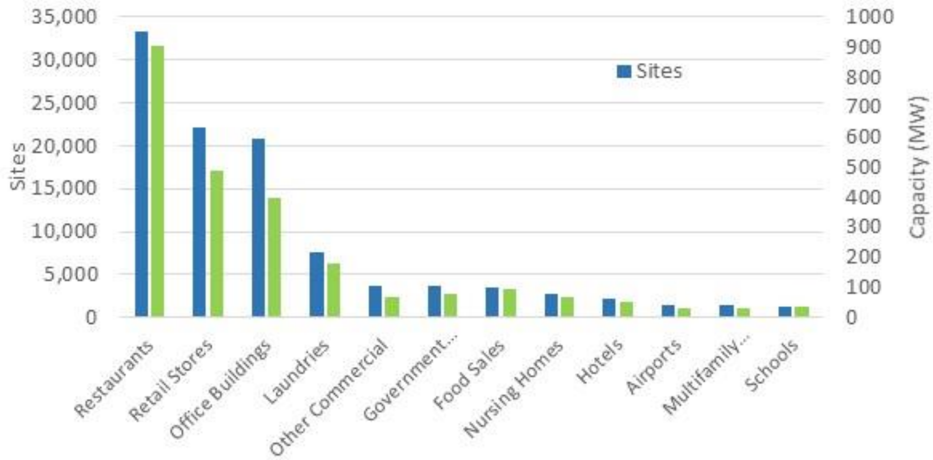
**Figure G-3: Technical Potential for Micro-CHP Applications 50 kW – 5 MW**




Source: ICF

For micro-CHP applications, excluding single family homes, the technical potential (2.5 GW total) is led by restaurants, retail stores and office buildings. The potential sites and capacity for 10-50 kW micro-CHP applications are shown in Figure G-4.

**Figure G-4: Technical Potential for Micro-CHP Applications, 10-50 kW**




Source: ICF

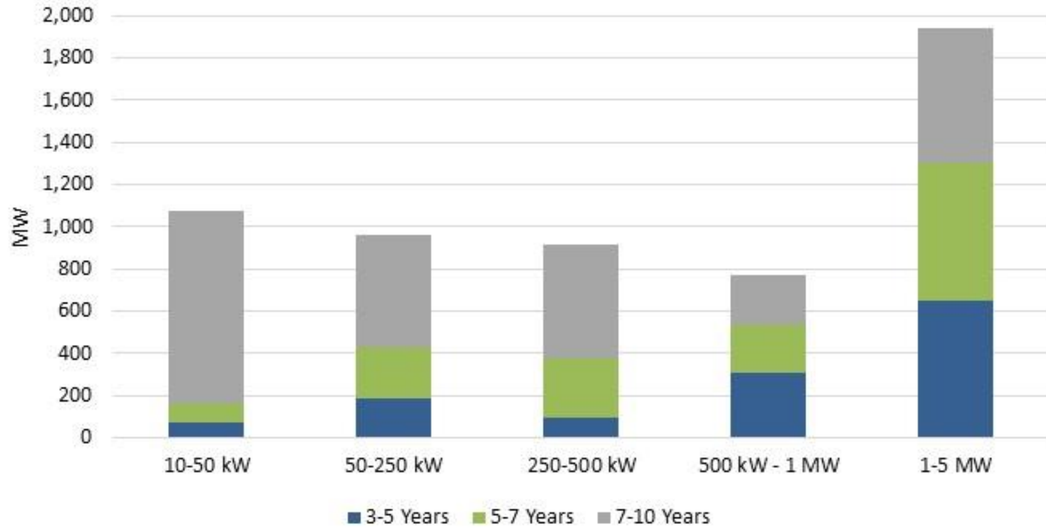
Technical potential for residential single family home CHP applications 1-2 kW in size was also considered in this market assessment. Based on the estimated number of single family homes over 3,000 square feet (considered to be the primary market for residential micro-CHP), there is close to 1 GW of technical potential at approximately 645 thousand homes. When the secondary market of 2,500-3,000 square feet homes are also considered, the technical potential for residential micro-CHP rises to 1.7 GW at over 1.1 million single family homes.

When combining the technical potential for micro-CHP and traditional CHP applications up to 5 MW, there is approximately 11.5 GW of total technical potential in California.

