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STAFF REPORT

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2023 Annual Report

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ABSTRACT

In 2000, Assembly Bill 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 2023 Annual Report* highlights project successes and research benefits of completed and in-progress projects from July 1, 2022, through June 30, 2023. In Fiscal Year 2022–2023, 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. The Gas Research and Development program is committed to ensuring that the State's gas system is effective and safe, while working toward its equitable decommissioning.

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 2023) is guiding the state to economywide carbon neutrality by 2045. To meet these goals, California is assessing pathways to decarbonization across all sectors to help enable the state's 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 California Energy Commission's Gas Research and Development Program invests in cutting-edge technologies and strategies to catalyze progress. Assembly Bill 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, while planning for the equitable decommissioning of the gas system to meet California's decarbonization and electrification goals. Program investment totals since 2004 are as follows:

- Building Decarbonization: $57 million
- Gas System Decarbonization: $29.9 million
- Industrial and Agricultural Innovation: $72.1 million
- Transportation: $62.8 million
- Resiliency, Health, and Safety: $85.4 million
- Entrepreneurial Ecosystem: $11.2 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 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 72 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 Assembly Bill 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 California Public Utilities Commission (CPUC) requirements, the Gas R&D Program projects focus on energy efficiency, renewable technologies, conservation, and environmental issues; support state energy policy; seek to provide 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, natural gas industry experts, academic researchers, the Disadvantaged Communities Advisory Group, disadvantaged community stakeholders, 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 72 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 nearly 70 percent of technology demonstration and deployment funds in underresourced communities through the companion electricity R&D program — the Electric Program Investment Charge (EPIC) — 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,

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.

the Disadvantaged Communities Advisory Group (DACAG), and the public. In addressing the 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 Assembly Bill 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 8–9).
- A summary of how funding is allocated to each of the investment areas of the program (addressed on page 10).
- A description of successful or promising projects funded in each of the investment areas of the program (addressed on pages 11–20).
- 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 web page.
- 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, moneys in the Gas Consumption Surcharge Fund are continuously appropriated, without regard to fiscal years."[2]
- A summary of how the CEC sought to optimize ratepayer funds through collaboration and cost-sharing (addressed on page 8).

This *Gas Research and Development Program 2023 Annual Report* highlights project successes and research benefits of completed and in-progress projects from July 1, 2022, through June 30, 2023, as well as overall program investments and impacts.

Collaborative and Cofunding Opportunities

2 Section 895 of the California Public Utilities Code is available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB148.

The CEC engages with a wide range of California stakeholders — including research institutions, governmental agencies, industry and utility representatives, and the public — to incorporate diverse perspectives on gas public interest energy research projects. The CEC has an ongoing collaboration with Pacific Gas and Electric (PG&E), San Diego Gas & Electric (SDG&E), and Southern California Gas (SoCalGas), which includes their participation as members of technical advisory committees (TACs) or project teams, or as demonstration site hosts. Moreover, CEC staff has regular coordination meetings with CPUC staff to support the execution of ongoing projects and share perspectives on emerging issues related to policy, reliable gas system operations, and cost.

