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STAFF REPORT

Gas Research and Development Program

2022 Annual Report

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California Energy Commission

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ABSTRACT

In 2000, AB 1002 (Wright, Chapter 932, Statutes of 2000) was enacted, requiring the California Public Utilities Commission (CPUC) to impose a surcharge on gas consumed in California. These monies funded energy efficiency programs and public-interest research and development to benefit gas ratepayers. AB 1002 also required the CPUC to designate an entity to administer the research component of AB 1002. In 2004, the CPUC issued Decision 04-08-010, designating the California Energy Commission (CEC) as the research fund administrator. In 2021, Section 25620.8 of the Public Resources Code was amended to provide further guidance on the preparation and submission of an annual report.

This *Gas Research and Development Program 2022 Annual Report* highlights project successes and research benefits of completed and in-progress projects from July 1, 2021, through June 30, 2022. In Fiscal Year 2021–2022, the CEC administered $24 million for gas research, development, and demonstration geared toward improving entrepreneurial support; building decarbonization; gas system decarbonization; industrial and agricultural innovation; transportation; and resiliency, health, and safety in California.

Keywords: California Energy Commission; California Public Utilities Commission; gas system decarbonization; energy efficiency; climate change; building end-use energy efficiency; industrial, agriculture, and water efficiency; renewable energy and advanced generation; energy infrastructure; gas pipeline integrity; low-emission transportation; disadvantaged communities; low-income communities; hydrogen; decarbonization; entrepreneurial support; resiliency, health, and safety

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EXECUTIVE SUMMARY

California's forward-leaning energy and climate policies and investments are driving significant progress in clean energy deployment and greenhouse gas emissions reductions while improving public health and safety. At the highest level, Senate Bill (SB) 100 (De León, Chapter 312, Statutes of 2018) set the state on the path to achieving 100 percent renewable and zero-carbon electricity by 2045, and Assembly Bill (AB) 1279 (Muratsuchi, Chapter 337, Statutes of 2022) is guiding the state to economywide carbon neutrality by 2045. To meet these goals, California is assessing pathways to decarbonization across all sectors now so that the state can transition to clean energy efficiently, safely, and equitably.

Gas system decarbonization is a key component to the broader shift to a decarbonized economy, and the Gas Research and Development Program invests in cutting-edge technologies and strategies to catalyze progress. AB 1002 (Wright, Chapter 932, Statutes of 2000) created the Gas Research and Development Program, recognizing that gas has been an important energy resource for California. AB 1002 directed the CPUC to impose a surcharge on all gas consumed in California to fund public-interest research and development.

The Gas Research and Development Program invests $24 million annually in gas-related energy efficiency, renewable energy and advanced generation, gas system infrastructure safety and integrity, energy-related environmental research, transportation, and entrepreneurial support. Program investment totals since 2004 are as follows:

- Entrepreneurial Ecosystem: $11.2 million
- Building Decarbonization: $54.8 million
- Gas System Decarbonization: $20.3 million
- Industrial and Agricultural Innovation: $72.5 million
- Transportation: $64.3 million
- Resiliency, Health, and Safety: $87.7 million

Recent focal areas of investment include low-carbon hydrogen for hard-to-decarbonize segments of the economy, such as heavy-duty transport and certain industrial applications. and research to guide strategic, equitable gas system decommissioning. The program also reflects California's commitment to clean, affordable, and safe energy for all. The program invests strategically to deliver communitywide benefits, advance energy equity, and ensure that the transition to a decarbonized future supports California's most vulnerable residents and communities. An estimated 71 percent of program funding has been invested in projects located in either a disadvantaged community or low-income community, or both, since Fiscal Year 2016–2017.

CHAPTER 1: Introduction

To support the evolution of California's gas system to better serve its ratepayers, the California Legislature passed AB 1002 (Wright, Chapter 932, Statutes of 2000), creating the Gas Research and Development (R&D) Program in 2000. This law enacted a surcharge on gas consumed within the service territories of California's investor-owned utilities. Since 2004, the CEC has administered the Gas R&D Program and funds a range of public-interest R&D activities in energy efficiency, renewable energy and advanced generation, and energy infrastructure. Per CPUC requirements, Gas R&D Program projects focus on energy efficiency, renewable technologies, conservation, and environmental issues; support state energy policy; offer a reasonable probability of providing benefits to the public; and consider opportunities for collaboration and cofunding with other entities.

The CEC submits an annual report of the last fiscal year and a new budget plan for the upcoming fiscal year to the CPUC. The CEC engages with the public when creating its budget plans and works with entities such as the state's investor-owned gas utilities, state and federal agencies, industry experts, academic researchers, and other interested parties. The CEC also conducts public workshops throughout the year to share project results, generate new research ideas, explore emerging topics, and track the latest industry practices. The workshops bring together utilities, researchers, manufacturers, technology adopters, and policy makers from state and federal agencies, such as the California Air Resources Board (CARB) and the United States Department of Energy, to encourage knowledge sharing and collaboration.

The CEC has prioritized energy equity by working to ensure that the benefits from clean energy reach underresourced communities. The Gas R&D Program has invested an estimated 71 percent of program funds in projects located in either a disadvantaged community or low-income community, or both, since Fiscal Year 2016–2017. The CEC has also invested 67 percent of technology demonstration and deployment funds in underresourced communities through the companion electricity R&D program — the Electric Program Investment Charge (EPIC) Program — far surpassing the 35 percent legislative requirement.[1]

In 2020, the CPUC adopted Resolution G-3571, which changes how the CEC develops and submits budget plans to the CPUC. The resolution requests additional outreach with the CPUC, the Disadvantaged Communities Advisory Group (DACAG), and the public. In addressing the

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1 *Disadvantaged communities* are those designated under to Health and Safety Code Section 39711 as representing the 25 percent highest-scoring census tracts in California Communities Environmental Health Screening (CalEnviroScreen) Tool 3.0. https://calepa.ca.gov/envjustice/ghginvest/. Low-income communities are those within census tracts with median household incomes at or below 80 percent of the statewide median income or the applicable low-income threshold listed in the state income limits updated by the California Department of Housing and Community Development.