## Economic Potential for Small CHP Applications

Economic potential refers to all sites that are capable of installing new CHP and which could achieve a payback period of less than 10 years. The economic potential for CHP was estimated by evaluating electricity and gas rates for major California utilities, and applying them to the operational performance of CHP systems by application, using equipment cost and performance characteristics. Overall, approximately 5.7 GW of economic potential was found for California CHP applications, including 10-50 kW micro-CHP and traditional CHP installations 50 kW to 5 MW in size. In Figure G-5, the economic potential is shown by CHP size range and payback period range.

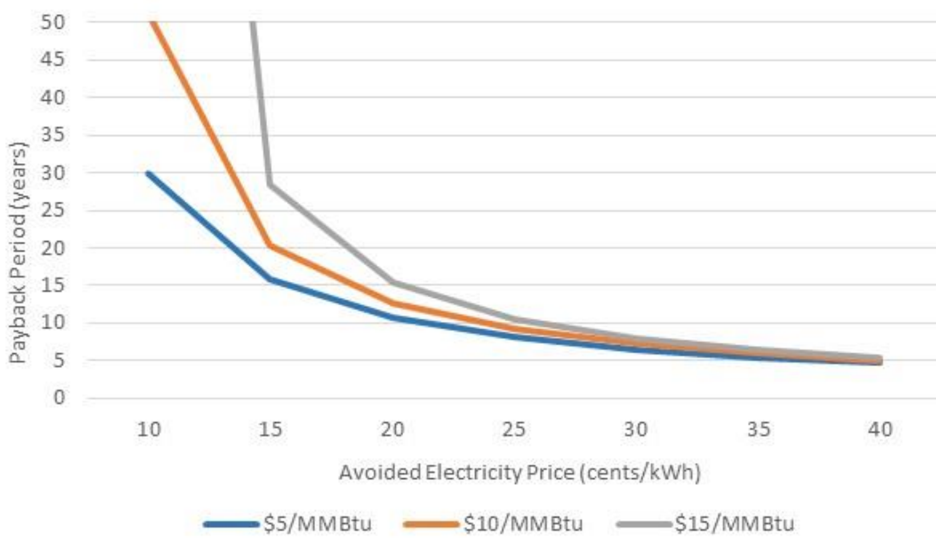
**Figure G-5: Economic Potential for Small CHP Applications in California, by Size Range**




Source: ICF

Economics for single family home CHP applications were also considered, using an emerging 1.5 kW solid oxide fuel cell identified in the analysis. Payback periods for net metering applications were calculated using different electricity and gas prices to determine where residential micro-CHP could be successful. At the current installed cost of $14,000 per kW ($21,000 total), the avoided electricity cost would need to be close to 25 cents/kWh or higher for a 10 year payback, or more than 40 cents/kWh for a 5 year payback. This is illustrated in Figure G-6.

**Figure G-6: Economics for Single Family Home CHP by Electricity and Gas Price**




Source: ICF

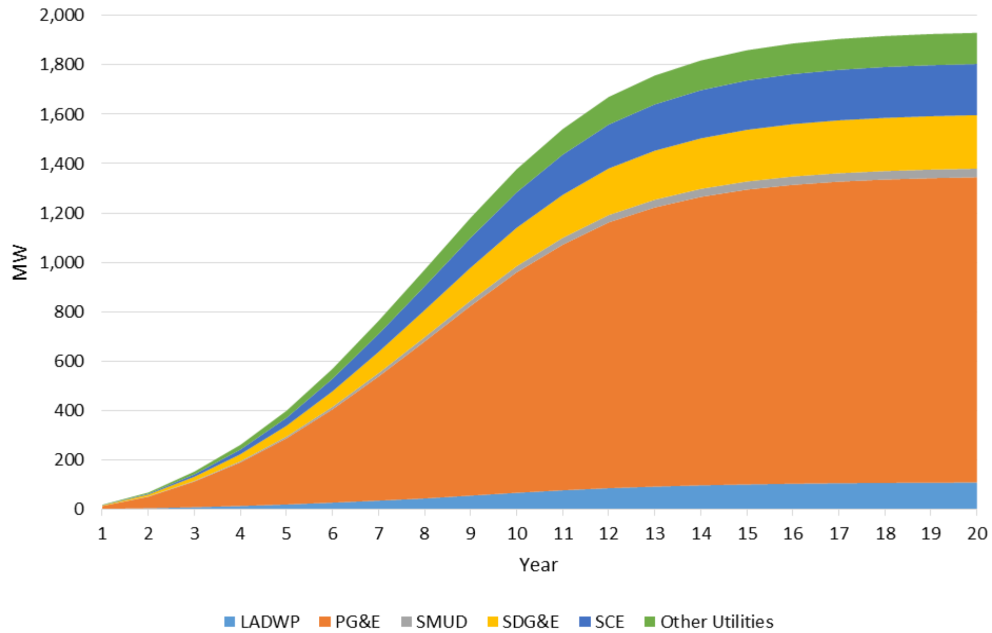
While the avoided electricity cost needs to be relatively high for single family home micro-CHP applications to be successful, average residential rates are in the vicinity of 20 cents/kWh, and some California residences can pay 40 cents/kWh for peak usage. If 1-2 kW micro-CHP systems become commercially available, and if product demand reaches a certain threshold level, installed costs could fall to $10,000/kW or below, creating a viable California residential market.

