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ENERGY COMMISSION

Energy Research and Development Division

STAFF REPORT

Natural Gas Research and Development Program

Proposed Budget Plan for Fiscal Year 2021-22

Gavin Newsom, Governor

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PREFACE

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

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

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

The *Natural Gas Research and Development Program Proposed Budget Plan for Fiscal Year 2021-22* is a staff report prepared by the CEC's Energy Research and Development Division.

For more information about the Energy Research and Development Division, please visit Research and Development at the Energy Commission's website.

ABSTRACT

In 2000, Assembly Bill (AB) 1002 (Wright, Chapter 932, Statutes of 2000) was enacted, requiring the California Public Utilities Commission (CPUC) to add a surcharge on natural gas consumed in California. This surcharge funded various energy efficiency programs and public interest research and development to benefit natural 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.

The *Natural Gas Research and Development Program Proposed Budget Plan for Fiscal Year 2021-22* describes the CEC's proposed natural gas research initiatives in energy efficiency, renewable energy and advanced generation, natural gas infrastructure safety and integrity, energy-related environmental research, and transportation. These initiatives support the state's energy policies and objectives, with several initiatives directly benefitting disadvantaged communities.

The proposed research funding for Fiscal Year 2021-22 is $24 million, and the budget plan covers July 1, 2021, through June 30, 2022. The budget plan was informed by input from California stakeholders, research institutions, equipment manufacturers, disadvantaged and low-income community representatives, and governmental partners.

CEC staff appreciates the coordination with CPUC on the proposed research initiatives and CPUC's ongoing support to enable access to needed utility infrastructure data.

Keywords: California Energy Commission; California Public Utilities Commission; natural gas; energy efficiency; pipeline safety; climate change; drought; buildings end-use energy efficiency; industrial, agriculture, and water efficiency; renewable energy and advanced generation; energy infrastructure; natural gas pipeline integrity; energy-related environmental research; transportation; disadvantaged communities; low-income communities

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EXECUTIVE SUMMARY

As California continues to pursue its ambitious emission reduction and renewable energy targets to tackle climate change and improve public health and safety, the role of natural gas in the energy system will change. Continued public research and development investments in energy technologies are critical for supporting this transition and ensuring that the state's clean energy goals are met safely and cost-effectively.

Recent laws, executive orders, technology advancements, and environmental research continue to reshape the landscape for the Natural Gas Research and Development (R&D) Program. For example, in 2018, former Governor Edmund G. Brown Jr. set two of the most ambitious climate targets in history by signing Senate Bill 100 (De León, Chapter 312, Statutes of 2018), requiring that all retail sales of electricity in California be renewable or zero-carbon by 2045, and by issuing Executive Order B-55-18, requiring that the entire California economy achieve carbon neutrality (net zero carbon emissions) by 2045. While these goals are 24 years in the future, planning must begin now for the state to transition successfully toward these goals cost-effectively.

In accordance with guidance from the California Public Utilities Commission (CPUC) and the California Energy Commission's (CEC) analysis of research gaps, the CEC proposes to pursue targeted research under the Natural Gas R&D Program in energy efficiency, renewable energy and advanced generation, natural gas infrastructure safety and integrity, energy-related environmental research, and transportation. This research will help build the technological foundation for achieving the goals of SB 100, Executive Order B-55-18, and other important state policies and objectives.

Natural gas plays an evolving role in California's energy system. It is used in homes and businesses, including for space and water heating, drying, and cooking. In the industrial and transportation sectors, it is used for process heating, combined heating and power, and vehicle operation. In 2019, Californians consumed about 2.1 trillion cubic feet of natural gas, with the industrial and electric power sectors together accounting for more than half of the consumption at 37 percent and 28 percent, respectively. According to the *California Energy Demand 2018-2030 Revised Forecast*, these numbers are expected to grow slowly, with estimates showing an average demand increase for natural gas of about 0.34 percent per year through 2030. However, recent market trends and carbon reduction goals signal a transition away from the use of natural gas derived from fossil sources.

As the state reduces reliance on fossil natural gas, research and development will help drive innovations that ensure a safe natural gas system, minimize environmental impacts including methane leakage, and enable cost-effective pathways for producing and using renewable natural gas (RNG) and hydrogen . Key objectives of the Natural Gas R&D Program are to:

- Enhance engagement with low-income and disadvantaged communities to ensure all Californians have access to clean, affordable energy, building on recent and current engagement (discussed in Chapter 2).
- Improve understanding of health and safety-related issues as California transitions to low- and no-carbon substitutes for fossil natural gas.
- Assess the environmental and climate implications of new energy technologies using low- and no-carbon substitutes for fossil natural gas.

- Inform future policy deliberations about the future of natural gas in California as the state moves toward its decarbonization goals.
- Support technologies that provide significant efficiency and emissions improvements for sectors such as transportation and industry that have a longer horizon to zero-net greenhouse gas emissions.
- Avoid supporting energy technologies that would become stranded assets by 2045, considering the time needed to develop new low-carbon, market-ready technologies.
- Reduce the production costs of low- and no-carbon substitutes for fossil natural gas, such as synthetic natural gas, RNG, and hydrogen.
- Enable the safe and economical use of hydrogen as a sustainable energy resource and examine opportunities to use existing natural gas infrastructure to support hydrogen distribution.
- Develop and demonstrate energy technologies that can enable negative emissions, such as biomethane production technologies, which could be paired with carbon capture and storage.
- Measure and enable the reduction of methane leaks that contribute to greenhouse gas emissions.

Research Approach and Stakeholder Participation

The CEC's Energy Research and Development Division staff develops natural gas research initiatives based on state energy policies, plans, and guidance; analysis of research gaps; and stakeholder input. Key policies, plans, and guidance include:

- CPUC Resolution G-3571.
- CPUC Decision 04-08-010.
- Senate Bill 100 (De León, Chapter 312, Statutes of 2018).
- Executive Order B-55-18.
- Assembly Bill 32, the Global Warming Solutions Act (Núñez, Chapter 488, Statutes of 2006).
- Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016).
- Integrated Energy Policy Reports.
- California Energy Efficiency Strategic Plan.

On January 29, 2021, CEC staff held a public workshop to present the proposed budget plan for the FY 2021-22 Natural Gas R&D Program and received comments from stakeholders supporting the proposed initiatives and offering helpful input and perspective on specific research topics. The workshop was attended by 117 people, not including the CEC panelists, and there were more than two dozen attendee questions and comments during the workshop discussion. CEC staff also received written public comments that have informed this proposed plan. See Appendices A and B for the staff workshop presentation and a summary of public comments and CEC staff responses.

On January 08, 2021, CEC staff held a coordination meeting with CPUC staff to present the proposed budget plan for the FY 2021–22 Natural Gas R&D Program and received comments from CPUC staff, offering helpful input and perspective on specific research topics, as well as suggesting potential research areas. This meeting also met the CPUC request in Resolution G-3571 to coordinate with CPUC staff in the Energy Division and Safety and Enforcement Division

in advance of the public workshop. See Appendix B for a summary of CPUC staff comments and CEC staff responses, including revisions made to initiatives based on the comments.

On January 22, 2021, CEC staff attended a Disadvantaged Community Advisory Group (DACAG) meeting to present the proposed budget plan for the FY 2021–22 Natural Gas R&D Program and received comments from stakeholders supporting the proposed initiatives and offering helpful input and perspective on specific research topics as they relate to underresourced community needs. See Appendix B for a summary of DACAG comments and CEC staff responses including revisions made to initiatives based on the comments. Moreover, before the DACAG meeting, CEC staff released December 4, 2020, an outreach survey titled "DACAG and Community Member Survey on Natural Gas R&D Initiatives for 2021" focused on the needs of underresourced communities with responses due on December 28, 2020. The survey and presentation at the DACAG meeting also met the CPUC's request in Resolution G-3571 to coordinate more closely with the DACAG and engage with appropriate disadvantaged community stakeholders to solicit feedback.

Natural Gas R&D Program Proposed Budget Plan for Fiscal Year 2021–22

The Fiscal Year (FY) 2021–22 Natural Gas R&D Program proposed budget plan allocates $24 million across five research areas, with 10 percent for program administration support (Table ES-1).

Table ES-1: Fiscal Year 2021-22 Natural Gas Research and Development Program Proposed Budget Plan

Research Areas	Proposed FY 2021-22 Natural Gas Budget
Energy Efficiency	$6,100,000
Renewable Energy and Advanced Generation	$4,000,000
Natural Gas Infrastructure Safety and Integrity	$4,000,000
Energy-Related Environmental Research	$3,500,000
Transportation	$4,000,000
Program Administration	$2,400,000
TOTAL	$24,000,000

Source: California Energy Commission

Data Access Needs

CEC staff appreciates the coordination with the CPUC on the proposed research initiatives and ongoing coordination on research data needs. To enable successful advancement of the initiatives, CEC staff requests CPUC's continued support in easing access to needed utility infrastructure data.

CHAPTER 1: Introduction

Recognizing the benefit of natural gas research to Californians, Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) directed the California Public Utilities Commission (CPUC) to add a surcharge on all-natural gas consumed in California to fund research and development specific to natural gas. The 2004 CPUC Decision 04-08-010 designated the California Energy Commission (CEC) as the administrator for the Natural Gas Research and Development (R&D) Program. The CPUC allocates $24 million annually and defines public interest natural gas research activities as those "directed towards developing science or technology, and 1) the benefits of which accrue to California citizens, and 2) are not adequately addressed by competitive or regulated entities."[1] The decision also directs Natural Gas R&D projects to:

- Focus on energy efficiency, renewable technologies, conservation, and environmental issues.
- Support state energy policy.
- Provide communitywide benefits including job creation, improved air quality, and economic stimulation.
- Consider opportunities for collaboration and co-funding with other entities, such as federal and local agencies.

Intersection of Research and Policy

The CEC's Natural Gas R&D Program responds to and informs state energy policies, plans, and guidance, including from the CPUC. For example, the program supports California's progress toward two landmark policies established in 2018: Senate Bill 100 (De León, Chapter 312, Statutes of 2018), requiring that all retail sales of electricity in California be renewable or zero-carbon by 2045, and Executive Order B-55-18, requiring that the entire California economy achieve carbon neutrality by 2045. While these goals are 25 years in the future, planning must begin now for the state to transition toward these end goals cost-effectively. Additional examples of policies supported by the Natural Gas R&D Program include the Short-Lived Climate Pollutant Reduction Strategy (Senate Bill 1383, Lara, Chapter 395, Statutes of 2016) and Senate Bill 350 (De León, Chapter 547, Statutes of 2015), which aims to increase clean energy funding directed to low-income and disadvantaged communities. The *2017 Climate Change Scoping Plan Update* underscores the pivotal role of innovative technologies in improving efficiency, increasing the production of renewable natural gas, and reducing leakage from natural gas infrastructure in meeting future climate change targets.[2]

1 California Public Utilities Commission Decision 04-08-010, p. 24.
2 California Air Resources Board. California's 2017 Climate Change Scoping Plan.

The Natural Gas R&D Program supports a range of CPUC policies, including:

- CPUC Resolution G-3571 (November 2020), which directs the CEC to consider research on topics based on CPUC proceedings and policies, including the impacts to indoor air quality from natural gas appliances.
- CPUC Resolution G-3555 (August 2019), which directs the CEC to consider research on pipeline corrosion and hydrogen blend impacts on infrastructure and end-use appliances.
- CPUC's General Order No. 112-F (January 2015), which addresses the rules for utilities to design, construct, test, operate, and maintain piping systems beyond the requirements set by federal regulations.
- CPUC's Gas Safety Plan (October 2012), which will improve the CPUC's safety and enforcement programs.

Additional examples of policies, plans, and guidance that drive or are informed by the Natural Gas R&D Program are shown in Table 1.