O'Hagan, Molly and Misa Werner. 2022. *Electric Program Investment Charge 2021 Annual Report.* California Energy Commission. Publication Number: CEC-500-2022-002-CMF.

elements of CPUC Resolution G-3571, CEC staff presented the proposed budget plan for the 2022–2023 Gas R&D Program at a meeting with a subset of DACAG committee members in January 2022 to solicit their feedback. Furthermore, in 2021, the Legislature passed AB 148 (Ting, Chapter 115, Statutes of 2021), which requires the CEC to submit the annual report with additional content that includes:

- Recommendations for improvements in the program. (The CEC does not propose any recommendations at this time.)
- A summary of the program effects and benefits (addressed on pages 3–5).
- A summary of how funding is allocated to each of the investment areas of the program (addressed on page 7).
- A description of successful or promising projects funded in each of the investment areas of the program (addressed on pages 8–17).
- A summary of expected program funding initiatives and activities over the next year (see Appendix C for a summary of the initiatives and budget proposed to the CPUC; addressed in detail within the CEC's proposed budget plan, available at https://www.energy.ca.gov/publications/2022/gas-research-and-development-program-proposed-budget-plan-fiscal-year-2022-23).
- Information on approved project budgets and benefits, all active projects, and recently completed projects (addressed via the gas project profiles on CEC's Energize Innovation Project Showcase, available at https://www.energizeinnovation.fund/projects?f%5B0%5D=funding_prog%3ANatural%20Gas). Users can download a spreadsheet of these gas project profiles by selecting the "Download XLS of projects" link on this webpage.
- A description of any recent changes to the spending guidelines or eligible projects of the program. (The program has not experienced recent changes to spending guidelines or eligible projects. However, as of 2021, gas R&D funds are now continuously appropriated. Per AB 148 Section 76, Section 895 of the Public Utilities Code is amended to read: "Notwithstanding Section 13340 of the Government Code, money in the Gas Consumption Surcharge Fund are continuously appropriated, without regard to fiscal years.")[2]

This *Gas Research and Development Program 2022 Annual Report* highlights project successes and research benefits of completed and in-progress projects from July 1, 2021, through June 30, 2022, as well as overall program investments and impacts.

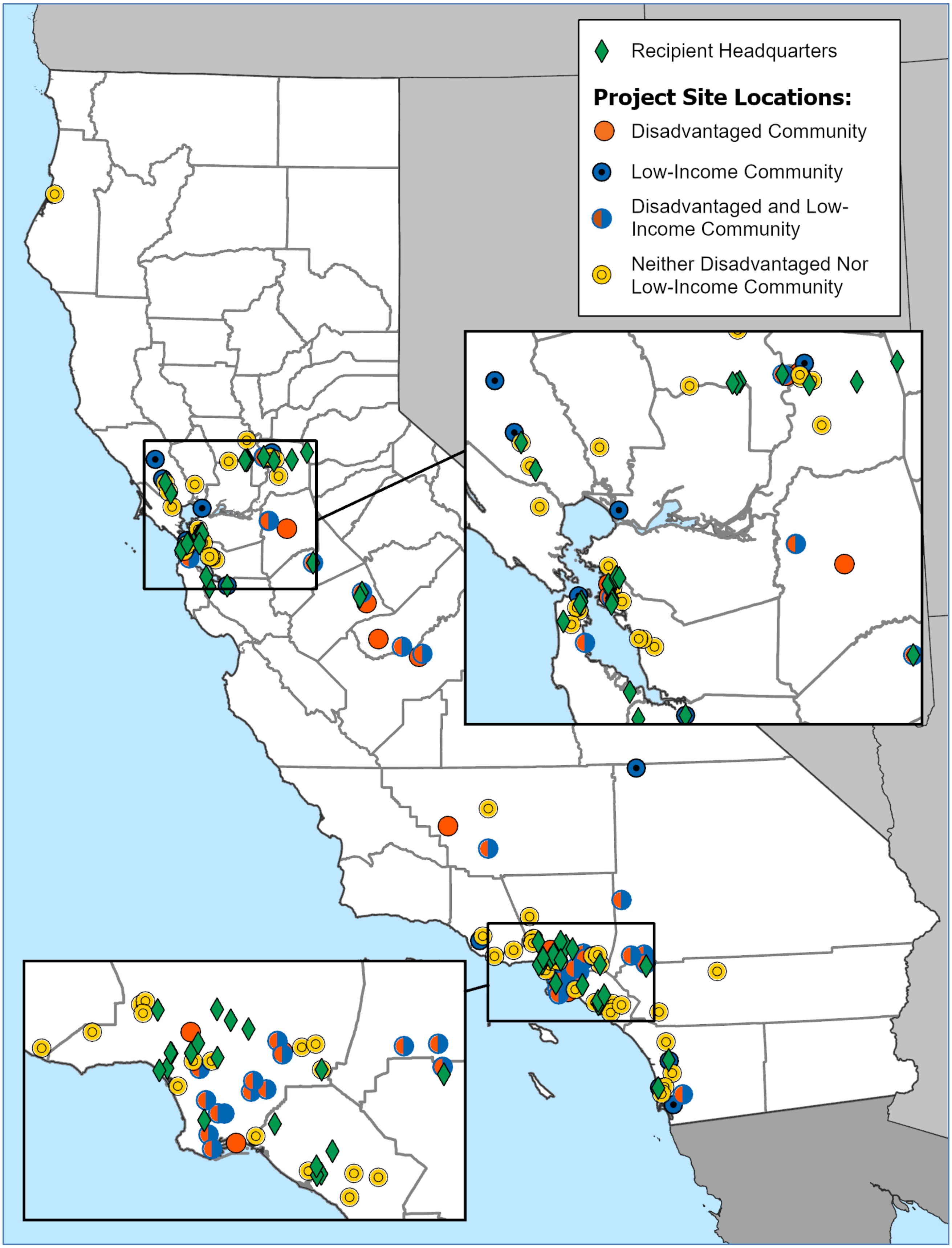
2 Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB148.

Program Investment and Impact

The CEC's Gas R&D Program has invested in a wide variety of research projects and technologies to ensure that California's gas system is improving to better serve ratepayers. Figure 1 shows the locations of recipient headquarters and project sites. Gas R&D Program impacts include the following:

- **About $311.3 million** has been invested to date across **297** projects.
- Project recipients have attracted **more than $6.1 billion in private investment** after being selected for a Gas R&D Program award.
- About **71 percent of program funds have been invested in disadvantaged and low-income communities**, or both, since Fiscal Year 2016–2017.
- At least **23 projects informed codes, standards, proceedings, or protocols** (adopted or under consideration), providing an estimated **$65 million per year in energy cost savings**.
- At least **44 technologies or products have been commercialized**, and many more are moving toward commercialization.
- More than **15,700 citations** have been made to publications referencing research results from CEC-funded gas R&D projects (through September 2022).