Due to variation and uncertainty with residential energy rates, and the lack of available systems, the economic potential for residential micro-CHP applications was not calculated for this market assessment. New residential time-of-use rates being adopted by California IOUs in 2019 have the potential to improve CHP economics and enable emerging micro-CHP technologies to penetrate the market.

## California CHP Market Adoption

Market potential refers to any sites which are expected to adopt new CHP systems based on economic potential and ICF's CHPower model. The results of the economic analysis were applied to ICF's CHPower adoption model in order to estimate the 20-year market penetration of new CHP installations for both traditional CHP applications up to 5 MW in size and micro-CHP applications in the 10-50 kW size range. For both markets, the majority of CHP adoption is expected to take place in PG&E's utility territory, which has the most favorable electricity and gas rates for CHP applications. SCE has the least favorable energy rates for CHP, resulting in significantly less forecasted adoption despite its large customer base. The market adoption forecast for traditional CHP applications is shown in Figure G-7.

**Figure G-7: Market Adoption Forecast for Small CHP Applications by Utility**




Source: ICF

The micro-CHP (<50 kW) market is expected to make up close to 350 MW out of the 1.9 GW of expected adoption for <5 MW CHP systems over the next 20 years. The amount of micro-CHP adoption could potentially increase with penetration into the residential single family home market. The total expected adoption would also increase with a capital cost incentive, such as the newly reinstated 10 percent investment tax credit for CHP, or with or electricity rate reform to reduce standby rates and departing load charges.

## Potential Emissions Impacts

The analysis showed that in 2037, with 1.9 GW of small and micro CHP adopted, there will be a significant amount of fuel savings and emissions reductions. Fuel requirements and emissions for CHP systems with market potential were compared to projected 2037 utility grid fossil fuel emissions in California, which would be displaced by baseload CHP.

Overall, an estimated 39 million MMBtu/year of fuel (primarily natural gas) could be conserved, a savings of 23 percent compared to separate heat and utility power. Along with these energy savings, by 2037, 3,200 tons per year of NOx emissions would be avoided through small and micro CHP installations. Greenhouse gas emissions would also be reduced by over 1 million tons of carbon dioxide (equivalent) on an annual basis.

## Conclusions

Economics for CHP in California are promising, with the potential for significant energy and emissions savings through CHP adoption. The technical potential, economic potential, and expected market adoption for small CHP applications in California are summarized in Table G-3.

**Table G-3: Results of California <5 MW CHP Market Assessment**

| CHP Market | Total Capacity (GW) | | |
|---|---|---|---|
| | Technical Potential | Economic Potential | Expected Market Adoption |
| Traditional CHP (50 kW-5 MW) | 7.4 | 4.6 | 1.6 |
| Micro-CHP (10-50 kW) | 2.5 | 1.1 | 0.3 |
| Single Family Home Micro-CHP (1-2 kW) | 1.7 | n/a | n/a |
| **Total (<5 MW)** | **11.6** | **5.7** | **1.9** |

Source: ICF

Based on this market assessment, there is technical potential of 11.6 GW for CHP systems 5 MW or smaller, including potential single family home applications. Almost 50% of this potential, or 5.7 GW, is estimated to be economical, capable of obtaining a payback period under 10 years. Three times the current installed capacity of <5 MW CHP in California is expected to come online over the next 20 years. This means market adoption is forecasted to be about 2 GW of CHP capacity. CHP is the cleanest and most efficient way to convert fossil fuels into energy, and it will continue to play an important role in the California energy market.