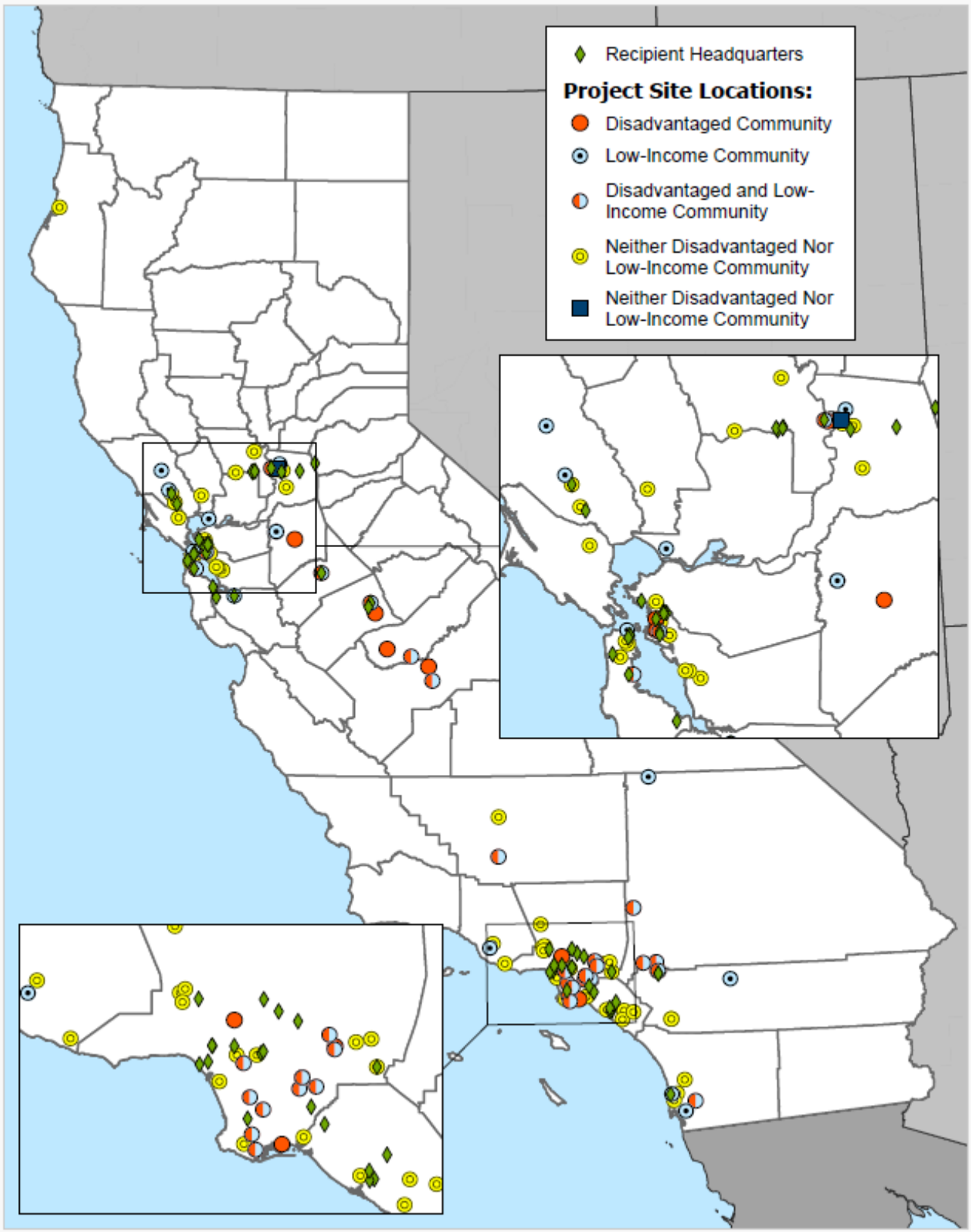
The CEC leverages cofunding opportunities by either requiring applicants for competitive solicitations to secure match funding (usually 10–20 percent), providing additional scoring points for applications that exceed the minimum match funding requirement, or both. The cumulative match investments and project successes total $152.6 million in match funding since the inception of the program. In FY 2022–2023, there were 59 active gas projects bringing in $50.1 million in match funds. A total of nearly $2.2 million of these match funds came from investor-owned utilities (IOUs, such as SoCalGas), $17.8 million from nonprofit entities such as Electric Power Research Institute (EPRI) and Gas Technology Institute, nearly $14.2 million from community- or publicly funded entities, and $17.3 million from private entities. The CEC plans to continue leveraging match to the extent possible as well as federal and private funding opportunities to maximize the impact of the Gas R&D Program.

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. To date, Gas R&D Program impacts include the following:

- **$318.5 million** has been invested across **301** projects.
- Project recipients have attracted **more than $6.1 billion in private investment** after being selected for a Gas R&D Program award.
- 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 **47 technologies or products have been commercialized**, and many more are moving toward commercialization.
- About **72 percent of program funds have been invested in disadvantaged and low-income communities**, or both, since Fiscal Year 2016–2017.

Figure 1: Map of Gas R&D Program Recipient Headquarters and Project Site Locations (Fiscal Year 2016–2017 Through June 30, 2023)



Source: CEC staff

Building Decarbonization: $57 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: $29.9 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: $72.1 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: $62.8 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: $85.4 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.