Table 1: Examples of the Intersection of Research and Policy for the Natural Gas Research and Development Program

Research Area	Policies, Guidance, and Plans
Natural Gas R&D Program	• Executive Order B-55-18 requires that California's economy achieve carbon neutrality by 2045. • Senate Bill 100 (De León, Chapter 312, Statutes of 2018) requires 60% of retail sales of electricity be generated from eligible renewable energy resources by 2030 and all retail sales of electricity be renewable or zero-carbon by 2045. • SB-1369 (Skinner, Chapter 567, Statues of 2018) requires the consideration of uses of green electrolytic hydrogen. • Public Utilities Code Section 895 provides statutory authority for the CEC to administer the natural gas funds using the Public Interest Energy Research (PIER) statutes. • Senate Bill 32 (Pavley, Chapter 249, Status of 2016) requires California to reduce GHG emissions to 40 percent below 1990 levels by 2030. • Assembly Bill 32 (Núñez, Chapter 488 Statutes of 2006) — California Global Warming Solutions Act of 2006 requires the development of Scoping Plans to reduce GHG emissions. • Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006) authorizes continuing investments in public interest energy research. • Integrated Energy Policy Report (IEPR) assesses major energy trends facing California's electricity, natural gas, and transportation fuel sectors and provides policy recommendations. • Public Resources Code 25620 allows the state to undertake public interest energy research, development, and demonstration projects.

Research Area	Policies, Guidance, and Plans
Energy Efficiency	• Energy Efficiency Buildings Standards (Title 24, Part 6) — goals for 2019 Standards.[3] • Appliance Energy Efficiency Standards (Title 20, Division 2, Chapter 4, Article 4, Sections 1601–1608: Appliance Efficiency Regulations) • Senate Bill 350 (De León, Chapter 547, Statutes of 2015) 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. • California Energy Efficiency Strategic Plan establishes goals for zero-net-energy buildings and to increase building energy efficiency cost effectively. • 2019 California Energy Efficiency Action Plan[4] addresses existing buildings, low-income barriers to energy efficiency, agriculture, industry, newly constructed buildings, conservation voltage reduction, and electrification.
Renewable Energy and Advanced Generation	• Senate Bill 100 (De León, Chapter 312, Statutes of 2018) requires 60% of retail sales of electricity be generated from eligible renewable energy resources by 2030 and all retail sales of electricity be renewable or zero-carbon by 2045. • SB-1369 (Skinner, Chapter 567, Statues of 2018) requires the consideration of uses of green electrolytic hydrogen. • Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016) 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 1613, the Waste Heat and Carbon Emissions Reduction Act (Blakeslee, Chapter 713, Statutes of 2007) 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. • Bioenergy Action Plan[5] implements Executive Order S-06-06, which set goals for the production and use of electricity and fuels made from biomass.

3 Cox, Rory. October 24, 2017. It All Adds up to Zero, California's Zero- Net -Energy Future, California Public Utilities Commission, Bay REN Forum.

4 Kenney, Michael, Heather Bird, and Heriberto Rosales. 2019. 2019 California Energy Efficiency Action Plan. California Energy Commission. Publication Number: CEC-400-2019-010-SF.

5 O'Neill, Garry. 2012. *2012 Bioenergy Action Plan*. California Energy Commission, Efficiency and Renewables Division.

Research Area	Policies, Guidance, and Plans
Natural Gas Infrastructure Safety and Integrity	• Senate Bill 887 (Pavley, Chapter 673, Statutes of 2016) issued requirements to ensure the safety and integrity of natural gas storage facilities. • Senate Bill 1371 (Leno, Chapter 525, Statutes of 2014) 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. • CPUC Order Institution Investigation I1702002 under Senate Bill 380 (Pavley, Chapter 14, Statutes of 2016) determines the feasibility of minimizing or eliminating the use of the Aliso Canyon natural gas storage facility in Los Angeles County while maintaining energy and electric reliability for the region.
Energy-Related Environmental Research	• CPUC Decision 19-10-054, Rulemaking 18-04-019, outlines strategies and guidance for climate change adaptation. • Assembly Bill 1496 (Thurmond, Chapter 604, Statutes of 2015) requires the state to monitor methane hotspots. • CARB's Short-Lived Climate Pollutant Reduction Strategy recommends actions to reduce emissions of short-lived climate pollutants, including from dairies, organics disposal, and wastewater.
Transportation	• Executive Order B-32-15 directed the development of the Sustainable Freight Action Plan, which 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. • Executive Order N-79-20 set goals to transition all drayage trucks to zero-emission by 2035, all off-road vehicles to zero-emission where feasible by 2035, and the remainder of medium- and heavy-duty vehicles to zero-emission where feasible by 2045. • SB-1369 (Skinner, Chapter 567, Statues of 2018) requires the consideration of uses of green electrolytic hydrogen. • 2016 Mobile Source Strategy determines the pathways forward for various mobile sectors that are necessary to achieve California's air quality and greenhouse gas reduction goals. • Low Carbon Fuel Standard (LCFS) 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.

Source: California Energy Commission

CPUC Resolution G-3571 Guidance for Fiscal Year 2021–2022 Plan

CPUC Resolution G-3571 directed the CEC to do the following in developing the Fiscal Year 2021–22 budget plan.

a) **Reduce greenhouse gas emissions from California's buildings:** Consider the report the CEC will produce to fulfill AB 3232 (Friedman, Chapter 373, Statutes of 2018) "zero-emissions buildings and sources of heat energy" when it is released.

b) **Incorporate Long-term natural gas research strategy to achieve decarbonization goals:** When it becomes available, discuss how the "Long-Term Technological Development Strategy to Meet Aggressive Statewide Decarbonization Goals," funded in FY 2019-20 in response to direction from Resolution G- 3546, was used to guide plan development.

c) **Engage Disadvantaged Communities Advisory Group:** Coordinate more closely with the DACAG to solicit feedback, including earlier coordination to lead a presentation of the FY 2021–22 Plan, if requested by the DACAG.

d) **Engage Disadvantaged Communities:** Increase efforts to identify and engage appropriate disadvantaged community stakeholders to provide feedback on the FY 2021–22 Plan and document those efforts in the FY 2021–22 Plan. If feedback is not received by disadvantaged community groups on the draft plan, describe any barriers that must be overcome to receiving feedback on future plans.

CPUC Resolution G-3571 also directed the CEC to consider research in the following topic area to inform the CPUC's proceedings and policies.

e) **Assess effects of natural gas on indoor air quality:** Quantify and document impacts to indoor air quality from natural gas appliances and the potential technically feasible improvements and potential risks to indoor air quality that could be achieved from fuel blending or electrification.

This FY 2021–22 budget plan for the Natural Gas R&D Program aligns with the guidance provided in CPUC Resolution G-3571. Additional discussions with CPUC staff helped inform the proposed initiatives for the FY 2021–22 budget plan by ensuring alignment with CPUC proceedings and policies. Chapter 2 details how the CEC continues to engage representatives from disadvantaged communities[6] and other stakeholders. Assessing indoor air quality is included as one of the initiatives, described later in the report.

CPUC Resolution G-3571 directed the CEC to do the following as part of the preformal submission to the Fiscal Year 2021–22 budget plan.

f) **Coordinate with CPUC staff:** At least three weeks in advance of CEC's public workshop on the proposed budget plan, coordinate with CPUC staff in Energy Division and Safety and Enforcement Division. The goal of this additional step is to ensure the best possible use of funds across programs.

g) **For as long as the pandemic continues to affect research efforts:** Consider any research gaps that might emerge due to recent budget decreases/reallocations in response to COVID-related economic effects and potential cofunding opportunities that the Natural Gas R&D Program can provide to limit the impact of these gaps on California energy goals.

h) **Post the Natural Gas Research and Development Program:** Propose budget plan publicly on the CEC's website before submitting an approval request to the CPUC and notify the CPUC of the web address when requesting approval of the plan.

i) **Distribute the Natural Gas Research and Development Program:** Propose budget plan through the CEC's research/R&D community listserves and include the names of the distribution lists served when requesting CPUC's approval of the plan.

6 Disadvantaged communities are defined as areas representing census tracts scoring in the top 25 percent in CalEnviroScreen 3.0.

Consult with Energy Division staff on which CPUC listserves from ongoing CPUC proceedings the CEC should notice its proposed plan.

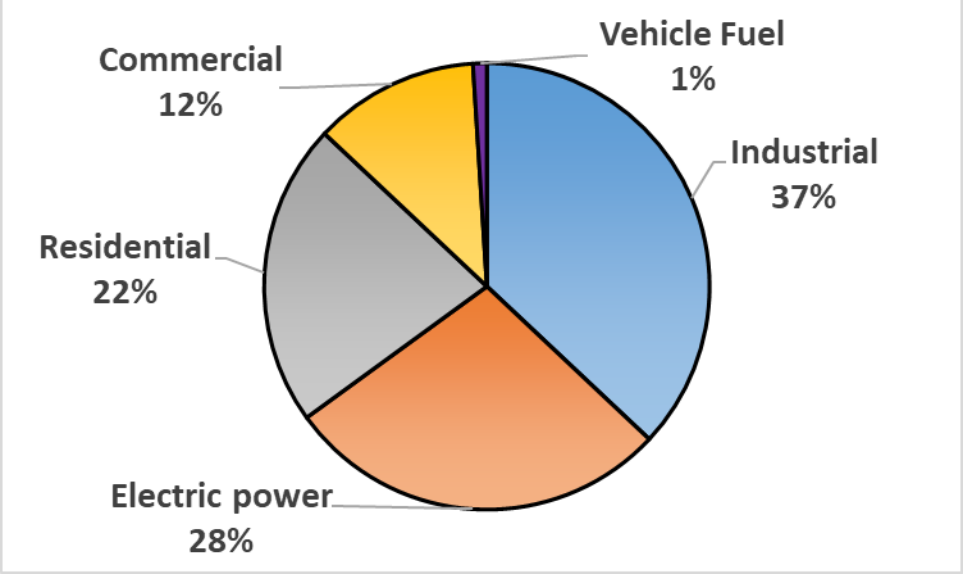
j) **Option to present during a CPUC commissioner committee meeting:** Consult with CPUC staff to allow for the option of presenting the Natural Gas Research and Development Program: Proposed Budget Plan to the CPUC commissioners during a CPUC commissioner committee meeting.

Importance of Natural Gas Research to Meet Decarbonization Goals

Natural gas is a major fuel in California's economy. In 2019, California's five end-use sectors — residential, commercial, industrial, transportation, and electricity generation — consumed about 2.1 trillion cubic feet (Tcf), or about 5.8 billion cubic feet (Bcf) per day.[7] The electricity generation and industrial sectors account for most of the natural gas use in California.

Figure 1 provides a breakdown of natural gas use per sector in 2019.

Figure 1: Percentage Use of Natural Gas by Sector in California (2019)



Source: U.S. Energy Information Administration

About 28 percent of the natural gas is used in electricity generation, which represented 43 percent of the total electricity produced in California in 2019.[8] Transportation accounts for only about 1 percent of natural gas consumption in California, though this number is likely to increase because of the growing number of natural gas trucks in the heavy-duty vehicle sector, where natural gas can serve as an alternative to diesel.[9]

Despite a 33 percent increase in California's population since 1990, natural gas demand in the residential sector has experienced a slight decline, while demand has been relatively flat in the commercial, industrial, and power generation sectors.[10] These results reflect California's

7 United States Energy Information Administration. Natural Gas Consumption by End Use (California, Annual, 2019).
8 California Energy Commission. 2019 Total System Electric Generation in Gigawatt Hours.
9 Bahrenian, Aniss. December 2020. *Transportation Energy Demand Forecast 2020 IEPR Update: 2020 IEPR Workshop*. California Energy Commission.
10 State of California, Department of Finance. California Population Estimates, with Components of Change and Crude Rates, July 1, 1900-2019. December 2019.

success in implementing energy efficiency standards for buildings, appliances, and utilities. Nevertheless, in the absence of additional near-term market or policy changes, overall demand for natural gas in California may grow slowly through 2030, with a 0.34 percent per year increase projected in the mid-demand case scenario of CEC's *California Energy Demand 2018-2030 Revised Forecast*. This projection scenario represents a "business-as-usual" environment, with consideration of current policies such as the Renewables Portfolio Standard, SB 350, and energy efficiency standards.[11]

In the long term, the state's clean energy and climate goals signal a transition away from fossil natural gas for the power generation, residential, and commercial sectors. Building electrification is a key strategy for decarbonizing homes and businesses. Dozens of local authorities in California have adopted ordinances and building codes to advance building electrification and transition away from natural gas use. Developing cost-effective pathways for producing and using renewable natural gas (RNG), and hydrogen is another key strategy for lowering GHG emissions. Use of the existing infrastructure to transport these fuels requires that pipeline leakage and other potential safety, operational, and environmental issues be addressed.[12] Improvements in the safe transport, including minimizing methane leakage, and efficient use of natural gas will also be important. Efficient use of natural gas is needed for end-use sectors that are harder to electrify, such as certain industry subsectors and transportation, and potentially in electricity generation. Natural gas can be used to meet electricity demand when renewable generation is varying.