Figure 1: Map of Gas R&D Program Recipient Headquarters and Project Site Locations (Fiscal Year 2016-2017 Through June 30, 2022)



Source: CEC staff

Entrepreneurial Ecosystem: $11.2 Million Invested

The growth of emerging clean energy start-ups is an important catalyst for commercializing technology advancements made through public-interest research. Funding in the Entrepreneurial Ecosystem category supports clean-tech entrepreneurship, in part by providing small grants that invest in start-ups for early-stage research and prototype development. The CEC's previous small grants program, the Energy Innovation Small Grant Program (EISG), provided funding for electric- and gas-related technologies. The EISG Program ended in 2017 and was replaced with the California Sustainable Energy Entrepreneur Development (CalSEED) Initiative Program. Previously, CalSEED was exclusively funded by the CEC's EPIC Program to support start-up companies advancing electricity-related technologies for precommercial stage research and prototype development. The CEC created a complementary CalSEED Program in the Gas R&D Program and expects to select the first cohort in 2023 or 2024.

Building Decarbonization: $54.8 Million Invested

The program invests in novel energy technologies to improve building decarbonization technologies, energy efficiency, affordability, health, and comfort of California's homes and businesses.

Gas System Decarbonization: $20.3 Million Invested

As California approaches decarbonization policy goals, this investment category supports a safe, healthy, and equitable transition to a zero-carbon energy system through leading-edge studies on fugitive methane emissions, gas infrastructure decommissioning, renewable hydrogen, and biomethane.

Industrial and Agricultural Innovation: $72.5 Million Invested

The industrial and agricultural sectors are an essential part of California's economy but have been difficult to decarbonize. The CEC's Gas R&D Program is prioritizing the need to develop and scale technology solutions that reduce fossil gas use, cut carbon emissions, and lower waste while increasing production of goods, such as biofuels from dairy digesters or wastewater treatment plants.

Transportation: $64.3 Million Invested

The program advances new technology solutions to increase the efficiency and clean operation of medium- and heavy-duty and off-road vehicles. The program has advanced the applications of efficient and low-emission vehicles and is researching hydrogen fuel advancements and applications.

Resiliency, Health, and Safety: $87.7 Million Invested

The CEC's Gas R&D Program helps Californians create a reliable, resilient, and safe energy system through state-of-the art research on pipeline safety, gas storage, climate and weather risk, indoor air quality and health, and forest biomass usage that reduces fossil-fuel reliance and wildfire risk.

CHAPTER 2: Project Highlights

This chapter highlights select projects that have demonstrated promising results or are beginning to produce important work from previous investments to the Gas R&D Program. More information is available on these projects, in addition to all active CEC R&D projects funded through the Gas R&D Program and EPIC, on the CEC's Energize Innovation Project Showcase. The project teams provided the metrics in these highlights except where otherwise noted.

Building Decarbonization

A Systems-Efficient Approach to Hospital Decarbonization

Large commercial buildings such as hospitals, institutional buildings, offices, and correctional facilities use large amounts of gas for space and water heating and other large loads such as cooking and steam sterilization. Hospitals, due to the nature of the work and running on a 24-hour basis, have higher energy intensity per square foot than any other building type in the commercial sector. The energy use of hospitals per square foot is more than double that of the typical commercial building. In the United States, the healthcare industry accounts for 8.5 percent of total greenhouse gas (GHG) emissions. For California to meet its GHG reduction goals, significant strides must be made in this sector.

Project Goals:

- Reduce annual fossil gas consumption and site GHG emissions by at least **30%**
- Reduce annual electricity by about **25%**
- Achieve simple payback **< 7 years**
- Reduce **3,400 metric tons** of carbon emissions

Systems to provide hot water for heating buildings and domestic hot water consume a large portion of the total site energy at hospitals. According to the University of Washington, the average United States hospital uses 42 percent of the total input energy for the reheat system and 11 percent for heating, ventilation, and air-conditioning (HVAC) units. These high energy needs are due to standards and design requirements for hospitals (for example, minimum outdoor air changes and total air changes depending on type of space), simultaneous heating and cooling, and the use of too much outside air in some cases. As a result, hospitals over-ventilate many spaces. The demonstration site for this project is an example. Built in 1994, Kaiser Permanente Baldwin Park (Figure 2) uses the typical space and water heating system for its era. It uses a chiller-boiler hydronic system with constant volume air handlers providing 24-hour ventilation with significant reheat. Innovative whole-building systems approaches are necessary to reduce the GHG footprint of existing buildings such as this.

Multiple systems must be designed, installed, and operated to optimize performance collectively with other energy systems within and outside the building to achieve a systems-efficient building. This project is demonstrating heat-recovery measures in the central utility plant to save heat energy on the domestic hot water and building-heating hot water systems. This demonstration will be accomplished through four primary measures that together represent a cost-effective and successful reduction in gas use:

- *Using a heat recovery chiller and integrating stack economizers to reduce steam boiler fuel requirements.* In a heat recovery chiller, the heat from the compressor, which would normally be rejected to the condenser and then a cooling tower, is provided to a water loop, which is then used for heating.
- *Implementing a variable-air-volume system*, which enables energy-efficient HVAC system distribution by optimizing the amount and temperature of distributed air. The air volume is varied based on need.
- *Designing air handlers with separate cold and hot decks to optimize economizer mode.* Hot deck/cold deck systems are an air handler-based solution where the airflow for the building is split into two parts: one heated and the other cooled. These two airflows are then mixed to create the right amount of heating and cooling for each space. In economizer mode, the cold deck can be used to route in fresh, cool air from outside of the building.
- *Employing an optimal control strategy to minimize building HVAC energy consumption.* This strategy is a feedback control system that adjusts its characteristics to respond to a changing environment.

Figure 2: Kaiser Permanente Baldwin Park

Demonstration site for "A Systems-Efficient Approach to Hospital Decarbonization."

Source: Kaiser Permanente

These integrated technologies were selected based on preliminary whole building modeling and an evaluation of the site's historical energy consumption. The goal of the integrated technology and system design approach is to reduce the gas consumption and GHG emissions of the site by at least 30 percent. This project will overcome barriers to decarbonizing large commercial buildings by demonstrating this integrated solution for reducing heating and hot water loads to significantly reduce energy use and emissions.