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 supported clean-tech entrepreneurship, in part by providing small grants that invest in start-ups for early-stage research and prototype development. The CEC's small grants program, the Energy Innovation Small Grant Program (EISG), provided funding for electric- and gas-related technologies. As the EISG Program ended in 2017, the CEC has since funded entrepreneurial development through the Electric Program Investment Charge.

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 Research 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

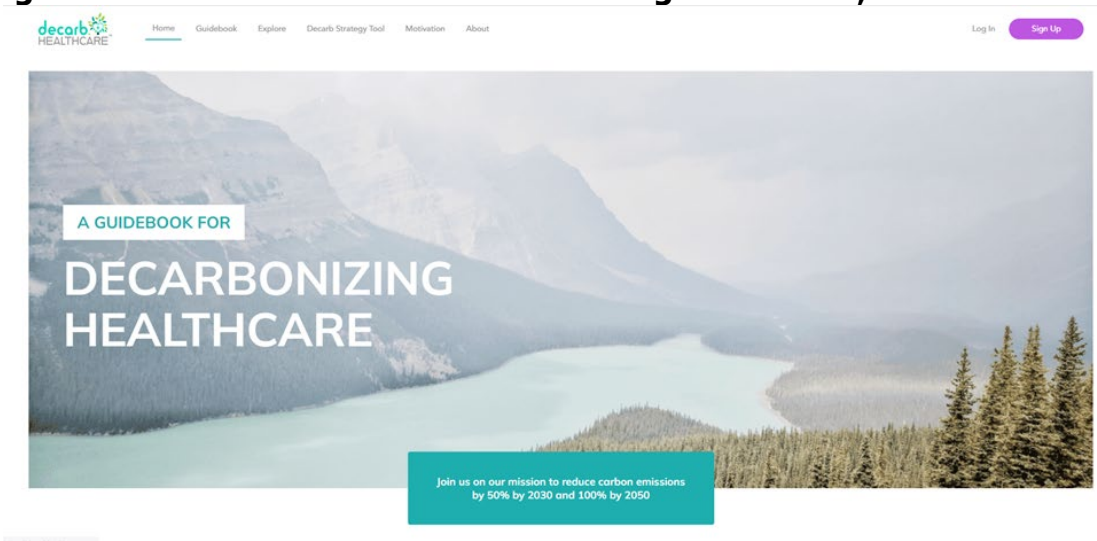
Empowering California's Healthcare Industry to Decarbonize Hospitals

With more than 39.2 million people, California is home to more than 300 hospitals — among the most in the nation. Currently, hospitals stand as the second-largest user of energy per unit of floor area of all building types within the state. Large, sophisticated heating, ventilation, and air conditioning (HVAC) systems and water-heating systems are required to satisfy the demand of these critical facilities that have 24/7 operation and are occupied by thousands of patients, employees, and visitors every day. These systems consume a substantial amount of gas statewide. Nationally, healthcare-related greenhouse gas (GHG) emissions increased 30 percent between 2006 and 2016. While many other sectors made progress to reduce emissions, the health care sector grew to contribute 8.5 percent of total U.S. emissions nationwide in that period.

> "We want to provide better care to our patients, but healthcare is a big contributor to carbon emissions that adversely impact the health of people as well as the planet, so why not change the way we practice?"
>
> *-Victor Dzau, MD, President National Academy of Medicine*

Transforming the sector is challenging. In addition to the need for increased energy efficiency and reduced energy costs, patient safety and the maintenance of hospital operations must remain central to any efforts to minimize gas use and decarbonize facilities. To provide comprehensive guidance and support to key stakeholders — including hospital owners, operators, designers, architects, engineers, and regulators — Mazzetti, an employee-owned Benefit Corporation, created the *Decarbonizing Healthcare Guidebook: A Living Resource for Emerging Energy Efficiency Equipment and Systems.* The website, accessible at https://decarbhealthcare.com/, provides a comprehensive and interactive guidebook on existing and emerging energy efficiency equipment and systems.