Since 2004, the Natural Gas R&D program has invested in research to develop technologies, tools, and strategies that increase energy efficiency, reduce energy cost, reduce air pollutants and GHG emissions, and improve the safety of pipeline infrastructure. The *Natural Gas Research and Development 2020 Annual Report* delivered to the CPUC provides a recent review of program achievements in FY 2019–2020.[13] Since the inception of the program in 2004, research has focused on using natural gas as safely, cleanly, and efficiently as possible. These topics remain important, but the FY 2021–22 budget plan places greater emphasis on research areas that align with the state's current priorities for decarbonization — including research on areas such as strategic decommissioning of natural gas system infrastructure, and alternatives to fossil-based natural gas such as hydrogen — as well as indoor air quality and pipeline safety. The full set of initiatives is presented in Chapter 2.

11 Kavalec, Chris, Asish Gautam, Mike Jaske, Lynn Marshall, Nahid Movassagh, and Ravinderpal Vaid. 2018. *California Energy Demand 2018–2030 Revised Forecast.* California Energy Commission, Energy Assessments Division. Publication Number: CEC-200-2018-002-CMF.
12 Campagna, Jennifer, Leon Brathwaite, Anthony Dixon, Jason Orta, and Peter Puglia. 2019. *2020 Natural Gas Market Trends and Outlook Report.* California Energy Commission. Publication Number: CEC-200-2020-002.
13 2020. Energy Research and Development Division. 2020. 2020 *Natural Gas Research and Development Program Annual Report.* California Energy Commission. Publication Number: CEC-500-2020-073.

CHAPTER 2:
Natural Gas Research and Development Program Proposed Plan for Fiscal Year 2021–2022

Developing Research Initiatives

Stakeholder Participation and Strategic Partnerships

The CEC engages with stakeholders to develop a research portfolio responding to challenges in the natural gas sector. Stakeholders provide invaluable input for the development of research initiatives. The CEC collaborates with a wide range of California stakeholders, research institutions, governmental agencies, and industry and utility representatives to develop a shared vision of natural gas public interest energy research projects. This thoughtful outreach improves accountability, transparency, communication, and responsiveness. The CEC relies on these strategic partnerships to avoid duplication, build upon previous R&D work, generate new ideas, leverage public and private investments, and ensure the research portfolio delivers benefits to the state's natural gas ratepayers.

The CEC undertook activities in 2020 that bolstered its commitment to engage stakeholders and ensure that a diverse range of applicants can participate in R&D projects:

- Broadening the use of social media platforms to educate and inform.
- Collaborating with the CEC's public adviser to promote grant-funding opportunities.
- Meeting with community leaders, stakeholders, and business leaders.
- Distributing R&D informational materials at conferences, meetings, workshops, and public events in 2020 such as:
    - Staff Workshop to Discuss Proposed Natural Gas Research Initiatives for FY 2020-21 (January 2020).
    - Pre-Application Workshop – GFO-19-504 – Decarbonizing Healthcare and Large Buildings (February 2020).
    - Commissioner Workshop on Building Decarbonization: Opportunities and Challenges of the Residential and Commercial Building Sectors (May 2020).
    - Building Decarbonization: AB 3232 – Fuel Substitution Scenario Analysis Tool Workshop (June 2020).
    - Pre-Application Workshop for GFO-20-604 – Hydrogen Fuel Cell Demonstrations in Rail and Marine Applications at Ports (H2RAM) (July 2020).
    - Staff Workshop on Research and Development Opportunities for Solar Thermal Water Heating in Commercial and Multifamily Buildings (October 2020).
    - Pre-Application Workshop – GFO-20-501 – Developing and Demonstrating Advanced Combustion Systems for the Industrial Sector (October 2020).
    - Pre-Application Workshop – GFO-20-502 – Solar Heating, Cooling, and Power for Industrial and Commercial Applications (November 2020).
    - Pre-Application Workshop – GFO-20-503 – Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Natural Gas Infrastructure (December 2020).

- Webinar hosted by SoCalGas and given by staff and the Gas Technology Institute (GTI) to present results from a research project that assessed and demonstrated residential gas heat pump water heaters in the Los Angeles Basin (December 2020).

Commitment to Diversity

California is a diverse state in population and geography. To serve all Californians, the CEC strives to increase diversity in its programs through outreach, funding opportunities, and planning.

In 2015, the CEC unanimously approved a formal Diversity Policy Resolution, consistent with state and federal law, to improve fair and equal opportunities for small businesses; women-, disabled veteran-, minority-, and LGBTQ-owned business enterprises; and economically disadvantaged and underserved communities to participate in and benefit from CEC programs. Assembly Bill 865 (Alejo, Chapter 583, Statutes of 2015) provided additional guidance, requiring the CEC to develop and implement a comprehensive outreach plan to broaden and diversify the applicant pool to CEC programs and track progress toward those objectives. Senate Bill 350 (De León, Chapter 547, Statutes of 2015) also took steps to ensure California's clean energy transformation includes a strong focus on equity to ensure all Californians realize benefits, especially those in the most vulnerable communities.

The CEC cofounded the Disadvantaged Communities Advisory Group (DACAG), as outlined in SB 350, to advise the CEC and the CPUC on ways to help disadvantaged communities benefit from proposed clean energy and pollution reduction programs, expand access to clean energy technologies, and receive affordable energy services. Furthermore, in its SB 350 Barriers Report, the CEC recommended that the CEC and CPUC should direct research, development, demonstration, and market facilitation programs to include targeted benefits for low-income customers and disadvantaged communities.[14]

CEC staff activities specifically related to the FY 2021–22 Natural Gas R&D Plan to support the CEC commitment to diversity include the following:

- Releasing an outreach survey on December 4, 2020, titled "DACAG and Community Member Survey on Natural Gas R&D Initiatives for 2021" focused on the needs of underresourced communities with responses due on December 28, 2020.
- Presenting and soliciting feedback on the R&D initiatives at the Disadvantaged Communities Advisory Group meeting on January 22, 2021.
- Notifying the Disadvantaged Communities Advisory Group of the January 29, 2021, Natural Gas Stakeholders Workshop and opportunities for public comment

CEC staff continues to conduct activities to meet these important diversity commitments. Some of these efforts in 2020 include:

- Continuing to advance an outreach plan to ensure women, minorities, LGBTQ individuals, and disabled veterans are informed and educated about R&D program activities and encouraged to participate in R&D project funding opportunities.

14 Scavo, Jordan, Suzanne Korosec, Esteban Guerrero, Bill Pennington, and Pamela Doughman. 2016. *Low-Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low-Income Customers and Small Business Contracting Opportunities in Disadvantaged Communities.* California Energy Commission. Publication Number: CEC-300-2016-009-CMF.

- Assisting applicants in understanding how to apply for funding from the CEC's programs.
- Continuing to advance efforts to address energy-related challenges and opportunities in underresourced communities.
- Continuing to track, monitor, and report on the participation of California-based entities and women-, minority-, disabled-veteran-owned, and small businesses as recipients of R&D awards, using the same definitions used by the investor-owned utilities in CPUC General Order 156.

More information about these and other CEC activities that support diversity are available on the CEC's website.

Advancing Clean Energy Equity

The California Legislature has made clean energy equity a policy priority, ensuring that the benefits from the state's programs are equitably shared, especially by those in the most vulnerable communities. The CEC has committed to a 35-percent target of technology demonstration and deployment funding under its Electric Program Investment Charge to be allocated to projects sited in disadvantaged and low-income communities, and the Natural Gas Program has kept pace, investing an estimated 65 percent of natural gas R&D funds since FY 2016–17 in projects located in either a disadvantaged community, low-income community, or both, representing $30.6 million in allocated research funds as defined by CalEnviroScreen. Of this total, 5 project sites were in a disadvantaged community, and 20 project sites were in a low-income community, $12.3 million was allocated to project sites in a disadvantaged or low-income community or both (Table 2).[15] Figure 2 shows the locations of the project sites.

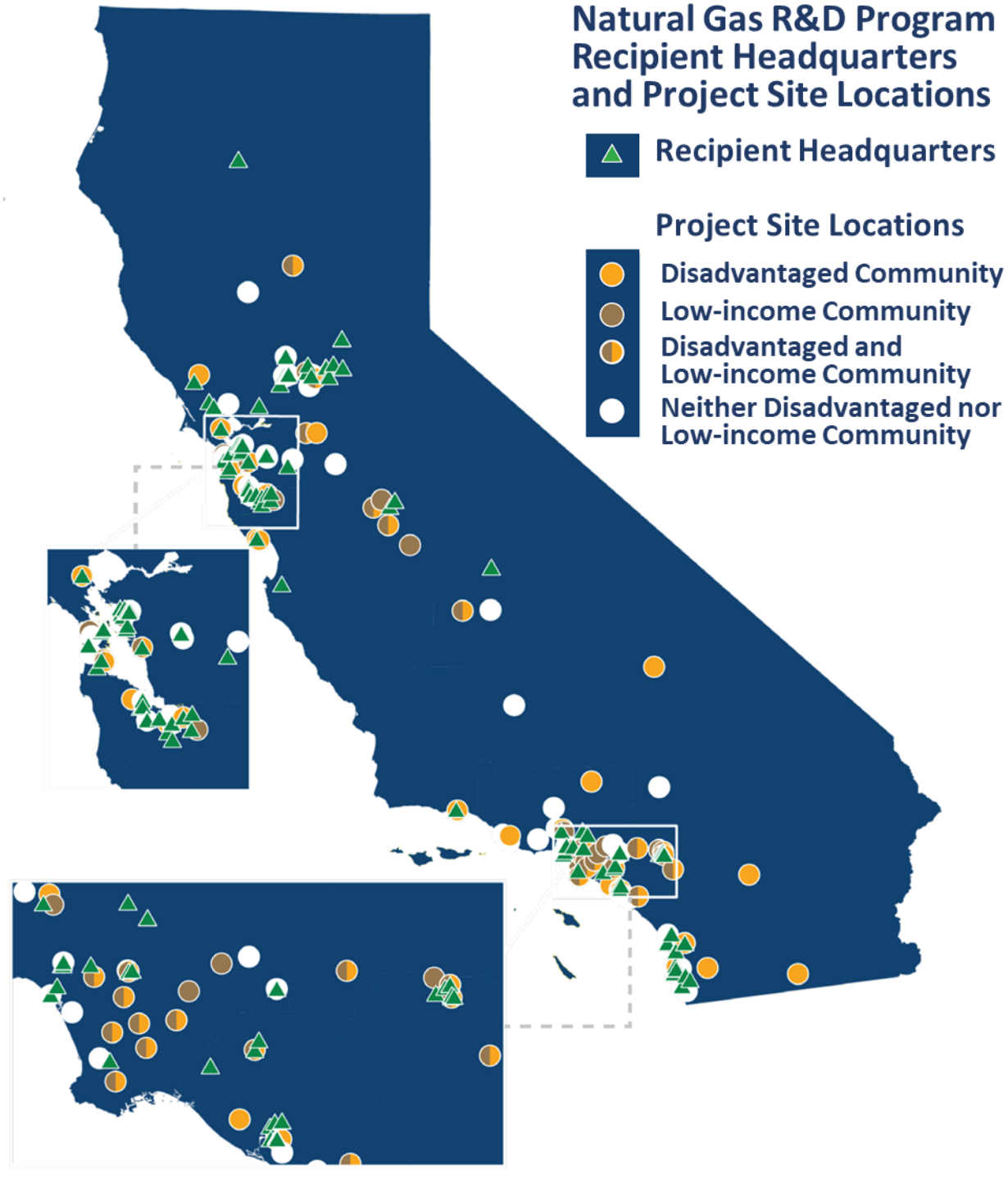
Table 2: FY 2021–22 Active Project Sites in Disadvantaged and Low-Income Communities

Diversity Category	# of Project Site(s)	Estimated Funding Amount	Percent of Funding
Disadvantaged Community (DAC)	5	$6.62	14%
Low-Income Community (LI)	20	$11.59	25%
DAC & LI	22	$12.38	26%
Total:	47	$30.61	65%

Source: California Energy Commission

15 Warner, Misa. 2020. Energy Research and Development Division. 2020. *Natural Gas Research and Development 2020 Annual Report.* California Energy Commission. Publication Number: CEC-500-2020-073.