Getting Out of Hot Water: Reducing Gas Consumption in Existing Large Commercial Buildings

Gas accounts for a third of all energy consumed by commercial buildings, and in California 90 percent of that gas is used to provide space and water heating, producing 9.7 million metric tons of carbon dioxide equivalent (CO_2e) annually.[3] Gas-fired boilers constitute the vast majority of space heating systems in large commercial buildings in California and typically supply hot water to reheat coils at building zones and sometimes also at air handling units. Many of the zones served by these systems have incorrect minimum airflows, wasting reheat energy as well as fan energy to unnecessarily recirculate indoor air. Furthermore, gas-fired boiler systems serving hot water reheat systems are generally inefficient. A recent study showed that 83 percent of the energy cost to operate such a system was lost due to high distribution losses and poor boiler efficiency.[4]

Despite the predominance of these types of systems in existing large buildings, there are no viable proposed solutions to decarbonize them without a full replacement. This is often not feasible from a cost perspective (even at boiler or air-handling unit [or both] end of life) as it effectively means replacing the entire HVAC system, including the zone-level reheat coils serving individual rooms, as well as disrupting occupants. However, to meet California's climate goals, it is essential to determine a pathway to cost-effectively reduce the carbon emissions associated with these systems. That includes determining a means of doing so that accounts for the myriad of conditions found in the existing building stock and provides impactful retrofit strategies like those illustrated in Figure 3.

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3 U.S. Energy Information Administration, 2012 Commercial Buildings Energy Consumption Survey.

California Commercial End-use Survey, https://www.energy.ca.gov/data-reports/surveys/california-commercial-end-use-survey.

CARB Emission Factor Database, 2019.

4 Raftery, Paul, Angela Geronazzo, Hwakong Cheng, and Gwelen Paliaga. 2018. "Quantifying Energy Losses in Hot Water Reheat Systems." *Energy and Buildings*. November 2018, Volume 179, Issue 1, pp. 183–199.

Figure 3: Boiler and Variable-Air-Volume Retrofits

Genentech Building, South San Francisco

Source: Center for the Built Environment

In this project, the Center for the Built Environment (CBE) is demonstrating, evaluating, and scaling packages of nonproprietary, low-cost software control and other measures to substantially reduce gas consumption in a large commercial building in South San Francisco (San Mateo County). This project includes measures to ensure that higher-cost items (for example, end-of-life boiler replacements) are done as energy- and cost-efficiently as possible. By reducing the heating airflow to proper levels, reducing distribution losses, and installing a smaller, right-sized boiler with full turn down and no minimum flow requirements, these measures can achieve substantial cost savings. The project targets three main areas of energy waste: unnecessary demand for space heating, hot water distribution losses, and poor boiler operational efficiency. Successful implementation is expected to reduce annual gas consumption by more than 60 percent and annual carbon emissions by 250 metric tons as well as achieve simple paybacks in fewer than seven years.

> "For too long, in both new construction and existing building retrofits, engineers have relied on out-of-date rules of thumb and assumptions on how buildings perform in actual operations. CBE's field-based work is analyzing new and more impactful retrofit strategies that will greatly help our industry scale our work at a rate needed to fight the impacts of climate change."
>
> *- Stet Sanborn, principal, SmithGroup*

Gas System Decarbonization / Industrial and Agricultural Innovation

Small Combined Cooling, Heating, and Power Packaged System With Innovative and Quick-Response Thermal Energy Storage

Traditional stand-alone small-scale combined heat and power systems offer energy resilience and GHG emissions reductions, but high capital cost, heat loss inefficiencies, and lack of power flexibility during fluctuating demand for commercial and industrial facilities have prevented wide adoption. These barriers sparked Element 16 Technologies to develop a highly efficient combined cooling, heating, and power system with thermal energy storage (CCHP-TES) that provides flexible load response during high peak hours and grid outages. Further progress in integrating CCHP systems with low-cost TES can enable greater heating and cooling flexibility and resiliency that support statewide energy and decarbonization goals.

Element 16 Technologies developed and demonstrated a CCHP-TES system for adoption in commercial sectors. The key aspect of this technology is the novel integration of low-cost molten sulfur as the storage fluid that can store and discharge heat efficiently. Storing exhaust heat energy in sulfur TES (Figure 4) adds flexibility to the CCHP system, allowing electricity and steam to be produced at different times. This storage allows the CCHP system to operate at high efficiency by storing waste heat for cooling or power generation during high demand. Since the sulfur TES system can store high-temperature heat, it can store and discharge energy more efficiently and compactly than water thermal storage.

> "NREL works with Element 16 on their sulfur thermal energy storage technology because it has the potential to supply industrial process heat and reduce reliance on fossil fuels. This technology could cut greenhouse gas emissions when integrated with renewable energy sources, while potentially reducing the industrial sector's cost of energy."
>
> *-Dr. Zhiwen Ma, senior engineer, NREL*

In this project, Element 16 successfully commissioned the CCHP-TES system at its own commercial facility in Arcadia (Los Angeles County) and demonstrated 85.4 percent thermal efficiency. The system achieved greater flexibility by demonstrating measured average charge and discharge rates of 12.6 kilowatt-hours (kWh) and 27.6 kWh, respectively. Notably, the successful deployment resulted in annual gas savings of approximately $7,000–$9,000, reducing the capital cost while providing a payback period under 9 years and reducing the commercial building's annual GHG emissions by about 30–40 tons. The National Renewable Energy Laboratory (NREL) supported this project by providing in-kind assistance to simulate the thermal storage capabilities to support the reliability and affordability of the system.

Figure 4: Element 16's Sulfur-Based Thermal Energy Storage

Element 16 staff with the sulfur-based TES in Arcadia (Los Angeles County)

Source: Element 16

In areas of high renewable energy penetration, the system can be optimally designed and intelligently controlled to reduce peak demand charges and interact seamlessly with the grid to provide dispatchable power and essential services. The improved economics and successful demonstration of this small-scale CCHP integrated with a sulfur-based TES will translate to increased distributed generation and adoption of highly energy-efficient systems, benefitting gas ratepayers and advancing California toward its GHG reduction targets.

Transportation

A Design and Feasibility Study of a Fuel Cell-Powered Commercial Harbor Craft

Commercial harbor craft are in the top three emitting categories at seaports, contributing more diesel particulate matter emissions than trucks in 2023 at the San Pedro Bay Ports. Tugboats or towing vessels are one of the largest emitting types of commercial harbor craft. Tugboats are self-propelled vessels engaged in pulling, pushing, maneuvering, berthing, or hauling alongside other vessels in harbors, over the open seas, or through rivers and canals. In 2023, tugboats will emit 19 percent of total commercial harbor craft $PM_{2.5}$ emissions[5] and 23 percent of total commercial harbor craft oxides of nitrogen (NOx) emissions.[6] Many communities surrounding areas where these vessels operate are underresourced communities. Addressing emissions from harbor craft is critical for the state to achieve its air quality and environmental justice goals.