Figure 2: The Guidebook for Decarbonizing Healthcare, Available Online



Source: https://decarbhealthcare.com/

The interactive tool is intended to aid hospitals in planning and designing retrofit projects to substantially reduce operating costs and provides customized design improvements to help substantially reduce gas use, increase efficiency, and provide a clear path to decarbonizing hospitals. The Guidebook introduces users to more than 25 decarbonizing technologies and related benefits, outlines barriers to implementation, provides financial analysis and business cases, and presents case studies. Additional critical implementation information is provided on financing strategies, as well as relevant building codes and design standards.

Launched in partnership with the California Energy Commission, the online platform is designed to serve as a living resource, allowing users and stakeholders to post new knowledge, ask questions, and report on progress. The platform enables the guidebook to be updated continuously with leading technologies, as well as lessons learned from real-world applications.

By the Numbers:

- **30 percent –** The increase in healthcare-related greenhouse gas emissions in the United States between 2006 and 2016, accounting for 8.5 percent of total U.S. emissions.
- **339 –** The number of hospitals in California in 2022.
- **$0 –** The cost to the public for use of the Decarbonizing Healthcare Guidebook, which highlights existing and emerging energy efficiency technologies to support hospital decarbonization.
- **25+ –** The number of technology areas, from variable-air-volume ventilation and heat recover chillers to building envelope improvements and alternative steam generation, covered by the guidebook.

Gas System Decarbonization

Setting California Communities on the Path to Electrification

As California electrifies, large numbers of customers are expected to depart the gas system, risking significant gas rate increases for those who remain on the system in order to cover the fixed costs. Without mitigation, these impacts are likely to be disproportionately borne by low-income homeowners, who may be less able to afford electric options, and renters, who likely face more barriers opting into electric alternatives. Careful planning is needed to minimize burdening remaining gas customers while also ensuring equitable reductions in greenhouse gas (GHG) emissions and improved air quality among California's communities.

> Ensuring an equitable transition is "probably the biggest, hardest part of phasing out natural gas from California."
>
> *-Geof Syphers, CEO of Sonoma Clean Power*

Energy & Environmental Economics, Inc. (E3), with the support of Gridworks, East Bay Community Energy, Environmental/Justice Solutions, and PG&E, has sought to explore and develop tactical gas decommissioning plans with targeted building electrification projects to equip California communities with a roadmap for more equitable electrification.

Leveraging PG&E's Gas Asset Analysis Tool, the project team has developed a framework for identifying and prioritizing sites for targeted electrification and tactical gas decommissioning within PG&E's gas distribution system. The framework initially determined 11 candidate sites with 1,500 total customers in the communities of Oakland, Hayward, and San Leandro as part of a draft schema. The project team then considered criteria, including hydraulic feasibility; gas system avoidable costs such as avoided pipeline replacement, operations, and maintenance; and sites already planning to undertake near-term capital projects, to select sites that could best support gas system decommissioning and leverage cost savings. Across the eleven sites analyzed, the team found that strategic gas decommissioning would result in net benefits of approximately $12,000 per customer. These benefits accounted for the estimated cost of gas main and service replacement avoided through strategic gas decommissioning and the estimated cost of electrification.

The project team then evaluated community priorities and ensured the presence of community champions to optimize goal alignment, recognizing that communities that are more receptive to gas alternatives may be more likely to engage in electrification efforts. The team identified three sites in Oakland and San Leandro for producing deployment plans by implementing feedback received through community and stakeholder engagement.

Through educational town hall events and focus groups, the project team employed best practices by providing translation services, stipends, and childcare services to encourage and facilitate community participation. The team also provided educational materials and opportunities for discussion and feedback to ensure the prepared strategies and deployment plans for the three pilot communities remained responsive to community needs and priorities.

In total, the three selected pilot communities cover more than 360 gas meters as part of the first phase of the project, which encompasses project design and development. If deployed,

the plans are anticipated to provide up to $9.7 million total in avoided costs from gas main replacement across the three sites.

Figure 3: E3 and Community Engagement

Source: Gridworks

By the Numbers:

- **480 percent –** The potential increase in gas rates by 2050 given high building electrification scenarios without cost mitigation efforts.
- **$12,000 –** The approximate net benefit of strategic gas decommissioning per customer in the eleven sites analyzed.
- **360 –** The number of gas meters encompassed by the final three project sites selected.
- **$9.7 million –** The total avoided costs from gas main replacement across the three selected pilot sites.