Figure 2: Natural Gas R&D Program Projects with Headquarters and Project Sites in Disadvantaged and Low-Income Communities



Source: California Energy Commission

Examples of Natural Gas R&D Program projects that are demonstrating clean energy technologies in and benefiting disadvantaged or low-income communities or both include the following:

- Element 16 Technologies, Inc. is demonstrating a low-temperature industrial heat-capture system to reduce natural gas usage and associated emissions at Searles Valley Minerals, a chemical processing plant in a low-income community in Trona (San Bernardino County).
- University of California, Merced, is demonstrating aluminum minichannel solar water-heating collectors to reduce natural gas usage at a multifamily home in a low-income community in Arleta in the San Fernando Valley.
- Mazzetti, Inc. is demonstrating an advanced air distribution system to improve heating, ventilation, and air conditioning (HVAC) operational efficiency and reduce energy usage at a hospital in a disadvantaged community in Harbor City in the Los Angeles area.
- Terzo Power Systems, LLC is demonstrating a natural gas, hybrid-electric nut harvester to reduce emissions and fuel consumption in a disadvantaged community in Madera.
- Trevi Systems, Inc. is demonstrating low-cost plastic heat exchanges for low-level heat recovery to reduce natural gas usage and associated emissions in industrial facilities in two low income communities with a winery Windsor and a brewery in Rohnert Park (Sonoma County).
- The Center for the Built Environment is demonstrating a scalable package of nonproprietary low-cost software control and other measures to reduce natural gas consumption in large commercial buildings, with demonstration sites in disadvantaged and low-income communities in South San Francisco, Carson, and Oakland.
- Gas Technology Institute is demonstrating a heat recovery chiller to reduce the natural gas consumption and GHG emissions at a hospital in a disadvantaged community in Baldwin Park in the San Gabriel Valley.

Natural Gas R&D projects have and will continue to engage with residents of disadvantaged communities and low-income communities and representative community-based organizations (CBO)[16] to realize targeted and equitable research benefits. Some current or recent examples of such engagement include the following:

- The Effective Kitchen Ventilation for Healthy ZNE Homes with Natural Gas Appliances project, led by the Lawrence Berkeley National Laboratory (LBNL), improved understanding of public health impacts associated with natural gas use inside multifamily homes. LBNL engaged building managers and residents of four income-qualifying apartment complexes in Hayward, San Francisco, Chula Vista, and Los Angeles to collect data on ventilation equipment conditions, usage, and indoor air quality representative of some of California's low-income homes. The data points are valuable because low-income homes are typically smaller and have higher occupant density than many single-family homes, which can result in higher indoor air pollutant concentrations from natural gas cooking appliances. Results of this project helped CEC's Building Standards Office formulate health-protective kitchen ventilation requirements, which are part of the pre-rulemaking draft 2022 Building Energy Efficiency Standards.

16 Community-based organizations include school organizations, sports clubs, faith-based groups, block or neighborhood associations, and others.

- The Phase Change Material-Enhanced Insulation for Residential Exterior Wall Retrofits project, led by UC Davis, will develop and test a phase change material-enhanced insulation solution for existing homes that have little or no wall insulation at three pilot sites, two of which are in low-income communities, while one is in an overlapping low-income and disadvantaged community. Phase change material is a substance that releases or absorbs energy at during phase transition (such as from solid to liquid) to provide useful heat or cooling. Cost-effective exterior wall retrofit solutions for the existing housing stock is highly applicable to low-income and disadvantaged communities and will reduce natural gas and electricity costs for heating and cooling while improving indoor air quality. UC Davis plans to engage with Merced County Community Action Agency (MCCAA) on the technical advisory committee of the project to provide guidance on maximizing project benefits to low-income and disadvantaged communities. Through its Weatherization Assistance Program, MCCAA provides assessments to upgrade qualified homes to improve health, safety, comfort, and efficiency — delivering vital energy cost savings. The phase change material-enhanced insulation developed through this project can help improve their weatherization strategy.
- The Cost-Effective Technologies and Strategies to Improve Energy Efficiency and Reduce Emissions of Direct Heating Equipment in California With Health Benefits project, led by LBNL, will develop strategies to reduce natural gas usage from heating equipment commonly used in low-income households (for example, wall and floor furnaces and room heaters) to lower energy bills and improve indoor air quality and thermal comfort. LBNL is collaborating with the Rising Sun Center of Opportunity and Every Neighborhood Partnership, inviting both organizations to participate on the technical advisory committee of the project and promote recruitment of households in the communities they serve for field evaluation and demonstration of high-efficiency heating equipment.

The CEC has also funded projects that developed and demonstrated a broad range of tools to improve the safety and integrity of natural gas infrastructure throughout California, including disadvantaged and low-income communities. Examples of these tools include a high-accuracy mapping system that creates spatially accurate maps of the pipeline system populated with traceability information, and an excavation encroachment notification system that provides utility operators with real-time situation awareness to better avoid excavation damage to pipelines. These tools help identify gas system risks at an early stage, address system vulnerabilities effectively, and promote the resiliency of natural gas infrastructure in the communities being serviced.

To help diverse communities and businesses identify funding and partnering opportunities to advance a clean energy future for all, the CEC launched a professional networking platform — EmpowerInnovation.net. On Empower Innovation, technology developers, clean energy funders, and local communities can communicate directly about shared interests and create mutually beneficial partnerships to respond to funding opportunities. CEC staff has helped onboard underresourced entities to the platform, such as local governments and CBOs serving tribes, disadvantaged communities, low-income communities, and opportunity zones. As part of the recruitment, CEC staff held a webinar for tribes, partnered with the Institute for Local

Government to support its BOOST program,[17] supported the cities of Arvin and Paramount in creating their profiles, and is coordinating additional webinars targeted at local governments and CBOs. CEC staff continues to share information on how to use the Empower Innovation Platform, including at preapplication workshops for Natural Gas R&D Program funding opportunities. The Empower Innovation Platform is a powerful tool to break down barriers to accessing funding for clean energy projects and creating partnerships, especially for communities that have historically been underrepresented.

Collaborative Roadmaps and Technology Assessments

Roadmaps and technology assessments are planning mechanisms and communication tools that establish a clear link between research and energy policy goals. Research roadmaps define the topic area, significant issues and barriers, data gaps, information needs, research priorities, and potential partnerships. CEC staff and a wide range of energy researchers and consumers participate in "road mapping" in many program areas to gather cutting-edge information that can help determine how to maximize the value of Natural Gas R&D Program investments.[18] Participants help identify natural gas research needs by program area. Collaborative thinking about energy solutions that cut across policy boundaries is integral to leveraging research dollars. Bringing natural gas and electricity stakeholders together to develop roadmaps minimizes resource shifting, encourages innovation, and promotes transparency.

An example of a research roadmap from the Natural Gas R&D Program is one that is underway (expected to be completed in early 2021) for the chemical and allied products industry — the fourth largest consumer of natural gas among California industries — to identify technologies and approaches to reduce natural gas use. In January 2021, the CEC released a solicitation to develop a roadmap on "Establishing a Long-Term Natural Gas Research Strategy to Achieve Aggressive Statewide Carbon Neutrality Goals." This roadmap would produce a long-term strategy to help decarbonize California by 2045 and is expected to identify prioritized research recommendations in all stages of the natural gas supply chain and all end-use sectors, except for utility-scale power generation.

Proposed Budget

The proposed breakdown of the FY 2021–22 budget by research area is in Table 3. Detailed descriptions of proposed initiatives in each research area are provided after the table.

17 The Institute for Local Government, in partnership with the California Strategic Growth Council, created the BOOST Pilot Program to help local governments build capacity and resources to develop projects and secure funding to increase access to clean air and water, clean transportation, affordable housing and economic opportunity.

18 Various roadmaps can be found at the Energy Commission's publications database. https://www.energy.ca.gov/energy-rd-reports-n-publications.

Table 3: FY 2021–22 Natural Gas Research and Development Program Proposed Budget Plan Summary

Research Areas	Proposed Budget
Energy Efficiency	$6,100,000
Renewable Energy and Advanced Generation	$4,000,000
Natural Gas Infrastructure Safety and Integrity	$4,000,000
Energy-Related Environmental Research	$3,500,000
Transportation	$4,000,000
Program Administration	$2,400,000
TOTAL	$24,000,000

Source: California Energy Commission

California Public Utilities Commission Resolution G-3507 — Unspent Funds

As requested by the CPUC in Resolution G-3507, the CEC has reviewed the unspent funds in the Public Interest Research Development and Demonstration Natural Gas Subaccount to identify the funds no longer available for future grants or contracts. The CEC has budget authority for a six-year fund life, including two years to encumber funding. After the two-year encumbrance cycle, an agreement term can be up to four years before the funds are liquidated and unusable for that agreement. While the Natural Gas R&D Program has succeeded in allocating all annual funding, it is common for some of these agreements to complete activities under budget with an amount of funds being unspent in the six-year cycle. In rare cases, the CEC stops work on a project before the term end date for various reasons, including challenges with finding replacement host sites for projects and unsatisfactory interim results on projects.

Each budget plan describes estimated allocations of funding among natural gas research and development areas. The CEC's Natural Gas R&D Program budget process allocates funding to CPUC-approved initiatives that are subsequently acted upon by developing specific projects selected through competitive solicitations. Depending on the strengths of proposals submitted to the CEC through this competitive process, the CEC may vary the amount of funding among CPUC-approved budget plan research areas, especially when strong proposals are available in high-priority research areas.

Per the CPUC's request in Resolution G-3507, Appendix C shows the research funds from FY 2014–15 to FY 2020–21 encumbered within two years of budget approval. Per CPUC's request in Resolution G-3555, the CEC will ensure that for any use of encumbered and unspent funds that the CEC requests for new projects, the request will identify the respective research areas for which the CPUC originally authorized the funding. Total expenditures from the FY 2014–15 through FY 2020–21 CPUC approved budget plans are not known at this date, since most of the projects are still in progress. An accounting of unspent funds can be determined after June 30, 2021. Due to COVID-19, CEC received a one-year extension to liquidate funds that were encumbered from the FY 2018–19 budget plan.

Proposed Research Initiatives

This proposed FY 2021-22 Natural Gas R&D Budget Plan ($24M) includes research funding for energy efficiency, renewable energy and advanced generation, energy infrastructure (including pipeline safety), energy-related environmental research, transportation, and program administration. A research initiative consists of one or more research projects, each designed to advance technology or an area of science. The CEC's Natural Gas R&D budget allocates funding to CPUC-approved initiatives that are then implemented by developing specific projects selected through competitive solicitations.

Energy Efficiency

Energy efficiency continues to be important in reducing energy demand and greenhouse gas emissions in buildings and the industrial, agriculture, and water sectors. Residential and commercial buildings and the industrial sector together use about 69 percent of the natural gas in California. As a result, past energy efficiency research has focused on developing, testing, and demonstrating precommercial and emerging technologies, strategies, and tools to reduce natural gas use in buildings and the industrial, agriculture, and water sectors.

AB 3232[19] requires the CEC to identify and evaluate methods to reduce the GHG emissions of buildings by 40 percent below 1990 levels by 2020. Preliminary findings suggest switching to highly efficient electric appliances such as heat pumps and space heaters is an effective strategy.[20] With electrification being a promising effective decarbonization strategy for buildings, energy efficiency efforts are shifting focus toward decarbonization of the industrial sector.

California's industrial sector accounts for 33 percent (or 661 billion cubic feet) of the state's natural gas consumption, contributes 23 percent of the state's GHG emissions, and has the second highest emissions reduction potential for meeting the 2030 targets as set forth in SB 350.[21] Process heat accounts for about 85 percent of industrial natural gas use in California.[22] Typical industrial process heating equipment includes boilers, furnaces, and evaporators, which produce heat via natural gas combustion. Industrial heating such as calcination, smelting, curing, and forming is difficult or not-cost effective to electrify or both because of high temperature of these processes and the low cost of natural gas. Carbon capture combined with utilization or sequestration is a promising approach from decarbonization of natural gas combustion processes, but additional research is necessary to promote adoption of these technologies in the industrial sector.

In alignment with the state's GHG reduction targets for 2030 and beyond, the FY 2021–2022 budget plan focuses on improving energy efficiency of industrial carbon capture and utilization to improve economics and promote wider adoption.

The proposed research budget for energy efficiency is $6 million (Table 4). Research will be coordinated with other research areas, as appropriate.