Anticipated benefits of a single hydrogen fuel cell tugboat replacing an equivalent state-of-the-art Tier 4 diesel-mechanical tugboat:

- 4,100 kg of NOx emissions reduced per year
- 260 kg of particulate matter emissions reduced per year
- 1,973 metric tons of carbon dioxide equivalent emissions reduced per year, if deployed with green hydrogen
- Potential to replace 229 diesel tugboats in operation statewide[7]

Liquid hydrogen (LH2) and fuel cells are promising technology options to eliminate emissions from marine vessels. While LH2 and fuel cells have been used in specific land-based industries, marine-ready fuel cells and LH2 storage have only recently become available. Safety, technical, and economic challenges need to be addressed before a tugboat using LH2 and fuel cells can be built and deployed.

This project supports the Hydrogen Zero Emission Tugboat (HyZET) Consortium, which comprises leading maritime stakeholders with expertise in electric propulsion systems, fuel cells, feasibility analysis, technology qualification, independent safety and quality assurance, vessel operation and design, and LH2 systems. The HyZET Consortium is developing an actionable, first-of-its-kind hydrogen fuel cell-powered tugboat design that will be ready for future construction, demonstration, and deployment at the Port of Los Angeles.

The consortium analyzed and baselined activity data from an existing diesel tugboat operated by Crowley at the Port of Los Angeles to assess benchmark metrics required for a one-to-one replacement. Key performance metrics, including a 90-ton bollard pull and one week refueling frequency, guided the preliminary vessel concept (Figure 5). The power plant design includes

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5 Fine, inhalable particles with diameters 2.5 micrometers and smaller (particulate matter).

6 California Air Resources Board. CHC Fact Sheet: Tugboats (Towing Vessels). November 2021.https://ww2.arb.ca.gov/resources/fact-sheets/chc-fact-sheet-tugboats-towing-vessels.

7 Ibid.

2,400 kW of fuel cells, 1,740 megawatt-hours of batteries, and dual LH2 tanks with 1,875-kilogram (kg) capacities each. The team developed a regulatory map to identify potential roadblocks and pathways for meeting local and international safety requirements. The HyZET Consortium is seeking follow-on funding to build and deploy the vessel following completion of this project.

Figure 5: Hydrogen Fuel Cell Tugboat Rendering

Crowley Engineering Services has also designed a hydrogen fuel cell tugboat layout for this rendering.

Source: Crowley Engineering Services

Resiliency, Health, and Safety

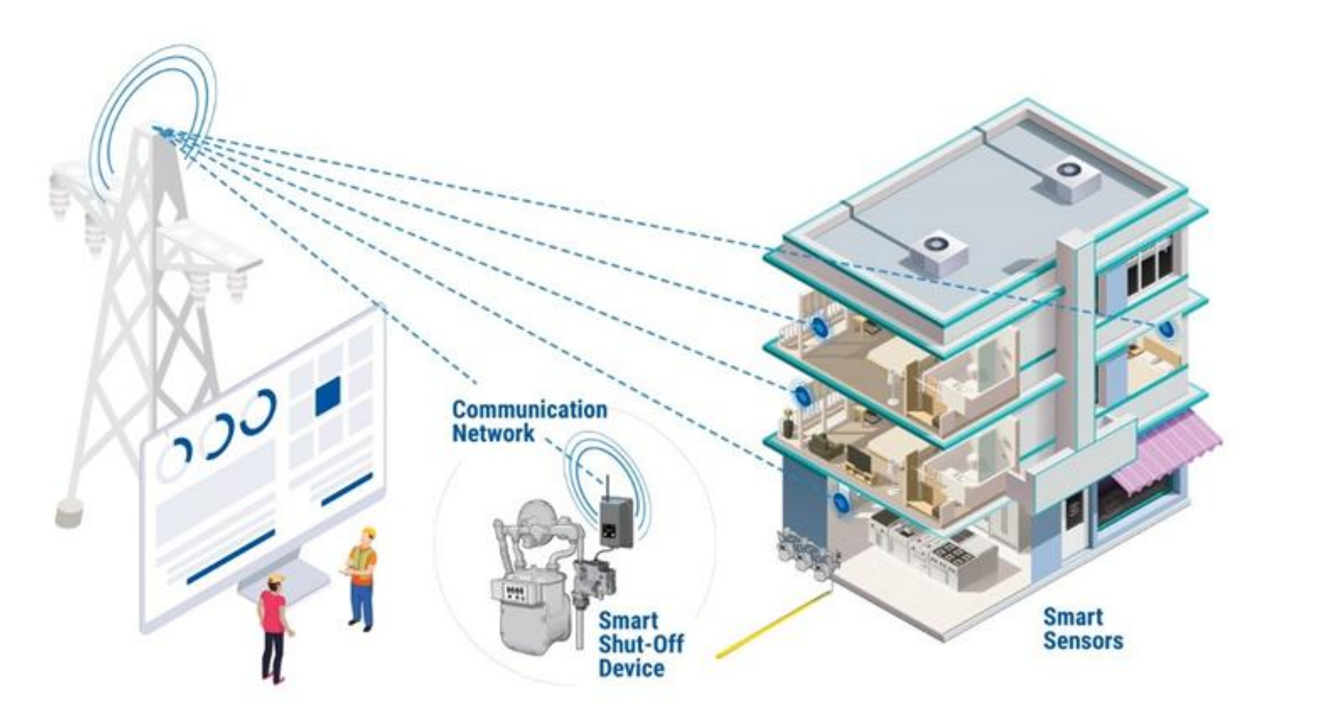
Smart Shutoff Technology for Homes and Businesses

Over the past 10 years, pipeline incidents in California have resulted in fatalities, injuries, and average costs of $63 million per year in damages.[8] Enhanced detection and response to hazardous incidents such as gas leaks, fires, natural disasters, system failures, operational errors, or external impacts can improve the safety of gas infrastructure servicing homes and businesses. Stand-alone safety devices such as excess flow valves or residential gas monitors are commercially available, but these devices do not possess "Internet of Things" (IoT) connectivity to automate the safety response among emergency personnel, gas customers, and gas utility companies. The deployment of smart shutoff systems with sensors and IoT connectivity enables fast responses to hazardous situations and helps overcome barriers of high-cost communication networks and limited connectivity.