Industrial and Agricultural Innovation

Decarbonizing California's Chemical Industry

The chemical industry is one of the largest industries worldwide, with an annual revenue of more than $4.5 trillion. While its products are a critical component in many of the world's largest value chains, the chemical industry is the second-largest user of primary energy in the United States, after only the petroleum industry. Representing almost a fifth of all manufacturing energy consumption, chemical manufacturing is one of several heavy industries that have proven difficult to decarbonize because of both the direct emissions that are a by-product of chemical reactions as well as emissions from processes dependent on very high heat or even fossil fuels as feedstock. Moreover, quality controls for products must meet rigorous safety regulations, and new manufacturing processes must be designed to also meet these standards.

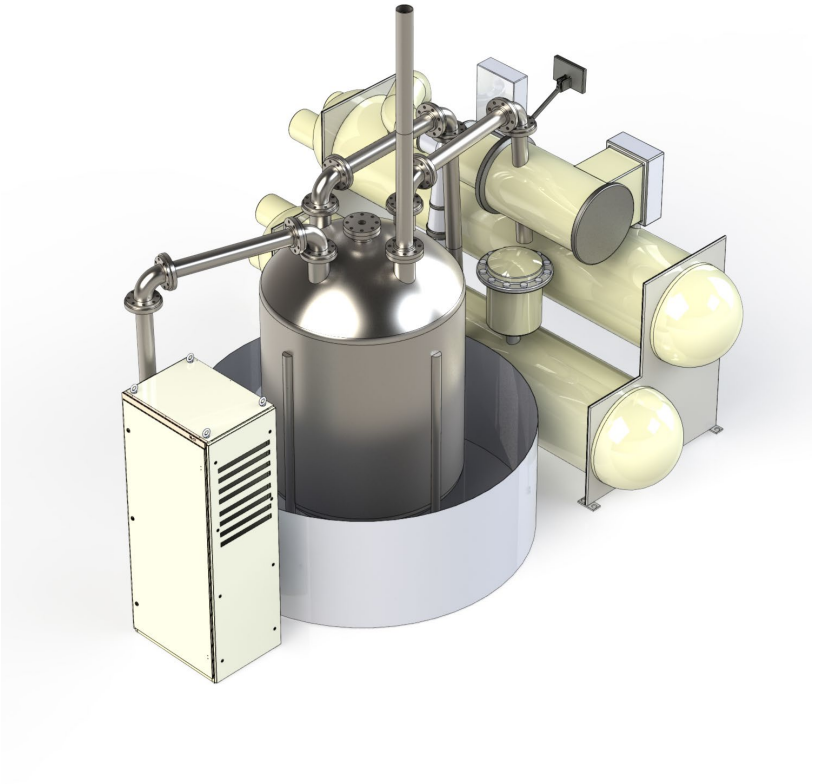
In California, the chemical industry is the third-largest industry subsector in terms of direct greenhouse gas emissions, prompting government and industry efforts to reduce the energy consumption and associated GHG emissions of chemical manufacturing. Under AB 32 and California Air Resources Board's Cap-and-Trade Program, chemical plants that emit more than 25,000 metric tons of CO_2e annually are required to reduce their emissions or purchase allowances annually. This move incentivizes the adoption of new technologies and solutions within the state's chemical industry, supporting technological competitiveness in global markets.

Element 16, founded in 2016 by three California engineers, has demonstrated the first economically viable, low-temperature industrial heat capture system with energy storage. The company's storage technology reduces gas purchases and the associated GHG emissions through process heat efficiency upgrades.

When processing plants are not operating at peak efficiency — due to weather, production volume, or maintenance outages — Element 16's system captures excess heat and stores it for future use. This stored thermal energy serves as a buffer for intermittent thermal processes, smoothing out the thermal load at the facility and reducing thermal shocks to equipment. The Element 16 system can also act as a backup heat supply, discharging heat during unexpected process heat shortages and outages and adding redundancy to critical production systems.