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19 Assembly Bill 3232, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB3232.
20 California Energy Commission, California Public Utilities Commission, and California Air Resources Board. Draft 2021 SB100 Joint Agency Report. December 2020. https://efiling.energy.ca.gov/getdocument.aspx?tn=235848.
21 "Optionality, flexibility & innovation pathways for deep decarbonization in California". Energy Futures Initiative. 2019. https://energyfuturesinitiative.org/s/EFI_CA_Decarbonization_Full-b3at.pdf.
22 California industrial energy efficiency market characterization study. XENERGY. December 2001 http://www.calmac.org/publications/California%20Ind%20EE%20Mkt%20Characterization.pdf.

Table 4: FY 2021–2022 Proposed Natural Gas R&D Budget Plan Summary
Energy Efficiency

Research Area—Energy Efficiency	Proposed Budget
Proposed Research Initiative: ▪ Industrial Carbon Capture and Utilization	$6,100,000

Source: California Energy Commission

Energy Efficiency Program Goals

- Develop and demonstrate affordable energy-efficiency technologies, processes, and strategies that support decarbonization (the reduction or elimination of carbon dioxide from energy sources).
- Maintain or increase productivity and increase industry competitiveness in the global market.
- Commercialize technologies with broad market potential.
- Conduct technology research, development, and demonstration to increase energy efficiency while reducing equipment and operating costs, natural gas use, and greenhouse gases and other air pollutant emissions.
- Improve air quality in disadvantaged and low-income communities by reducing emissions of criteria air pollutants, including nitrogen oxides.

Industrial Carbon Capture and Utilization

The Issue:

Decarbonization of the industrial sector is challenging because the electrification pathway is usually not cost-effective for such high-temperature processes as calcination, smelting, curing, and forming. The low price of natural gas is another reason for industrial sector to rely heavily on the natural gas at least for the upcoming decade.

Industrial carbon capture and utilization (CCU) has high potential, especially with the Low Carbon Fuel Standard (LCFS) and federal Section 45Q carbon capture credits available for such projects. Industrial carbon capture and utilization is the process that captures carbon dioxide emissions from industrial sources and reuses the carbon dioxide directly or converts it to higher value products. Under the 45Q rule, industrial manufacturers that capture carbon from their operations can earn money for permanently storing or utilizing the carbon dioxide. Factors affecting how attractive carbon capture technology is include costs per ton of CO_2 captured compared to Annual Auction Reserve Prices[23] and available credits, integration into the existing production process, potential to use the captured CO_2 on-site or sell it, and additional benefits provided by carbon capturing system. Improvements to efficiency and economics of existing and emerging technologies that capture and convert carbon dioxide on-site into high-value commodities will enable profitability of the industrial CCU itself and ensure sustainable decarbonization of California's industrial sector.

23 "Auction Notice. California Cap-and-Trade Program and Québec Cap-and-Trade System Joint Auction of Greenhouse Gas Allowances." California Air Resources Board. December 2018. https://www.arb.ca.gov/cc/capandtrade/auction/feb-2019/notice.pdf.

The Research:

The most common industrial process that is hard to electrify is heating that accounts for about 85 percent of industrial natural gas use in California and includes high-temperature industrial processes such as calcination, smelting, curing, and forming. This initiative proposes RD&D that identifies research gaps and develops cross-cutting technologies for carbon capture and use in the industrial sector. Targets include major emitters of carbon dioxide identified by mandatory reporting of GHG emissions by cap-and-trade programs. These entities use high-temperature processes and include glass, cement, metals, and chemicals. Possible research areas include:

1. Developing a roadmap for carbon capture and utilization in California's industrial sector to identify research gaps, prioritize research needs, and provide recommendations for research funding.
2. Establishing an energy baseline of existing carbon capture and utilization technologies. This baseline includes a quantitative bases of the energy requirements and associated costs that can be used to compare improvements energy efficiency and economic improvements as well as inform a life-cycle assessment.
3. Performing fundamental research on enabling technologies in two areas:
    a. *Carbon capture effectiveness* — Increase effectiveness, efficiency, and economics of capturing carbon dioxide and related purification. Evaluate and establish the effects of carbon capture on criteria air pollutants (NO_x) and particulates.
    b. *Carbon utilization* — Develop novel chemical and biological carbon conversion technologies or improve economics of the existing ones or both.

The first two research areas would inform and help develop a long-term plan for implementing carbon capture and utilization in the industrial sector, while the third area will advance enabling technologies needed for carbon capture and utilization. Research objectives are to (1) improve efficiency of carbon capture and carbon utilization technologies, to (2) reduce energy use and operational costs, which in turn will (3) promote wider adoption of carbon capture and eventually help (4) decarbonize industrial sector.

Carbon Capture Effectiveness

Use of natural gas for industrial heating produces a low concentration of carbon dioxide and high residual oxygen concentration. This use also increases the footprint of carbon capture equipment and decreases the associated efficiency and lifetime. One way to resolve this is advanced (oxygen-enriched) combustion, which was included in a previous NG research plan (2019–2020) and implemented in a solicitation[24] and resulted in two projects that demonstrate full-scale oxygen-enriched combustion systems for glass and metals industries.

This initiative will seek research related to advanced materials and novel separation/ purification processes that could improve efficiency of CO_2 separation and removal of impurities (water, oxygen, sulfuric oxide [SO_2], NO_x) as well as harmful particulates. This

24 GFO-20-501 – "Developing and Demonstrating Advanced Combustion Systems for the Industrial Sector". October 2020. https://www.energy.ca.gov/solicitations/2020-10/gfo-20-501-developing-and-demonstrating-advanced-combustion-systems.

research area has the potential to reduce energy requirements by 20 percent or more, compared to current carbon capture technology, which is a goal of this research.[25]

Carbon Utilization

Captured carbon dioxide is mostly used for enhanced oil recovery, but this method is suitable only for high-rate production sites, may pose environmental risk, and has an unclear long-term prospective in California. This initiative seeks projects that will develop novel methods or advance existing methods to convert carbon dioxide captured into higher-value products that could generate revenue streams offsetting the cost of carbon capture. The objective is to improve the efficiency of these technologies, increase the cost-effectiveness of these technologies, and increase integration with carbon capture. The following are some examples of promising processes for use of carbon dioxide:

- Numerous R&D efforts, funded by various governmental agencies and private entities,[26] are focused on emerging chemical and biological conversion technologies that convert CO_2 into various types of fuels, precursors for plastics, and other valuable products, including food.[27] Carbon dioxide may also be used for curing of the concrete, capturing it into the solid compounds in a process called "mineral carbonation."
- Transformation of carbon dioxide into carbon nanotubes (CNT) (tubes made of carbon measured in nanometers) is one of the most promising technologies to promote carbon capturing because of the extremely high prices of the product. Price of a ton of CNT may go over $200,000 depending on the properties of the nanotubes.[28] Even low-grade nanotubes have a wide array of potential applications and may substantially improve the characteristics of plastics, concrete, coatings, and other products. Multiple research groups are developing this technology,[29] but much effort is yet to be done to provide improved and stable product properties.

The Benefits:

- **Technology Potential**. Development of this technology removes a barrier to adoption of carbon capture technologies for industries and could promote reduction of industrial GHG emissions. Improved efficiency and economics of carbon capture could increase adoption of this technology, while technologies for utilization of carbon dioxide could enable wide adoption of carbon capture and reduce industrial GHG emissions. Moreover, advancement of carbon capture technology could also enable direct air capture (DAC) technologies, although DAC is not the focus of this research.
- **Market Connection**. This initiative focuses on development of technologies for a wide variety of industrial sources of carbon dioxide at different scales from small to large.

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25 *Quadrennial Technology Review 2015*. Chapter 4D: Carbon Dioxide Capture for Natural Gas and Industrial Applications. https://www.energy.gov/sites/prod/files/2015/12/f27/QTR2015-4D-Carbon-Dioxide-Capture-for-Natural-Gas-and-Industrial-Applications.pdf; and Weng, W. et al. Capture and Electro-Splitting of CO2 in Molten Salts (2019). DOI: 10.1016/j.jechem.2018.06.012.

26 Funded projects listing. ARPA-E. https://arpa-e.energy.gov/?q=project-listing.

27 *Gaseous Carbon Waste Streams Utilization: Status and Research Needs* (2018). The National Academies Press. http://nap.edu/25232.

28 Stuart Licht. *Co-production of Cement and Carbon Nanotubes With a Carbon Negative Footprint*. 2017. https://arxiv.org/ftp/arxiv/papers/1608/1608.00946.pdf

29 X Prize. Carbon. Prize teams. https://carbon.xprize.org/prizes/carbon/teams; and Rao, R. et al. Carbon Nanotubes and Related Nanomaterials: Critical Advances and Challenges for Synthesis Toward Mainstream Commercial Applications (2018). DOI: 10.1021/acsnano.8b06511.

Conversion of carbon dioxide into various valuable commodities could have extensive connections with a variety of market segments.

- **Energy and Cost Savings**. Improvements to the efficiency of carbon capture equipment could lead to at least 20 percent reduction in energy use compared to current carbon capture technologies. Conversion of carbon into more valuable products can help the economics of carbon capture by providing a revenue stream that could offset the costs.
- **Environmental Benefits**. The technology developed has a high potential to reduce industrial GHG emissions. Furthermore, carbon capture processes remove criteria air pollutants that are known to be harmful, including SO_2, NO_x and particulate matter because they need to be removed for technical reasons.[30]
- **Equity Considerations.** Many industrial plants are in underserved communities. Carbon capture processes remove criteria air pollutants that are known to be harmful and particulate matter because they need to be removed for technical reasons, which would improve air quality in these communities. Carbon capture effectiveness projects include efforts to improve the efficiency in removing criteria air pollutant and particulate matter.

Natural Gas Infrastructure Safety and Integrity

The infrastructure providing natural gas to customers is vast and covers most of the state. It includes production wells, treatment plants, transmission lines, compressor stations, distribution lines, meters, and small pipes inside homes and buildings. California's natural gas system consists of more than 115,000 miles of gas pipelines and more than 9 million services.

Natural gas is highly combustible, contains toxic compounds, and has a very potent greenhouse gas, methane, as one of the main components. California's natural gas wells and pipelines face risks that could cause damage or catastrophes. The massive natural gas leak at the Aliso Canyon natural gas storage field in Southern California focused attention on California's aging natural gas infrastructure. Furthermore, five years of extreme drought exacted a toll on transmission pipelines, prompting the CEC to research drought-induced subsidence impacts on natural gas pipelines. Events such as the 2015 Aliso Canyon leak and the 2010 San Bruno explosion are reminders that public safety, public health, and greenhouse gas emissions are considerations in natural gas research. Further, climate change exacerbates risks such as exposing natural gas infrastructure directly or indirectly to wildfires, landslides, coastal and inland flooding, and ground subsidence due to overdrafting of groundwater. Finally, the natural gas system must evolve substantially to contribute to the state's goals for a 40 percent GHG reduction by 2030 and carbon neutrality by 2045.

The CEC has historically funded research in energy infrastructure assessing the current vulnerability of the natural gas system to prevent damages from excavation, corrosion, and other threats. This work includes developing and demonstrating risk management tools and monitoring technologies to evaluate the integrity of the natural gas system. Independent research funded by the CEC complements research conducted by industry, helping address public safety issues and prevent catastrophic failures with a long-term, systemwide view and a focus on achieving the state's GHG reduction goals.

30 Energy Futures Initiative and Stanford University. *An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions.* October 2020; and European Environment Agency. *Air Pollution Impacts From Carbon Capture and Storage (CCS)*. 2011.

The proposed research budget for natural gas infrastructure safety and integrity is $4.0 million (Table 5). Research will be coordinated with other study areas, as appropriate.

Table 5: FY 2021–2022 Proposed Natural Gas R&D Budget Plan Summary Energy Infrastructure Safety and Integrity

Research Area — Natural Gas Infrastructure Safety and Integrity	Proposed Budget
Proposed Research Initiatives: ▪ **Technologies for Monitoring Ground Movement Around Pipelines and Mitigating Natural Force Damages** ▪ **Technology Development and Demonstration for Plastic Pipeline Repair and Integrity Improvement**	$4,000,000

Source: California Energy Commission

Natural Gas Infrastructure Safety and Integrity Program Goals

The Natural Gas Infrastructure Safety and Integrity area seeks to advance technologies to increase safety and enhance the transmission and distribution capabilities of the natural gas system while reducing greenhouse gas emissions.