The Gas Technology Institute has developed and tested a smart shutoff safety system to help gas customers maintain and safeguard customer-owned gas lines. Smart sensors, a gas shutoff device, and communication layers are integrated into a system that monitors and detects hazards such as gas leaks and fires (Figure 6). The low-power LoRaWAN (long-range, wide-area network) provided by Senet Inc. guarantees the security and reliability of seamless data communication among sensors, shutoff devices, and gas utilities. When an incident occurs, the system automatically sends out alerts or immediately terminates gas flows depending on the severity and informs the utility and customers of the risks. "Newer wireless technology, such as the LoRaWAN communication network, enables small/low-cost multiyear battery powered devices such as methane and fire sensors to transmit alerts to the customer and gas utility so that they can immediately respond to potential danger," says Mark Ewen, executive vice president of Senet Inc.

8 U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA). "Pipeline Incident 20-Year Trends." https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends.

Figure 6: Schematic Layout of the Smart Shutoff System



The system integrates smart sensors, a gas shutoff device, and communication layers.

Source: Gas Technology Institute

This CEC gas R&D project is demonstrating the smart shutoff safety technology with Southern California Gas Company and Pacific Gas and Electric Company to test system responses and collect performance data in a controlled laboratory environment, a residential building, and a restaurant. Broad deployment of this technology could significantly decrease the risk of threats and hazards posed by gas-related incidents compared to the current use of manual valves.

The smart shutoff technology helps prevent gas leaks and hazards in commercial buildings and residences, improving occupant safety and reducing methane emissions. By developing innovative solutions for the implementation, integration, and communication of advanced safety sensing and risk mitigation technologies, this project leads to technological advancements and breakthroughs in smart sensors, shutoff valves, and software integration and overcomes barriers to market adoption. The detection and intervention capabilities help protect lives and property as well as recovery costs from hazardous incidents.

Anticipated Benefits:

97% → estimated improvement in the probability of intervention to avoid catastrophic events

>60 billion standard cubic feet → potential annual methane emissions reduction from installing 450,000 smart gas safety shutoff systems

$500 → the cost per system

$9 billion → estimated market for this tech by 2024

LIST OF ACRONYMS

Term	Definition
AB	Assembly Bill
CalSEED	California Sustainable Energy Entrepreneur Development Initiative
CARB	California Air Resources Board
CBE	Center for the Built Environment
CEC	California Energy Commission
CCHP	Combined cooling heat and power
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
EPIC	Electric Program Investment Charge Program
EISG	Energy Innovation Small Grant Program
GTI	Gas Technology Institute
GHG	Greenhouse gas
HyZET	Hydrogen zero-emission tugboat
HVAC	Heating, ventilation, and air conditioning
IoT	Internet of Things
kg	Kilogram(s)
kW	Kilowatt(s)
kWh	Kilowatt-hour(s)
LH2	Liquid hydrogen
LoRaWAN	Long-range, wide-area network
NOx	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
PM	Particulate matter
R&D	Research and development
SB	Senate Bill
TES	Thermal energy storage

APPENDIX A: Investment Areas and Related Portfolio Topics Align to State Policies and CPUC Proceedings

The CEC's current Gas R&D Program was established through AB 1002 (Wright, Chapter 932, Statutes of 2000) and is further shaped by more recent policies such as SB 100 (De León, Chapter 312, Statutes of 2018). Program research priorities change as knowledge is gained and policies evolve.

Building Decarbonization

- Senate Bill 350 (De León, Chapter 547, Statutes of 2015), available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB350, establishes targets for statewide energy efficiency savings and demand reduction that will achieve a cumulative doubling of statewide energy efficiency savings for retail customers by 2030.
- The *2019 California Energy Efficiency Action Plan*, available at https://www.energy.ca.gov/filebrowser/download/1900, addresses existing buildings, low-income barriers to energy efficiency, agriculture, industry, newly constructed buildings, conservation voltage reduction, and electrification.
- The *Integrated Energy Policy Report*, available at https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report, assesses major energy trends facing California's electricity, gas, and transportation fuel sectors and provides policy recommendations.

Gas System Decarbonization

- Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016), available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB1383, requires reductions in statewide emissions of methane by 40 percent, hydrofluorocarbon gases by 40 percent, and anthropogenic black carbon by 50 percent below 2013 levels by 2030.
- Assembly Bill 1496 (Thurmond, Chapter 604, Statutes of 2015), available at http://www.leginfo.ca.gov/pub/15-16/bill/asm/ab_1451-1500/ab_1496_bill_20151008_chaptered.htm, requires the state to monitor methane hotspots.
- The *Short-Lived Climate Pollutant Reduction Strategy*, available at https://ww2.arb.ca.gov/sites/default/files/2020-07/final_SLCP_strategy.pdf, recommends actions to reduce emissions of short-lived climate pollutants, including from dairies, organics disposal, and wastewater.

- Senate Bill 32 (Pavley, Chapter 249, Status of 2016), available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32, requires California to reduce GHG emissions to 40 percent below 1990 levels by 2030.

Industrial and Agricultural Innovation

- Assembly Bill 1613 (Blakeslee, Chapter 713, Statutes of 2007), the Waste Heat and Carbon Emissions Reduction Act, available at http://www.leginfo.ca.gov/pub/07-08/bill/asm/ab_1601-1650/ab_1613_bill_20071014_chaptered.html, requires an electrical corporation to purchase excess electricity from combined heat and power systems that comply with sizing, energy efficiency, and air pollution control requirements.
- Senate Bill 1122 (Rubio, Chapter 612, Statutes of 2012), available at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201120120SB1122, requires the CPUC to direct the electrical corporations to collectively procure at least 250 megawatts from eligible bioenergy projects, including projects using biogas (biofuel produced from decomposition of organic waste) from wastewater treatment plants, municipal organic waste diversion, food processing, and codigestion; dairy and other agricultural bioenergy; and bioenergy using by-products of sustainable forest management.

Transportation

- The *California Sustainable Freight Action Plan*, available at https://ww2.arb.ca.gov/our-work/programs/california-sustainable-freight-action-plan, establishes targets to improve freight system efficiency by 25 percent by 2030, deploy more than 100,000 freight vehicles and equipment capable of zero-emission operation, and maximize near-zero freight vehicles and equipment powered by renewables by 2030.
- The *Mobile Source Strategy*, available at https://ww2.arb.ca.gov/resources/documents/2020-mobile-source-strategy, reduces emissions from the heavy-duty truck sector with cleaner combustion engines, renewable fuels, and zero-emission technology to meet GHG-reduction targets and attain federal health-based air quality standards for ozone and particulate matter.
- The Low Carbon Fuel Standard, available at https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard, reduces the full fuel-cycle carbon intensity of the transportation fuels pool used in California by encouraging the transition to fuels that have a lower carbon footprint.

Resiliency, Health, and Safety

- Senate Bill 887 (Pavley, Chapter 673, Statutes of 2016), available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB8

87, issues requirements to ensure the safety and integrity of gas storage facilities.