Aiming to demonstrate a 15 percent reduction in gas usage at a chemical processing plant in Southern California, Element 16's installation in partnership with the CEC was the first large – industrial-scale demonstration of Element 16's intermittent waste heat capture product. With the Element 16 Heat Capture System first installed in May 2022, this project is already saving the facility tens of thousands of dollars in annual gas and water costs. The project is moreover demonstrating to the chemical industry that heat capture systems can reliably improve plant economics.

Figure 4: Element 16's Thermal Energy Storage System



Source: Element 16

By the Numbers:

- **925 million metric tons –** The amount of CO_2 emitted by the chemistry industry worldwide in 2021, or roughly 2 percent of total global emissions.
- **Third –** The chemical industry's rank in California among largest GHG emitting industrial subsectors.
- **15 percent –** The anticipated reduction in gas usage at Element 16's demonstration site at a chemical processing plant in southern California.
- **2030 –** The year by which chemical production must decouple from CO_2 emissions to meet the Net Zero Emissions by 2050 (NZE) Scenario.[3]

3 IEA staff. *Tracking Clean Energy Progress 2023.* July 2023. Paris, France. Available at https://www.iea.org/reports/tracking-clean-energy-progress-2023. License: CC BY 4.0.

Transportation

Hydrogen Fuel Cells and Cleaning Up California's Railyards

Communities living and working near rail operations at ports, railyards, and other locations bear a disproportionate health burden due to their proximity to harmful emissions. To help mitigate these emissions, the California Air Resources Board (CARB) recently approved the In-Use Locomotive Regulation, establishing zero-emission requirements for locomotives operating in California starting in 2030.[4]

Better understanding of zero-emission technologies like hydrogen fuel cells is needed to help inform and promote adoption within the rail sector. As the gas system evolves to potentially support clean hydrogen conveyance in the future, the rail sector could be an important end-use to target. One possible avenue for early intervention are switcher locomotives, which perform first- and last-mile freight rail functions at ports and railyards. California has more than 800 such locomotives in use. As they are often older and possess minimal emissions-mitigating aftertreatment, these switcher locomotives degrade air quality in communities located around the state's ports and railyards, including dense urban areas like West Oakland, Wilmington, West Long Beach, Chula Vista, and Coronado.

> "Locomotives are a key part of California's transportation network, and it's time that they are part of the solution to tackle pollution and clean our air."
>
> *-CARB Chair Liane Randolph*

The Institute of Gas Technology (GTI Energy) and its project partners have been working to integrate a hydrogen fuel cell module, onboard hydrogen storage, and a battery module to collectively provide an efficient zero-emission alternative to diesel switcher locomotives and chart a path for hydrogen fuel cell technology use in rail applications across California. Building and demonstrating a hydrogen fuel cell switcher locomotive with Sierra Northern Railway, a Class III short-line railroad that operates around the Port of West Sacramento, GTI Energy anticipates that the new zero-emission switcher locomotive will displace up to 10,000 gallons of conventional diesel fuel per year. This means an anticipated 138 tons of CO_2, 3 tons of NOx, and 200 kg of PM10 displaced annually, reducing air pollution and the associated negative health impacts for surrounding communities.

[4] CARB. Locomotive Fact Sheets. https://ww2.arb.ca.gov/our-work/programs/reducing-rail-emissions-california/locomotive-fact-sheets

Figure 5: Sierra Northern's Zero-Emission Hydrogen Switching Locomotive

Source: Sierra Northern Railway

By the Numbers:

- **800+ –** The number of switcher locomotives in use in California in 2021.
- **10,000 Gallons –** The estimated annual diesel consumption displaced by the Sierra Northern zero-emission switcher locomotive.
- **138 Tons –** The amount of CO_2 to be displaced annually by the new zero-emission switcher locomotive.
- **3 Tons –** The amount of NOx, in addition to 200 kg of PM10, to be displaced annually by the new zero-emission switcher locomotive.

Resiliency, Health, and Safety

Electromagnetic and Optical Sensor Technologies for Gas Storage Safety Monitoring

Roughly 67 percent of underground gas storage wells in California were spudded, or had begun the process to be drilled, before the 1980s.[5] With approximately 400 gas storage wells across the state, the system's total working gas capacity was 322,868 million cubic feet in 2022. After decades of degradation and corrosion caused by the frequent injection and withdrawal of gas, well integrity has become a rising worry for Californians. Concerns about the potential for another massive gas leak caused by wellbore failure — like that of Aliso Canyon in 2015 — are one such consideration.