Technologies for Monitoring Ground Movement Around Pipelines and Mitigating Natural Force Damages

The Issue:

Natural force damages may rupture natural gas pipelines, result in loss of containment of gas flow, and lead to potential public safety issues, property damages and significant environmental impact. Natural force damages include incidents caused by outside forces attributable to acts of nature such as earth movement, flooding, landslide, and earthquakes. Based on the study from Gas Technology Institute, natural force damages account for a relatively small percentage of overall pipeline failures (12.8 percent for transmission and 9 percent for distribution);[31] however, when they do occur, they can sometimes result in catastrophic failures, release large volumes of natural gas, and interrupt natural gas supply, services, and market. Pipeline and Hazardous Materials Safety Administration (PHMSA) reported on January 9, 2018, a failure of a transmission pipeline in Montecito (Santa Barbara County) resulted in a fire and explosion because of heavy rains and localized flooding and the release of an estimated 12,000 MCF of natural gas.[32]

PHMSA requires natural gas pipelines to be designed to withstand external loads, including those that may be imposed by natural forces. Pipeline operators must develop practical measures to monitor geological movement and protect transmission lines or mains from geological hazards, which may affect the current or future safe operation of the pipeline.

31 California Energy Commission, *Pipeline Safety and Integrity Monitoring Technologies Assessment*, August 2019, Publication Number CEC-500-2019-053.https://ww2.energy.ca.gov/2019publications/CEC-500-2019-053/CEC-500-2019-053.pdf.

32 *Federal Register,* "Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by Earth Movement and Other Geological Hazards", https://www.federalregister.gov/documents/2019/05/02/2019-08984/pipeline-safety-potential-for-damage-to-pipeline-facilities-caused-by-earth-movement-and-other#:~:text=On%20January%209%2C%202018%2C%20a,flooding%20contributed%20to%20the%20incident

Pipeline operators rely on patrol programs to inspect surface conditions on and adjacent to the transmission line right-of-way for indications of leaks, construction activity, and other factors affecting safety and operation. The frequency of patrols is based upon the size of the line, operating pressures, class locations, terrain, seasonal weather conditions, and other relevant factors and is normally performed quarterly.

The frequency of patrols has spurred the need for continuous monitoring and assessment of natural force threats and pipeline conditions to identify any potential leaks in vulnerable areas, take appropriate action concerning changes in pipeline conditions, develop applicable steps to protect pipelines, and facilitate emergency responses. Realtime monitoring and measurement along pipelines provide means to take both the pipeline mechanical properties and anticipated geologic movement into consideration to manage the integrity of the pipeline. Additional mitigation can be then prioritized by considering the likelihood of failure and the consequences of failure. Mitigation typically includes modified trench designs, trench adjustment, pipe replacement, or installation of automated isolation valves.

In 2019, CEC awarded two projects to develop open-source software to better assess risks to natural gas storage and pipeline systems from earthquakes. Real-time monitoring data along pipelines will enhance these open-source tools by incorporating those data into the simulation and analysis. The data will also improve the safety and integrity of natural gas pipelines by helping regulators and pipeline operator's direct mitigation efforts to the most vulnerable components.

The Research:

The initiative will fund the development and demonstration of remote sensing and monitoring technologies with real-time and intelligent sampling, monitoring algorithms, and data management approaches to monitor ground movement around pipelines and develop strategies to reduce the risk of potential damages. Access to continuous, real-time measurements and area-specific data can give utility operators, field crews, and first responders more time to plan, allocate resources, and take effective actions to address potential leaks and damage to pipelines. Possible projects will develop and improve technologies to:

- Identify geodetic monitoring points to track potential ground movement (geodetic refers to measurement of the shape and area of large areas, the exact position of geographical points, and the curvature, shape, and dimensions of the earth).
- Track ground movement that may otherwise not be detectable during ROW patrols.
- Evaluate stress/strain in the pipeline and conduct stress/strain analysis for pipe bending and denting from movement. Use aerial or satellite mapping or other technology to track changes in ground conditions.

Technologies must demonstrate a "whole-system approach" from data collection to integration with utility integrity management system and risk assessment tools. Specifically, projects must demonstrate applicable solutions to the pipeline operators and implementation of the technologies for broader applications to reduce the risk due to natural force damages. Projects should focus on advancing technology and commercial readiness level by optimizing device performance, improving cost effectiveness, and demonstrating the technologies at full scale in the field with partnership from California gas utilities.

This research initiative corresponds to CPUC Resolution G-3571 requirements on ensuring safety of natural gas system and decreasing fugitive methane emissions.

The Benefits:

- **Energy Sector.** The technologies developed and demonstrated in this initiative are intended to improve the safety and integrity management of natural gas pipelines. With the state-of-the-art remote sensing and monitoring technologies, pipeline operators can monitor ground movement around pipelines and develop strategies to reduce the risk of potential natural force damages.
- **Technology Potential**. A breakdown of significant pipeline incidents in gas transmission and distribution systems shows that natural force damages contribute to 12.8 percent transmission incidents and 9 percent distribution incidents between 2005 and 2018. These technologies will enable utilities to conduct real-time, continuous, and comprehensive monitoring at geodetic monitoring points to track potential ground movement. Mitigation can be planned accordingly by considering the likelihood of failure and the consequences of failure.
- **Market Connection.** Sectors and user groups of interest in the proposed initiative include natural gas utilities, pipeline owners and operators, and pipeline inspectors and surveyors.
- **Environmental Benefits.** Reducing damages to pipelines help decrease direct and indirect greenhouse gas (GHG) emissions. GHG emission reduction can also be achieved through better management of natural gas pipeline systems with real-time and continuous monitoring of pipeline assets.
- **Equity Considerations.** Underserved communities are usually more vulnerable to natural disasters. This research will put engineering measures in place to protect these communities from being negatively impacted by natural force damages.

Technology Development and Demonstration for Plastic Pipeline Repair and Integrity Improvement

The Issue:

Plastic pipelines are corrosion resistant and cost-effective compared to metal pipes and are more commonly used in natural gas distribution pipeline systems. As of 2018, plastic pipelines accounted for 72.7 percent of natural gas services in the United States, and provided nearly 6 million gas services California with more than 55,000 miles of plastic gas mains.[33] Moreover, the use of plastic pipelines has been steadily increasing year after year with vintage steel pipes being replaced by plastic counterparts. In January 2019, PHMSA enacted amendments to Federal Pipeline Safety Regulations (49 CFR Part 192) on plastic piping systems to further enhance plastic pipeline safety and adopt innovative technologies.[34]

The safety and integrity of plastic pipelines are significantly impacted by a broad range of risks and threats, such as third-party damages, natural hazards, aging of plastic material and components, and degradation of repairs over time. These events may lead to pipeline failures under various modes, including slow crack growth, ductile rupture, and rapid crack propagation,[35] and result in fugitive methane emissions until leaks are identified and pipelines

33 "Annual Distribution and Transmission Miles of Pipeline," American Gas Association, December 2019. https://www.aga.org/research/data/distribution-and-transmission-miles-of-pipeline/.

34 "Pipeline Safety: Plastic Pipe Rule." Pipeline and Hazardous Materials Safety Administration, Department of Transportation (DOT), January 2019. https://www.federalregister.gov/documents/2018/11/20/2018-24925/pipeline-safety-plastic-pipe-rule.

35 Hazard Analysis and Mitigation Report, California Public Utilities Commission, June 2014. https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=8947.

are repaired. Traditional approaches to plastic pipe repair involve excavation and squeeze-off, which are not only costly and inefficient, but may cause further damages to pipeline systems with gas service interruption.[36] Most gas companies rely on visual inspection to determine the integrity of a plastic pipeline. Visual inspection can be useful but does not provide conclusive evidence of future performance. Plastic pipeline integrity would be enhanced through advancements in a broad range of technological areas, such as early detection of pipe failures, more accurate inspection of pipe status, and cost-effective repair of plastic pipes while minimizing service interruption.

The Research:

This research initiative focuses on the development and demonstration of technologies that advance the overall integrity of plastic pipelines in California. The research areas include:

- Technologies to measure or monitor plastic pipes for early notification of potential risks and risk mitigation and predict and mitigate various types of damages to pressurized plastic pipelines, such as gouges, cracks, and anomalies.
- New and cost-effective technologies to repair plastic pipe damages without the need of pipe squeeze-off, gas by-pass, or excavation to access the pipe.
- Technologies to evaluate, measure, or monitor the performance of repaired plastic pipe systems, including various system components, such as joints and fittings.
- Robotic internal inspection and repair technologies for small-diameter plastic pipelines.
- Emerging technologies that minimize or avoid natural gas service interruption during pipeline repair.

The projects will target technologies with greatest potential and impact that can be advanced to a technology readiness level (TRL) of 7 or higher and demonstrate with applications to natural gas plastic pipeline systems in California, including gas services in disadvantaged and low-income communities. The project should address the safety and verify economic advantages through technology deployment with utility partners. In addition, the project must demonstrate how the technologies help reduce natural gas leaks from plastic pipelines and quantify the reduction of methane emissions in short and long terms.

This research initiative corresponds to CPUC Resolution G-3571 requirements on ensuring safety of natural gas system and decreasing fugitive methane emissions.

The Benefits:

- **Energy Sector**. The technologies developed and demonstrated in this initiative are intended to improve the safety and integrity of natural gas plastic pipelines and minimize or prevent pipe failures and gas service interruption.
- **Technology Potential**. The deployment of the technologies would help assess, repair, and prevent damages to plastic pipes widely used in natural gas mains and service lines.
- **Market Connection**. Sectors and user groups of interest in the proposed initiative include general natural gas utilities, and manufacturers, owners, operators and inspectors of natural gas mains and service lines.

36 Gas Network Innovation Strategy, Energy Networks Association, March 2017. https://www.nationalgrid.com/sites/default/files/documents/Gas%20Network%20Innovation%20Strategy%20For%20Consultation%20Final.pdf.

- **Energy and Cost Savings**. The use of the technologies from this initiative will reduce plastic pipeline failures and decrease natural gas system down time and associated costs. Improved repair technologies for plastic pipes can further bring down the cost of pipeline system maintenance.
- **Environmental Benefits**. Integrity improvement of natural gas mains and service lines reduces fugitive methane emissions.
- **Equity Considerations.** Disadvantaged and low-income communities are more vulnerable to natural gas incidents such as gas leaks, pipe ruptures and explosions. The research will enhance the safety, reliability and resiliency of natural gas infrastructure and gas service in these communities.

Renewable Energy and Advanced Generation

The Renewable Energy and Advanced Generation (REAG) area covers research addressing cost and other barriers to increasing market penetration of renewable energy critical to meeting the state's GHG emissions goals. The REAG area has traditionally included research on renewable gas, distributed generation (DG), and renewable combined-heat-and-power (CHP) systems under the Natural Gas R&D Program.[37] Technologies of focus have included hybrid, fuel-flexible, high-efficiency, and low-emission DG and CHP systems for use with fossil natural gas or renewable gas. For the past several years, this research area has advanced technologies for the conversion, cleanup, and upgrading of biomass resources (forest wood waste, landfill gas, and anaerobic digester gas) to renewable gas for onsite use, conveyance to remote use, or vehicle fuel applications. Recently, this research area has also helped reduce natural gas consumption in CHP systems and advance solar thermal technologies that can deliver process heat or boiler applications.

Last year, the REAG initiative further prioritized decarbonization solutions via the renewable gas route to help achieve the state's clean energy and greenhouse gas reduction goals by focusing on the cost-effective production of renewable hydrogen and biomethane as a potential replacement for — or blending with — fossil natural gas. For this year, the research initiative complements last year's initiative on hydrogen production by addressing the downstream use and equipment needs, particularly for power generation technologies. The proposed initiative will support the advancement and deployment of fuel-flexible power generation technologies and systems that can run efficiently using a high blend of hydrogen in the fuel stream, allowing the reduction of greenhouse gas emissions from fossil-derived fuel gas.

The proposed research budget for renewable energy and advanced generation is $4 million (Table 6). Research will be coordinated with other research areas, as appropriate.

[37] Distributed generation refers to a variety of technologies that generate electricity at or near where it will be used, such as solar panels. Combined heat and power refers to concurrent production of electricity or mechanical power and useful thermal energy (heating or cooling).