- Senate Bill 1371 (Leno, Chapter 525, Statutes of 2014), available at http://www.leginfo.ca.gov/pub/13-14/bill/sen/sb_1351-1400/sb_1371_bill_20140921_chaptered.html, requires the CPUC to determine whether existing practices are effective at reducing methane leaks and promoting public safety, and whether alternative practices may be more effective.
- Senate Bill 380 (Pavley, Chapter 14, Statutes of 2016), available at http://www.leginfo.ca.gov/pub/15-16/bill/sen/sb_0351-0400/sb_380_bill_20160510_chaptered.pdf, determines the feasibility of minimizing or eliminating the use of the Aliso Canyon gas storage field in Los Angeles County while maintaining energy and electric reliability for the region.
- Senate Bill 901 (Dodd, Chapter 626, Statutes of 2018), available at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB901, directs revisions to fuel or feedstock procurement requirements for generation from bioenergy projects intended to reduce wildfire risks.

APPENDIX B: Glossary

This glossary is adapted from that of the *2021 SB 100 Joint Agency Report*. For more information on commonly used energy terminology, see the following industry glossary links:

- California Air Resources Board Glossary, available at https://ww2.arb.ca.gov/about/glossary
- California Energy Commission Energy Glossary, available at https://www.energy.ca.gov/resources/energy-glossary
- California Energy Commission Renewables Portfolio Standard Eligibility Guidebook, Ninth Edition Revised, available at https://efiling.energy.ca.gov/getdocument.aspx?tn=217317
- California Independent System Operator Glossary of Terms and Acronyms, available at http://www.caiso.com/Pages/glossary.aspx
- California Public Utilities Commission Glossary of Acronyms and Other Frequently Used Terms, available at https://www.cpuc.ca.gov/glossary/
- Federal Energy Regulatory Commission Glossary, available at https://www.ferc.gov/about/what-ferc/about/glossary
- U.S. Energy Information Administration Glossary, available at https://www.eia.gov/tools/glossary/

Bioenergy: Energy derived from any form of biomass or the metabolic by-products.

Biogas: Biogas is a type of biofuel that is naturally produced from the decomposition of organic waste (such as food scraps) and includes methane, CO_2, and other gases. Biofuels differ from fossil fuels because a biofuel is fuel from recently living biological matter, where fossil fuels come from long-dead biological matter.

Carbon dioxide (CO_2): A naturally occurring gas, CO_2 is also a by-product of burning fossil fuels (such as oil, gas, and coal), burning biomass, land-use changes, and industrial processes (for example, cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance.

Carbon neutrality: CO_2 and other greenhouse gas (GHG) emissions generated by sources such as transportation, power plants, and industrial processes must be less than or equal to the amount of CO_2 that is stored, both in natural sinks such as forests and mechanical sequestration such as carbon capture and sequestration. Executive Order B-55-18 established a target for California to achieve carbon neutrality by 2045 and maintain net negative emissions thereafter. For more information, see the CARB Carbon Neutrality web page.

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change: Climate change refers to a change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean or variability (or both) of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic (human-induced) changes in the composition of the atmosphere or in land use. Anthropogenic climate change is defined by the human impact on Earth's climate while natural climate changes are the natural climate cycles that have been and continue to occur throughout Earth's history. Anthropogenic climate change is directly linked to the amount of fossil fuel burning, aerosol releases, and land alteration from agriculture and deforestation. For more information, see the Energy Education Natural vs. Anthropogenic Climate Change web page.

CO_2 equivalent (CO_2e) emissions: The amount of CO_2 emissions that would cause the same integrated radiative forcing or temperature change, over a given time horizon, as an emitted amount of another greenhouse gas (GHG) or a mixture of GHGs. There are several ways to compute such equivalent emissions and choose appropriate time horizons. Most typically, the CO_2-equivalent emission is obtained by multiplying the emission of a GHG by the respective global warming potential (GWP) for a 100-year time horizon. For a mix of GHGs it is obtained by summing the CO_2-equivalent emissions of each gas. CO_2-equivalent emissions are a common scale for comparing emissions of different GHGs, but this does not imply equivalence of the corresponding climate change responses. There is generally no connection between CO_2-equivalent emissions and resulting CO_2-equivalent concentrations.

Decarbonization: The process by which countries, individuals or other entities aim to reduce or achieve zero-fossil carbon emissions. It typically refers to a reduction of the carbon emissions associated with electricity, industry, and transport. Decarbonization involves increasing the share of no- or low-carbon energy sources (renewables such as solar and wind) and decreasing the use of fossil fuels.

Demand response (DR): Demand response refers to providing wholesale and retail electricity customers with the ability to choose to respond to time-based prices and other incentives by reducing or shifting electricity use (“shift DR”), particularly during peak demand periods, so that changes in customer demand become a viable option for addressing pricing, system operations and reliability, infrastructure planning, operation and deferral, and other issues. It has been used traditionally to shed load in emergencies ("shed DR"). It also has the potential to be used as a low-greenhouse gas, low-cost, price-responsive option to help integrate renewable energy and provide grid-stabilizing services, especially when multiple distributed energy resources are used in combination and opportunities to earn income make the investment worthwhile.

Disadvantaged community: Disadvantaged communities refer to the areas throughout California that most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, air and water pollution, presence of hazardous wastes, as well as high incidence of asthma and heart disease. One way that the state identifies these areas is by collecting and analyzing information from communities all over the state. CalEnviroScreen, an analytical tool created by the California Environmental Protection Agency, combines different types of census tract-specific information into a score to determine which communities are the most burdened or "disadvantaged." For more information, see the California Office of Environmental Health Hazard Assessment's CalEnviroScreen web page.

Disadvantaged Communities Advisory Group (DACAG): An advisory body of 11 members that advises both the CEC and CPUC pursuant to the Clean Energy and Pollution Reduction Act of 2015 (also known as SB 350). SB 350 called upon the CPUC to help improve air quality and economic conditions in disadvantaged communities by, for example, changing the way the state plans the development and future operations of power plants, or rethinking the location of clean energy technologies to benefit burdened communities. In addition, SB 350 required the CPUC and the CEC to create a group representing disadvantaged communities to advise the agencies in understanding how energy programs impact these communities and could be improved to benefit these communities.

For more information, see the Disadvantaged Communities Advisory Group web page (https://www.energy.ca.gov/about/campaigns/equity-and-diversity/disadvantaged-communities-advisory-group).