> "It is difficult to predict borehole degradation trajectory with the sparse data generated by traditional methods. Having higher frequency datasets covering the entire borehole is key to provide an early warning of potential borehole failures."
>
> *-Yuxin Wu, Lawrence Berkeley National Laboratory*

Current California Geologic Energy Management Division (CalGEM) regulations require inspections to assess well integrity every two years, unless otherwise justified. However, existing wellbore integrity inspection technologies are intrusive, disruptive to normal operations, expensive, and unable to provide continuous real-time visibility into the degradation trajectory.

Lawrence Berkeley National Lab (LBNL), in close coordination with PG&E, has developed, lab tested, and is now field demonstrating an integrated and real-time suite of gas storage wellbore operation and integrity monitoring technologies. This new method for monitoring uses an optical sensor (optical fiber) and electromagnetic time domain reflectometry (EM-TDR) to send electromagnetic waves into an electronically conductive material, like steel. Then, based on the electromagnetic signal received back, degradations can begin to be identified. The EM-TDR technology provides real-time operation status monitoring and, as casings are made of steel, does not require any additional downhole equipment to be installed.

When coupled with installation of the optical fiber technology, the EM-TDR can provide increased monitoring and diagnosis confidence and reduce false alarms. These cables, installed inside the borehole casing, can provide continuous monitoring of strain and temperature change due to borehole vibration, deformation, and leakage, providing critical monitoring and integrity data as often as every minute. The real-time visibility achieved could thereby help to justify less frequent inspections to assess well integrity.

While still an early-stage technology, the optical fiber and EM-TDR can help optimize maintenance priorities to minimize loss and interruption to energy supplies with a rapid and

[5] California Council on Science and Technology. Long-Term Viability of Underground Natural Gas Storage in California. Chapter 1, Section 1.1. December 2017. https://ccst.us/wp-content/uploads/Chapter-1-v2-Section-1-1.pdf

cost-effective deployment. Looking forward, the project team is considering the potential to connect the technologies to operation controls, enabling autonomous emergency shutoffs.

Figure 6: Fiber Optics Installation at PG&E's McDonald Island Gas Storage Field

Source: LBNL

By the Numbers:

- **400 –** The approximate number of underground gas storage wells in California.
- **322,868 million cubic feet –** The total working gas capacity of California's underground gas storage facilities in 2022.[6]
- **2 years –** The default required frequency of wellbore integrity inspections.
- **1 minute –** The frequency by which the EM-TDR and optical fiber technology can report data on wellbore conditions.

6 U.S. Energy Information Administration staff. "Natural Gas Summary." August 2023. Available at https://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_SCA_a.htm.

LIST OF ACRONYMS

Term	Definition
AB	Assembly Bill
CARB	California Air Resources Board
CEC	California Energy Commission
CO_2	Carbon dioxide
CO_{2e}	The number of metric tons of CO2 emissions with the same global warming potential as one metric ton of another greenhouse gas
CPUC	California Public Utilities Commission
DACAG	Disadvantaged Communities Advisory Group
E3	Energy & Environmental Economics, Inc.
EISG	Energy Innovation Small Grant Program
EM-TDR	Electromagnetic time domain reflectometry
EPIC	Electric Program Investment Charge Program
EPRI	Electric Power Research Institute
GTI Energy	Gas Technology Institute
GHG	Greenhouse gas
HCS	Heat capture systems
HVAC	Heating, ventilation, and air conditioning
LBNL	Lawrence Berkeley National Laboratory
NOx	Oxides of nitrogen
PG&E	Pacific Gas and Electric
R&D	Research and development
SB	Senate Bill
SDG&E	San Diego Gas & Electric
SoCalGas	Southern California Gas
TAC	Technical advisory committee
TES	Thermal energy storage
ZNE	Zero Net Energy

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 CHP 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=201520160SB887, 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 several 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 it as follows: 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, HFCs, 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 because 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 2023-2023

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