Additional details can be found in the following report:

Jones, David, Keith Davidson, Rod Hite, and Annie Howley. 2018. *A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California*. California Energy Commission. Publication Number: CEC-500-2019-030.

## Integration Issues, Barriers, and Recommendations

The *Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California* identifies, characterizes, and assesses combined heat and power (CHP) technologies and applications under 5 MW in size for residential, commercial, and light industrial markets in California. This Fact Sheet highlights the impact of policies and regulations on the potential for CHP adoption in California, the role for CHP in a renewable energy future, and potential solutions to barriers that impede the adoption of CHP.

## Policy and Regulatory Considerations

California energy policy, legislation, regulations, and consumer advocacy for sustainable energy practices over the last decade are substantially changing the behavior of utilities that generate and deliver energy. Key legislation and regulations that are shaping California's energy future in general, and the role of distributed generation (DG) in particular, are summarized below:

- AB 32 (2006) and SB 32 (2016): Requires the State to cut GHG emissions to 1990 levels by 2020, and 40% below 1990 levels by 2030.
- AB 350 (2015): Increases the Renewable Portfolio Standard (RPS) to 50% by 2030.
- AB 398 (2017): Continues Cap-and-Trade Program through 2030. Although the legislation continued transitional support to many industrial segments competitively threatened by higher energy prices, a continuation of the transitional assistance for CHP through 2020 was not addressed in the October 2017 CARB1 Final Regulation Order.
- AB 1637 (2016): Makes qualifying natural gas fuel cell customer generators eligible for a Net Energy Metering (NEM) tariff that exempts the customer from departing load and standby charges. A 2017 bill (AB 36) that enabled all CHP technologies meeting the same qualifying criteria as fuel cells to be entitled to the same net metering benefits was passed by the Assembly and Senate. However, this bill was vetoed by the Governor.
- CARB Scoping Plan (2017): Incorporates ongoing efforts and new actions to achieve 2030 GHG reduction goals and beyond. Unlike prior scoping plans, there was no mention of CHP.
- CPUC Decision 16-06-055 (2016): Revised the Self-Generation Incentive Program (SGIP) pursuant to SB 861 and AB 1478. The decision included a biogas blending requirement for all natural gas CHP projects that effectively excluded natural gas CHP projects from participation in SGIP, except for sites that are co-located or in close proximity to a biogas source.
- CPUC Decision 16-09-056 (2016): Effective January 1, 2018, all DG technologies using diesel, natural gas, gasoline, propane, or liquefied petroleum gas (in CHP

or non-CHP configurations) were prohibited for use during demand response events.

- CEC Building Efficiency Standards (2015): These standards, also referred to as "Title 24," require all new residential buildings to be zero net energy (ZNE) beginning in 2020, and all new commercial buildings to be ZNE beginning in 2030. While natural gas appliances are exempt from the ZNE methodology, it is unclear how natural gas CHP will be treated.
- Federal Tax Incentives: Accelerated tax depreciation (MACRS) continues and the Investment Tax Credit (ITC) has been extended for five years in the 2018 budget bill.
- Integrated Distributed Energy Resource Request for Offers (IDER RFOs): California Investor Owned Utilities (IOUs) issue IDER RFOs to defer the need for capital expenditures for traditional distribution infrastructure upgrades. Natural gas solutions are not allowed in some RFOs, while others do allow natural gas solutions if they meet the SGIP efficiency and environmental criteria.

While the trend in California policies and regulations has made California more challenging for CHP, the CHP industry continues to advocate that CHP technologies offer a clean and economical solution with a small carbon footprint. The CHP industry feels that, collectively, California energy policies and regulations do not generally encourage natural gas CHP. Currently in California, CHP technologies are not eligible for meaningful support from State agencies.

## The Role for CHP in the Transition to a Renewable Grid

Renewables will be an ever increasing part of California's energy mix; within the next decade a substantial number of energy users will meet a portion of their electricity requirements with solar photovoltaics (PV). As indicated earlier, AB 350 increases the Renewable Portfolio Standard (RPS) to 50% by 2030. However, due to intermittent generation and space limitations, PV can seldom meet the entire electricity load thus making room for CHP to supply clean, low GHG electricity when PV electricity is insufficient or unavailable. In addition to providing electricity, CHP systems provide useful thermal energy for on-site needs, reducing the use of less efficient natural gas boilers.