Distributed energy resource(s) (DER): Distributed energy resources are any resource with a first point of interconnection of a utility distribution company or metered subsystem. Distributed energy resources include:

- Demand response, which has the potential to be used as a low-greenhouse gas, low-cost, price-responsive option to help integrate renewable energy and provide grid-stabilizing services, especially when several distributed energy resources are used in combination and opportunities to earn income make the investment worthwhile.

- Distributed renewable energy generation, primarily rooftop photovoltaic energy systems.
- Vehicle-grid integration, or all the ways plug-in electric vehicles can provide services to the grid, including coordinating the timing of vehicle charging with grid conditions.
- Energy storage in the electric power sector to capture electricity or heat for use later to help manage fluctuations in supply and demand.

Electric Program Investment Charge Program (EPIC): The CEC's Electric Program Investment Charge (EPIC) invests in scientific and technological research to accelerate the transformation of the electricity sector to meet the state's energy and climate goals. EPIC invests more than $130 million annually in areas including renewable energy, climate science, energy storage, electric system resilience, and electric technologies for buildings, businesses, and transportation. For more information, see the CEC EPIC web page and the CPUC Energy Research, Development, and Deployment web page.

Energy efficiency: Energy efficiency means adapting technology to meet consumer needs while using less energy. The CEC adopts energy efficiency standards for appliances and buildings, which reduce air pollution and save consumers money. The CPUC regulates ratepayer-funded energy efficiency programs and works with the investor-owned utilities, other program administrators, and vendors to develop programs and measures to transform technology markets within California using ratepayer funds. For more information, see the CEC Energy Efficiency web page and the CPUC Energy Efficiency web page.

Equity (energy equity): The CEC has not formally adopted a definition of "equity" or "energy equity." However, Executive Order N-16-22 explains equity as taking action to address existing disparities in opportunities and outcomes by designing and delivering services and programs, consistent with federal and state constitutional requirements, to address unequal starting points and drive equal outcomes so all Californians may reach their full potential and lead healthy and rewarding lives.

Fossil fuels: Carbon-based fuels from fossil hydrocarbon deposits, including coal, oil, and fossil gas.

Fuel cell: An energy conversion device that combines hydrogen with oxygen in an electrochemical reaction to produce electricity. A fuel cell powered by green hydrogen is an RPS-eligible resource.

Green hydrogen (green H_2): Green hydrogen means hydrogen gas that is not produced from fossil fuel feedstock sources and does not produce incremental carbon emissions during primary production.

Greenhouse gas (GHG): GHGs are those gaseous constituents of the atmosphere, natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and clouds. This property causes the greenhouse effect. Water vapor (H_2O), CO_2, nitrous oxide (N_2O), methane, and ozone are the primary GHGs in the Earth's atmosphere.

Moreover, there are several entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and methane, the Kyoto Protocol deals with the GHGs sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. In response to AB 32 (California Global Warming Solutions Act of 2006, Núñez, Chapter 488), the definition of GHGs defined in Health and Safety Code Section 38505 includes nitrogen trifluoride in addition to those defined under the Montreal and Kyoto Protocols.

Investor-owned utility (IOU): Investor-owned utilities (IOUs), with regard to electricity, provide transmission and distribution services to all electric customers in their service territory. The utilities also provide generation service for "bundled" customers, while "unbundled" customers receive electric generation service from an alternate provider, such as a community choice aggregator (CCA). California has three large IOUs offering electricity service: Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric.

Methane: Methane, also known as CH_4, is one of the six GHGs to be mitigated under the Kyoto Protocol and is the major component of pipeline gas and associated with all hydrocarbon fuels. Emissions also occur as a result of dairy and livestock operations and disposal of organics in landfills, and the management of these organics represents a major mitigation option. Methane is a short-lived climate pollutant. Unlike CO_2, which lasts for about 100 years in the atmosphere, reductions of methane can create a relatively quick reduction in global warming.

Metric ton: A metric ton is a unit of weight equal to 1,000 kilograms (or 2,205 pounds).

Microgrid: A microgrid is an interconnected system of loads and energy resources, including distributed energy resources, energy storage, demand response tools, or other management, forecasting, and analytical tools. Microgrids are appropriately sized to meet customer needs, within a clearly defined electrical boundary that can act as a single, controllable entity, and can connect to, disconnect from, or run in parallel with, larger portions of the electrical grid, or can be managed and isolated to withstand larger disturbances and maintain electrical supply to connected critical infrastructure (from Senate Bill 1339).

Particulate matter (PM): Any material, except pure water, that exists in the solid or liquid state in the atmosphere. The size of particulate matter can vary from coarse, wind-blown dust particles to fine particle combustion products.

Renewables Portfolio Standard (RPS): The Renewables Portfolio Standard, also referred to as RPS, is a program that sets continuously escalating renewable energy procurement requirements for California's load-serving entities. The generation must be procured from RPS-certified facilities (which include solar, wind, geothermal, biomass, biomethane derived from landfill or digester or both, small hydroelectric, and fuel cells using renewable fuel or qualifying hydrogen gas or both).

Resilience/resiliency: The capacity of social, economic, and environmental systems to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain the associated essential function, identity, and structure while maintaining the capacity for adaptation, learning, and transformation.

Solar PV: A technology that uses a semiconductor to convert sunlight directly into electricity via the photoelectric effect.

Zero-emission vehicles (ZEVs): There are three types of zero-emission vehicles:

- Battery-electric vehicles (BEVs) that refuel exclusively with electricity
- Plug-in hybrid electric vehicles (PHEVs) that can refuel with either electricity or another fuel, typically gasoline. BEVs and PHEVs are collectively known as "plug-in electric vehicles," or plug-in EVs.
- Fuel cell electric vehicles (FCEVs) that refuel with hydrogen

APPENDIX C:
Proposed Initiatives and Budget for Fiscal Year 2022-2023

Table ES-1: Proposed FY 2022–23 Gas R&D Budget Plan

Initiative Themes	Initiative Title	Proposed Budget
Targeted Gas System Decommissioning	Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools	$3,500,000
Decarbonization of Gas End Uses	Large-Volume Hydrogen Storage for Targeted Use Cases	$3,000,000
	Industrial Clusters for Clean Hydrogen Utilization	$1,000,000
	Mitigate Criteria Air Pollutants in Hydrogen Combustion	$4,500,000
	Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport	$4,500,000
Energy Efficiency	Analysis of Residential Hot Water Distribution Designs	$1,500,000
Entrepreneur Development	California Sustainable Energy Entrepreneur Development (CalSEED) – Low Carbon Gas	$3,600,000
Program Administration		$2,400,000
TOTAL		$24,000,000

Source: California Energy Commission