Table 6: FY 2021–2022 Proposed Natural Gas R&D Budget Plan Summary
Renewable Energy and Advanced Generation

Program Area — Renewable Energy and Advanced Generation	Proposed Budget
Proposed Research Initiatives: ▪ Developing and Demonstrating Hydrogen-based Power Generation Systems	$4,000,000

Source: California Energy Commission

Renewable Energy and Advanced Generation Program Goals

The goals for the Renewable Energy and Advanced Generation area are to reduce barriers, increase the amount of renewable energy, and reduce dependence on fossil-derived natural gas by:

- Accelerating efficient and cost-competitive production of renewable gas —biomethane and renewable hydrogen — and demonstrating the associated diversified applications for clean and advanced power generation.
- Developing cost-effective, fuel-flexible, energy-efficient, low-emission, and hybrid energy generation systems and technologies.
- Advancing the development and market availability of clean and efficient distributed generation and renewable combined heating, cooling, and power technologies.

Developing and Demonstrating Hydrogen-Based Power Generation Systems

The Issue:

Natural gas continues to be a significant source of greenhouse gas and air pollutant emissions in California's electricity sector. In-state gas-fired generation accounts for more than half of the power sector CO_2 emissions in California, with the vast majority of the remainder from electricity imports, which are also generated partly by natural gas.[38,39] Moreover, natural gas-fired electricity generation is a source of criteria pollutants such as nitrogen oxides (NO_x). The development and deployment of hydrogen-based generation technologies — paired with advanced hydrogen production methods — can reduce the consumption of natural gas and its emissions footprint in the power grid.

One promising pathway to reduce greenhouse gas emissions in natural gas-fired power generation is through blending of low-carbon hydrogen into the fuel mixture of gas generators. Although adding hydrogen to natural gas on end-use systems holds promise, use of hydrogen for power generation has not been commercially demonstrated in California. While there have been recent developments in hydrogen-blend turbines, research is needed to address issues of performance, cost, and safety. One primary research need is developing and demonstrating combustion systems that can operate on high blends of hydrogen — exceeding 30% hydrogen and progressing towards 100 percent hydrogen — to realize the full decarbonization benefits. To enable higher hydrogen blends for power generation applications, issues must be addressed such as modifications on prime mover (electricity generation) technologies. The modifications would introduce additional cost and require precautions to

38 California Independent System Operator webpage (https://www.caiso.com/TodaysOutlook/Pages/emissions.aspx).

39 California Energy Commission Energy Almanac (https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2019-total-system-electric-generation).

ensure safety and material integrity.[40] It is important to better understand these challenges and identify and resolve other challenges through the demonstration of power generation technologies that can use hydrogen blends. Additionally, there is a need to advance smaller-scale systems that could support local power generation (for example, microturbines and advanced reciprocating engines); recent developments have focused on large-scale gas turbines.

The Research:

This initiative will fund the development and demonstration of power generation technologies that can run efficiently on high blends of hydrogen in the fuel stream, including modifications to current power generation technologies. These power generation technologies could include small-scale and large, utility-scale systems. Projects could advance and demonstrate, for example, generation system efficiency, emissions reductions (greenhouse gases and NO_x), and safe operation (for example, operating without leaks, maintaining system integrity).

The Benefits:

- **Energy Sector.** The proposed technology development and demonstration would increase hydrogen adoption, potentially reducing statewide consumption of fossil-based natural gas in power generation.
- **Technology Potential.** There is a large potential for hydrogen to decarbonize power generation and increase its market share as a fuel. Realizing this potential requires developing and demonstrating economic power generation technologies that can operate on a high blend of hydrogen.
- **Market Connection.** Hydrogen can potentially be used across a range of sectors, including electric power as well as a variety of commercial and industrial sectors that use natural gas onsite.
- **Energy and Cost Savings.** Technology advancements that enable use of hydrogen blends in power generation systems could reduce consumption of fossil-based natural gas (and potentially other fuels) and associated costs.
- **Environmental Benefits.** Reducing fossil-based natural gas consumption and developing power generation applications for low-carbon hydrogen supports California's greenhouse gas emission reduction goals.
- **Equity Considerations**. Developing and demonstrating hydrogen-based power generation systems will contribute to the state's clean electricity goals and provide opportunities to better understand potential improvements to local air quality.

Energy-Related Environmental Research

In the Energy-Related Environmental Research area, the CEC continues to evaluate climate risks and resilience options for the natural gas sector, study strategies to decarbonize the natural gas system, and improve understanding of methane emissions from the natural gas system — in the field and commercial and multifamily buildings — and inform mitigation strategies.

The proposed research budget for energy-related environmental research is $3.5 million (Table 7). Research will be coordinated with other research areas, as appropriate.

40 M.W. Melaina. Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues. March 2013.

Table 7: FY 2021–2022 Proposed Natural Gas R&D Budget Plan Summary
Energy-Related Environmental Research

Research Area — Energy-Related Environmental Research	Proposed Budget
Proposed Research Initiatives: ▪ **Quantify Exposures to Indoor Pollutants in Multi-Family Homes That Cook with Natural Gas or Alternatives** ▪ **Location-Specific Analysis of Decommissioning to Support Long-Term Gas Planning**	$3,500,000

Source: California Energy Commission

Energy-Related Environmental Research Program Goals

The goals of the Energy-Related Environmental Research area are to develop cost-effective approaches to evaluating and resolving environmental effects of energy production, delivery, and use in California; explore how new energy applications and products can solve or reduce environmental problems; identify vulnerabilities of the energy system to climate change; and develop cost-effective approaches to ensure reliable energy services.

Quantify Exposures to Indoor Pollutants in Multifamily Homes That Cook With Natural Gas or Alternatives

The Issue:

Prior research, including prominent contributions funded by the Natural Gas R&D Program, has demonstrated that residential cooking with natural gas appliances generates pollutants that degrade indoor air quality (IAQ). In the absence of adequate mechanical ventilation, tightly sealed homes with gas cooking can exceed thresholds set for ambient air quality for NO_2 (1-hour basis). Gas combustion also contributes to elevated $PM_{2.5}$,[41] which can similarly exceed ambient air quality standards (24-hr basis) in tightly sealed homes. These pollutants have been associated with health impacts, including asthma, cardiopulmonary disease, and premature birth. Smaller homes — including apartments typically occupied by low-income residents — are associated with higher pollutant concentrations. While research funded by the Natural Gas R&D Program has supported development of Title 24 Building Energy Efficiency Standards that will protect human health through ventilation requirements for new homes, the issue of exposures to vulnerable populations in existing homes requires further exploration to support mitigation measures.

The Research:

This research will quantify actual human exposures to indoor air pollutants, including $PM_{2.5}$ and NO_2, in multifamily homes. Multifamily homes and other homes occupied by low-income residents are of particular interest given that they typically have smaller volumes for dilution. Underresourced communities, as well as vulnerable populations (for example, children and the elderly), will be emphasized. Homes that cook with natural gas as well as alternatives to natural gas (for example, electric resistance, induction) will be considered to assess the benefits associated with eliminating natural gas cooking in multifamily homes. This research

41 PM2.5 refers to fine particulate matter pollutants up to 2.5 micrometers in diameter.

will support characterization of chemical composition, size distribution, and characteristics that relate to health impacts of combustion and cooking-generated PM in kitchens. This improved characterization of PM in home kitchens should inform a more accurate assessment of the health implications and may also inform low-cost strategies for monitoring PM in home kitchens.

This research directly addresses CPUC's direction in Resolution G-3571 (p. 15) to support research to "quantify and document impacts to indoor air quality from natural gas appliances and the potential technically feasible improvements and potential risks to indoor air quality that could be achieved from fuel blending or electrification."

The proposed research addresses critical knowledge gaps in understanding health impacts associated with indoor air quality from cooking by providing an empirical basis for exposure assessment. Prior field work and modeling efforts to investigate IAQ issues associated with residential cooking established that tightly sealed homes with gas cooking can frequently exceed health based NO_2 thresholds. However, exposure assessment of California residents to NO_2 in homes — critical to evaluating the actual health risks and associated benefits of reducing indoor NO_2 pollution — has yet to be undertaken. Furthermore, assessment of indoor exposures to $PM_{2.5}$ associated with cooking episodes, as well as characterization of the chemical constituents, size distribution, or other attributes that factor into health impacts, have not yet been conducted. Unlike NO_2 — for which gas combustion is the overwhelmingly dominant indoor source — $PM_{2.5}$ is typically generated by cooking events regardless of cooking fuel (for example, gas vs. electric) since the interaction of heat, water, oil, and food can form particles. Natural gas combustion also contributes to $PM_{2.5}$ formation in the absence of cooking. Thus, whereas indoor sources of NO_2 are virtually eliminated when a home shifts from natural gas to electric cooking, some $PM_{2.5}$ will be produced by cooking regardless of fuel source. Understanding the differences in the potential health impacts of cooking generated $PM_{2.5}$ in homes that burn natural gas relative to those that are electrified requires research into the characteristics and concentrations of $PM_{2.5}$ associated with home cooking in a variety of situations (for example, fuel type, cooking style).

The Benefits:

- **Energy Sector**. This initiative provides direct support to the state's energy policy by providing an empirical basis for understanding the health implications of cooking with various fuels in multifamily homes as well as associated ventilation needs. Both issues are considered in Title 24 Building Energy Efficiency Standards.
- **Technology Potential**. By quantifying pollutant exposures from natural gas cooking appliances in California homes, this research will help determine the extent to which there is a health-based need for alternative cooking appliances, such as electric stoves or additional ventilation strategies or both, including advanced sensor and building control technologies.
- **Market Connection.** Sectors of interest for this initiative include manufacturers in the HVAC, ventilation, and appliances industries. This initiative provides an opportunity for the market to create and invest in technologies that simultaneously promote energy efficiency and healthy indoor air quality.
- **Energy and Cost Savings**. Quantification of pollutant exposures as well as improved characterization of pollutants generated by cooking with natural gas or gas substitutes provides a basis for quantifying health-related benefits associated with energy- and cost-saving cooking and ventilation technologies.

- **Environmental Benefits.** By providing an empirical basis for assessing human exposures as well as attributes of indoor pollutants that affect health impacts, this research lays a foundation for addressing indoor air pollution in multi-family homes and assessing the health benefits of building decarbonization measures.
- **Equity Considerations.** The proposed research will focus on quantification of health-damaging pollutants in multi-family homes in under-resourced communities, with an emphasis on capturing exposures of those most vulnerable to air pollution exposures (for example, children and the elderly).

Location-Specific Analysis of Decommissioning to Support Long-Term Gas Planning

The Issue:

Prior research funded by the Natural Gas R&D Program has established that long-term planning for California's retail natural gas system is imperative to meeting the state's mid-century decarbonization goals while containing cost, addressing equity concerns, and ensuring infrastructure safety. This gas system transition planning requires detailed, data-driven analyses of opportunities and challenges associated with gas system decommissioning and electrification. Further, CPUC staff have expressed the time-sensitive need to rely on CEC-funded research to support the CPUC's long-term gas planning rulemaking (R. 20-10-007), a key venue for charting the state's gas system transition.

In anticipation of this need, the FY 2020-2021 R&D Budget Plan provided funding to develop a data-driven, actionable tool to support strategic and equitable natural gas decommissioning. The tool is expected to facilitate systematic identification of areas for strategic decommissioning grounded in economic assessment of decommissioning and electrification and based on location-specific utility infrastructure (e.g., such as natural gas pipe type, condition, and associated safety risk; and electricity distribution system capacity).

To complement the physical asset focus of this tool, analysis of operational issues at candidate decommissioning sites is also needed to assess the implications of decommissioning for remaining segments of the gas system.

The Research:

The proposed initiative focuses on location-specific analysis of promising candidate sites for decommissioning (e.g., those with known pipe integrity and corrosion issues), examining the implications of decommissioning on the remaining gas system (e.g., changes in gas system operating pressures). The operational perspective of this initiative provides a crucial complement to the physical asset focus of the data-driven tool in the FY20-21 budget plan. The research will help bridge the gap between high-level gas system planning and local decommissioning pilots, providing CPUC, local governments, IOUs, and other stakeholders with a valuable tool for assessing the technical and economic feasibility of, and other issues related to, decommissioning specific segments of the gas system.

Analyses will include examination of operational considerations of the gas system based on approaches (e.g., hydraulic modeling and other approaches) that assess issues related to reliability, financing, and other regulatory or legal issues in the context of declining overall demand for gas and potentially increased variability in gas demand for electricity generation. This type of analysis is critical to planning a transition that maintains gas system reliability and that facilitates replicable approaches to decommissioning.