## Barriers and Recommendations

Key barriers and recommendations to the adoption of small and micro-scale CHP systems are summarized in the tables below.

**Technology**

| Barriers | Recommendations |
|---|---|
| • Smaller systems tend to have a higher capital cost burden for a number of reasons, including higher soft costs (permitting, interconnection agreements, and engineering), and installation costs.<br>• There is a lack of understanding of Flexible (Flex) CHP technology capabilities and market potential.<br>• There is no commercial micro-CHP (< 50 kW) technology option currently available in California. | • Reduce cost and time burdens for small scale CHP systems through smart factory packaging systems and UL certifications.<br>• Assess CHP technology capabilities and limitations to flexibly operate in support of economic, environmental and reliable grid performance. Assess other grid value-stacking benefits to be afforded a Flex CHP fleet. Explore methods for harnessing Flex CHP benefits and aggregating program participation. Consider demonstration and utility pilot projects.<br>• Seek innovative CHP demonstration projects in applications that provide co-benefits such as water purification or indoor farming.<br>• Develop and demonstrate near-zero emission, efficient small CHP (< 5 MW) and micro-CHP (<50 kW) for the large untapped market potential.<br>• Develop packaging solutions for small CHP that reduce installed costs, offer high overall efficiencies, provide high availability, and that can easily integrate with PV and storage.<br>• Help ease interconnection process via inverters on small CHP. |

**State Policies, Legislation and Regulations**

| Barriers | Recommendations |
|---|---|
| • Natural gas CHP, even though it is the most efficient and cleanest fossil resource, is considered a baseload 24/7 technology and not a fit for California's energy future.<br>• Except for a few CHP sites in close proximity to a biogas source, the SGIP biogas minimum effectively eliminates CHP from eligibility.<br>• Cap-and-Trade allowance costs could seriously impact new CHP adoption despite its GHG benefits. The covered entity exclusion "But for CHP" in effect until 2020 was not renewed post 2020 putting CHP for many applications in jeopardy.<br>• NEM benefits have only been extended to one CHP technology regardless of performance attributes of others. | • Recognize Flex CHP as a potentially cost-effective resource to manage electricity supply and demand. Thoroughly assess the potential, the benefits and implementation practicality of the concept. Consider a utility pilot to vet the concept in the field.<br>• Encourage DER solutions through policies, legislation, and regulations that are performance based and technology neutral.<br>• Help ensure flexible operation through electric utility owned CHP.<br>• Include flexible CHP in the utility integrated resource plans. |

**Electric Tariffs**

| Barriers | Recommendations |
|---|---|
| • Non-bypassable surcharges (departing load charges) are selectively applied to generation from certain CHP technologies despite performance attributes. Most other customer measures are exempt from these punitive surcharges.<br>• High standby charges can deter new CHP and vary widely by utilities throughout the state. Again, only select CHP technologies pay these charges. Most DG technologies are exempt from standby tariffs.<br>• High demand charges, particularly non-coincident demand charges and ratchets, adversely affect natural gas DG. Renewable DG benefits from a special tariff where a large portion of these charges are converted to avoidable energy charges. | • Eliminate non-bypassable surcharges on all efficient and clean customer DER measures.<br>• Recognize DG availability as a class when developing standby and demand charges for DG downtime, shifting a greater portion of the charges for backup power to energy vs demand.<br>• Reduce demand charges on short-term outages through a renewable tariff equivalent for CHP. |

**Interconnection**

| Barriers | Recommendations |
|---|---|
| • Interconnection process time and cost has become long and costly, and is particularly damaging for smaller CHP systems. | • Extend the fast track process to smaller CHP and reduce fees to very small CHP systems (< 200 kW). |

**Conclusion**

Barriers, including policies, electric tariffs, technology limitations, and interconnection requirements, will continue to hinder CHP adoption in California. However, by implementing these recommendations, the state can encourage a growth in the adoption of efficient, low-emission CHP technologies.

Additional details can be found in the following report:

Jones, David, Keith Davidson, Rod Hite, and Annie Howley. 2018. *A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California*. California Energy Commission. Publication Number: CEC-500-2019-030.

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## Combined Heat and Power – Technology Recommendations

The *Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California* identifies, characterizes, and assesses combined heat and power (CHP) technologies and applications under 5 MW in size for residential, commercial, and light industrial markets in California. This Fact Sheet provides an overview of CHP technology hurdles and potential technology recommendations to help reduce the impacts of the barriers for CHP systems.