Opportunities for examining natural gas decommissioning and electrification opportunities in low-income and disadvantaged communities will be prioritized. Past Natural Gas R&D research

has underscored the need for a managed gas system transition that addresses equity considerations, including the concern that low-income households may be least able to electrify. By focusing the proposed analysis on low-income neighborhoods, these neighborhoods will be more likely to be selected as early pilot decommissioning sites.

This initiative will be informed by a CEC workshop conducted in collaboration with the CPUC, engaging IOUs and other key stakeholders to gather information and perspectives on data needs, continued stakeholder engagement process, equity considerations, among other issues.

The proposed research will directly inform CPUC's long-term gas planning rulemaking (R. 20-10-007) with critical analyses of locations identified for potential decommissioning, with particular attention to gas system operational implications.

The Benefits:

- **Energy Sector**. This initiative supports state energy planning, providing an analytical basis for identifying potential locations for targeted decommissioning.
- **Market Connection**. This initiative provides insight into maintaining a reliable, stable market for natural gas ratepayers, with an emphasis on low-income ratepayers to help address equity considerations and promote participation in the early stages of gas system transition.
- **Energy and Cost Savings**. Operational analyses that support reliable operations will lead to cost savings by avoiding disruptions to service, which have direct impacts on natural gas ratepayers as well as indirect impacts – through natural gas power generation – on electricity ratepayers.
- **Equity Considerations.** The proposed analysis will focus on examination of natural gas decommissioning opportunities in low income and disadvantaged communities. The overarching goal is to inform an equitable and cost-effective gas system transition.

Transportation Research

California's transportation sector is critical to the state's economy. For example, freight transportation is responsible for one-third of the state's economic product and jobs.[42] However, transportation is also the largest contributor to the state's greenhouse gas emissions, directly accounting for 40 percent of GHG emissions and 80 percent of NO_x emissions. Primarily diesel-powered heavy-duty on-road vehicles and off-road vehicles are the largest contributors to statewide NO_x emissions and continue to heavily impact air quality in the state's severely polluted air basins. To address these concerns, research, development, and demonstration of advanced zero- and near-zero emission vehicle technologies is necessary to drive a market transition away from fossil fuels to meet clean air standards and GHG reduction goals.

When used as an alternative fuel to diesel, renewable natural gas and hydrogen can reduce petroleum dependency, GHG emissions, local air pollution, and operating costs for businesses and consumers. The CEC funds transportation research to address market barriers and continuously advance the science of gaseous fueled vehicle technology to reduce emissions to zero- or near-zero levels. Previous work includes developing near-zero NO_x natural gas engines, which led to the successful commercialization of several engines certified at CARB's optional low-NO_x standards. The CEC has funded research on a variety of technologies to increase the efficiency and competitiveness of natural gas vehicles, including high-energy

42 *California Sustainable Freight Action Plan.* July 2016.

ignition, hybridization, fueling infrastructure improvements, and innovative engine concepts. The CEC has also funded demonstration of natural gas-powered off-road vehicles to expand the air quality benefits of natural gas to another highly polluting mobile source. Starting with the FY 2019-20 Budget Plan, the transportation research area has expanded to target development and demonstration of hydrogen fuel cell technologies in rail, marine, and heavy-duty on-road vehicle applications.

The proposed budget for Transportation Research is $4.0 million (Table 8). Research will be coordinated with other research areas, as appropriate.

Table 8: FY 2021-2022 Proposed Natural Gas R&D Budget Plan Summary Transportation Research

Program Area — Transportation Research	Proposed Budget
Proposed Research Initiative: ▪ **Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport**	$4,000,000

Source: California Energy Commission

Transportation Research Program Goals

The goals of transportation-related research projects in selected sectors are to:

- Improve the energy efficiency and performance of gaseous fueled vehicles to reduce emissions and improve competitiveness.
- Increase the use of renewable gas, including renewable natural gas and hydrogen, to reduce the GHG emissions from the transportation sector.
- Improve fueling infrastructure technology capabilities to promote the further adoption of low-carbon gaseous fueled vehicles.

Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport

The Issue:

Hydrogen has potential to serve as a zero-carbon energy resource across multiple sectors and support California's economy-wide decarbonization goals. Although renewable hydrogen is currently expensive, cost reductions of 50 percent or greater are possible by 2050 with scale-up in demand, reductions in production capital costs, and greater availability of renewable electricity.[43]

In September 2020, Governor Newsom signed Executive Order N-79-20, which sets goals for California to transition to 100 percent zero-emission medium- and heavy-duty vehicles by 2045 where feasible, 100 percent zero-emission drayage trucks by 2035, and 100 percent zero-emission off-road vehicles and equipment by 2035 where feasible.[44] Recent California Air Resources Board regulations such as the Innovative Clean Transit and Advanced Clean Trucks rules have set requirements for fleet purchase and manufacturer sales for zero-emission trucks

[43] Christensen, Adam. *Assessment of Hydrogen Production Costs from Electrolysis: United States and Europe*. June 2020. https://theicct.org/sites/default/files/publications/final_icct2020_assessment_of%20_hydrogen_production_costs%20v2.pdf.

[44] Executive Order N-79-20. September 23, 2020. https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-text.pdf.

and buses. Hydrogen can play a key role in achieving the state's goals and requirements for sustainable heavy transport.

Hydrogen fuel cell-electric vehicles (FCEVs) are an attractive zero-emission technology to replace diesel vehicles for heavy transport. FCEVs feature high payload carrying capacity, fast refueling times, and long range. A study by Energy and Environmental Economics, Inc. estimates that nearly 200,000 heavy-duty FCEVs could operate in a carbon neutral California by 2045.[45] Scaling up demand for renewable hydrogen in heavy transport can spur cost reductions and broader utilization of hydrogen to decarbonize other difficult-to-abate sectors, including the industrial sector and natural gas system.

Despite California's 61 planned and open retail hydrogen refueling stations for light-duty vehicles,[46] few stations have been deployed to support heavy-duty FCEVs. Few heavy-duty FCEV models are available in the marketplace today. However, wider commercial availability is expected in the early-mid 2020s because of ongoing demonstrations, policy drivers, and major investments from manufacturers.[47]

Hydrogen refueling infrastructure solutions are needed to support renewable hydrogen demand growth in a diverse heavy-duty vehicle market with a large variety of operational characteristics. Hydrogen delivery and refueling costs currently make up around 80 percent of the total cost of hydrogen at the dispenser ($13-16/kg).[48] Technical advancements are needed to improve hydrogen refueling infrastructure that can support heavy transport by increasing station efficiency, reliability, capacity, and operational flexibility while reducing capital and operating costs to accelerate progress towards parity with diesel.

The Research:

This initiative focuses on developing advanced hydrogen refueling infrastructure components and systems for high-capacity stations that can support the transition of heavy transport applications to zero-emission hydrogen fuel cell technology. Projects should focus on fueling infrastructure technology advancements that promote compatibility and standardization across multiple heavy-duty FCEV types including trucks, transit buses, and off-road vehicles and equipment. Possible research includes, but is not limited to:

- Developing a high capacity mobile hydrogen refueler that can store, deliver, and dispense hydrogen on-demand to heavy-duty FCEVs. Mobile on-demand hydrogen refueling can support early heavy-duty FCEV deployments, especially for off-road equipment at ports and smaller fleets where permanent on-site infrastructure may be challenging to site. The refueler should emulate existing mobile diesel tanker services that can directly fuel multiple types of equipment to enable comparable operational efficiency and flexibility at competitive costs.
- Developing station designs with dedicated hydrogen production matched to fuel demand, integrated hydrogen use with other sectors to help drive scale, co-location

[45] Energy and Environmental Economics. Achieving Carbon Neutrality in California: PATHWAYS Scenarios Developed for the California Air Resources Board. October 2020. https://ww2.arb.ca.gov/sites/default/files/2020-10/e3_cn_final_report_oct2020_0.pdf

[46] California Energy Commission. Zero Emission Vehicle and Infrastructure Statistics: Hydrogen Refueling Stations in California. Accessed November 2020. https://www.energy.ca.gov/data-reports/energy-insights/zero-emission-vehicle-and-charger-statistics

[47] Gladstein, Neandross & Associates (GNA). State of Sustainable Fleets 2020. August 2020. Available at: www.stateofsustainablefleets.com

[48] Elgowainy, Amgad. Economic and Environmental Perspectives of Hydrogen Infrastructure Deployment Options. June 2019. https://www.nationalacademies.org/event/06-26-2019/docs/DFBC29CB0ED57AA1906B259D58C5DD0F399FB5F1D6A6

with other alternative fuel types including renewable natural gas, and/or use of chemical hydrogen carrier options (e.g. liquid organic hydrogen carriers or ammonia) to reduce the costs of distributing hydrogen to fueling stations.

- Demonstrating improved hydrogen infrastructure components and interfacing technologies for filling a variety of models and types of heavy-duty FCEVs – including compressors, chillers, dispensers, and fueling protocols – to reduce the cost of dispensed hydrogen, increase maximum fill rates to support larger vehicles, and improve reliability.

The Benefits:

- **Energy Sector**. Increasing demand for low-carbon hydrogen use in heavy transport can lead to investments in scaled production. Widespread availability of low-cost hydrogen can help decarbonize difficult-to-abate end-uses, including industrial processes and the natural gas system.
- **Market Connection**. Enabling reliable, low-cost, and high-capacity hydrogen fueling infrastructure will improve the business case for heavy-duty FCEV adoption and station deployment in California.
- **Energy and Cost Savings**. This initiative aims to accelerate progress in achieving total cost of ownership parity between heavy-duty FCEVs and diesel vehicles by reducing the capital and operating costs of hydrogen fueling infrastructure.
- **Environmental Benefits**. This initiative will reduce GHG emissions from the transportation sector by supporting a transition away from diesel to renewable hydrogen.
- **Equity Considerations.** Diesel exhaust attributes to about 70 percent of total known cancer risk related to air toxins in California and contributes to the formation of PM2.5 and ozone.[49] This initiative will support hydrogen fueling infrastructure demonstration projects located near major roadways, ports, and freight hubs to accelerate adoption of zero-emission heavy-duty vehicles and off-road equipment. Reducing costs and expanding availability of hydrogen fueling infrastructure will improve air quality and zero-emission transportation accessibility, especially in under-resourced communities that are heavily impacted by these mobile sources.

[49] California Air Resources Board. Workshop Discussion Draft 2020 Mobile Source Strategy. September 2020. https://ww2.arb.ca.gov/sites/default/files/2020-09/Workshop_Discussion_Draft_2020_Mobile_Source_Strategy.pdf

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AB	Assembly Bill
ARD	Applied research and development
ARPA-E	Advanced Research Projects Agency-Energy – a United States Department of Energy Program advancing high-impact energy technologies by providing funding, technical assistance, and marketreadiness
ASHRAE Guideline 36-2018	Voluntary American Society of Heating, Refrigerating, and Air-Conditioning Engineers guideline for High-Performance Sequencesof Operation for HVAC Systems.
California ISO	California Independent System Operator
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
CPUC Rule 21	Electric Rule 21 describes requirements for interconnection, operating, and metering facilities connected a utility's distributionsystem in the service territory of PG&E, SCE, or SDG&E.
Disadvantaged community	A community that scores at or above 75 percent in the version of CalEnviroScreen that was available at the time of project application.
HVAC	Heating, ventilation, and air conditioning
IEPR	Integrated Energy Policy Report
IOU	Investor-owned utility
NG	Natural Gas
NOPA	Notice of proposed awards
PG&E	Pacific Gas and Electric Company
RD&D	Research, development, demonstration, and deployment
RNG	Renewable Natural Gas, also known as Sustainable Natural Gas or biomethane, is a biogas which has been upgraded to a quality like fossil natural gas and having a methane concentration of 90% or greater.
SB	Senate Bill
Smart grid	A smart grid is the thoughtful integration of intelligent technologiesand innovative services that produce a more efficient, sustainable, economic, and secure electrical supply for California communities.
Smart inverter	An inverter with communications capability to send and receivemessages that can ensure proper operation of the electric grid
Title 24 Energy Code	California Code of Regulations, Title 24, Parts 6 and 11
U.S. DOE	United States Department of Energy
ZNCR	Zero-net-carbon ready

APPENDICES

Appendix A: Natural Gas Stakeholders Workshop Presentation, Appendix B: Summary of Public Comments and CEC Responses, and Appendix C: Funding Encumbrance Table are available as a separate volume, Publication Number CEC-500-2021-022-APA-C.