## Technology Barriers

Technological barriers for CHP installations have often been magnified for smaller systems, 5 MW in size and less, installed on the customer side of the meter. These barriers have hindered the market adoption of small CHP systems. There is currently 8,500 MW of operational CHP capacity in California with only 663 MW from systems less than 5 MW in size.[90] Yet, compared to larger CHP systems, there is significantly more technical potential remaining for new CHP capacity in applications suited for CHP systems less than 5 MW in size.

The prospective CHP market for technologies less than 5 MW are primarily commercial, institutional and light industrial applications. For the most part, the energy needs for these facilities are skewed toward higher power and lower thermal requirements compared to larger industrial plants that have traditionally hosted CHP. Electric and thermal loads in these applications tend to vary significantly on both an intra-day and seasonal basis.

Existing CHP technologies often lack the performance and cost attributes to provide a compelling economic solution for many commercial and light-industrial applications. The weaknesses of available CHP technologies vary by technology and size, but they can include low electric efficiencies, emission control challenges, and high capital and maintenance costs.

In applications requiring more electricity than thermal energy, low to modest CHP electric efficiencies in systems less than 1 MW in size lead to electrically undersized CHP or poor thermal utilization, resulting in economic and operational challenges.

[90] U.S. Department of Energy. U.S. DOE Combined Heat and Power Installation Database. Accessed February 2018. Available online: https://doe.icfwebservices.com/chpdb/

Additionally, emission control technologies add to the cost of CHP installations, which can further limit economic viability in California.

Smaller CHP systems are usually beset with higher capital and maintenance costs on a per unit output basis. With the exception of components that are mass produced for other applications, this general rule applies to the natural gas prime movers, balance-of-plant equipment, and installation. Soft costs, including project development and sales, system design, project management, city and air district permits, and grid interconnection agreements, also tend to be higher on a per unit output basis compared to larger CHP systems.

Other CHP features that are lacking in some technologies include:

- Capability for grid isolated operation and remote operational dispatch control for resiliency and grid support.
- Availability of high grade heat while maintaining high overall efficiency, limits market applicability.
- Ease of compliance with Rule 21 without the need for redundant and expensive protection devices.
- Cost-effective micro-CHP products suitable for the California market.
- Backup capacity for nuisance and short-term maintenance outages which can trigger expensive demand charges.

## Technology Recommendations

Technology recommendations to help ameliorate these deficiencies are listed below.

| | Technology Recommendations |
|---|---|
| Prime Mover | • Develop small CHP prime movers 500 kW and smaller with electric efficiencies greater than 40%, a $800/kW cost for the prime mover/generator subsystem and air criteria emissions lower than the CARB DG Certification Standard.<br>• Research innovative emission control technologies that are appreciably cleaner than the CARB Certification DG standard on a sustainable basis.<br>• Utilize higher quality heat for technologies less than 3 MW in size with overall efficiencies of 80%.and installed costs under $2,500/kW. |
| CHP System | • Implement innovative CHP demonstration projects that target large market segments that can be served with a standardized package and balance-of-plant design.<br>• Develop standardized add-on electric and thermal storage subsystems for small CHP packages.<br>• Develop and demonstrate prospective economic micro-CHP systems that are CARB Certifiable. |
| Flex CHP | • Verify Flex CHP capabilities to ramp up and down per specifications and via remote dispatch.<br>• Develop Flex CHP systems with battery integration to provide additional functionality and ancillary services. |
| Technology Assessments and Design Tools | • Design a manual that clearly describes grid interconnection requirements and procedures in California's five major utilities for various generator types – induction, synchronous and inverter based systems. Explore methods for accelerating the interconnect process for smaller CHP systems less than 500 kW in size.<br>• Develop benchmarking guidelines for CHP using case studies and best practice design methods.<br>• Assess CHP technology capabilities and limitations to flexibly operate in support of economic, environmental and reliable grid performance. Assess grid value-stacking benefits that can be provided by a versatile CHP fleet. Explore methods for harvesting and monetizing Flex CHP benefits and aggregating program participation. Consider demonstration and utility pilot projects.<br>• Develop a micro-CHP roadmap for widespread economic viability in California. |

Additional details can be found in the following report:

Jones, David, Keith Davidson, Rod Hite, and Annie Howley. 2018. *A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California*. California Energy Commission. Publication Number: CEC-500-2019-030.