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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 2020-21

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 2020-21* 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, or contact the CEC at 916-327-1551.

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 2020-21* 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 2020-21 is $24 million, and the budget plan covers July 1, 2020, through June 30, 2021. The budget plan was informed by input from California stakeholders, research institutions, equipment manufacturers, and governmental partners.

CEC staff appreciates the coordination with CPUC on the proposed research initiatives. To support the successful advancement of the initiatives, CEC staff requests CPUC's support in providing 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 by 2045. While these goals are 25 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 a central 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 2018, Californians consumed about 1.8 trillion cubic feet of natural gas, with the power generation and residential sectors together accounting for more than half of the consumption at 45 percent and 24 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 2030 or 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-3555.
- 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.*

- *Energy Action Plan.*
- *California Energy Efficiency Strategic Plan.*

On January 21, 2020, CEC staff held a public workshop to present the proposed budget plan for the FY 2020-21 Natural Gas R&D Program and received comments from stakeholders supporting the proposed initiatives and offering helpful input and perspective on specific research topics. 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 responses.

Natural Gas R&D Program Proposed Budget Plan for Fiscal Year 2020-21

The Fiscal Year (FY) 2020-21 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 2020-21 Natural Gas Research and Development Program Proposed Budget Plan

Research Areas	Proposed FY 2020-21 Natural Gas Budget
Energy Efficiency	$3,000,000
Renewable Energy and Advanced Generation	$4,000,000
Natural Gas Infrastructure Safety and Integrity	$9,100,000
Energy-Related Environmental Research	$1,500,000
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. To support the successful advancement of the initiatives, CEC staff requests CPUC's support in easing access to needed utility infrastructure data. This access will be particularly important for the following initiatives:

- Analytics for Pilot Demonstration of Strategic Electrification and Decommissioning of Natural Gas Infrastructure

- Development of a Data-Driven, Actionable Tool and Case Studies to Support Strategic and Equitable Natural Gas Decommissioning.

If access to needed data is not attained, CEC staff proposes to reallocate funds to other proposed initiatives that can be successfully pursued.

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 cofunding 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,

1 CPUC Decision 04-08-010, p. 24.

increasing the production of renewable natural gas, and reducing leakage from natural gas infrastructure in meeting future climate change targets.[2]

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

- CPUC Resolution G-3555, which directs the CEC to consider research on topics based on CPUC proceedings and policies, such as pipeline corrosion, hydrogen blend impacts on infrastructure and end-use appliances, and biomethane impurities.
- CPUC's General Order No. 112-F, which addresses the rules for utilities to design, construct, test, operate, and maintain piping systems beyond the requirements set by federal regulations.
- CPUC Resolution G-3519, which directs the CEC to support research studies stemming from the Aliso Canyon leak.
- CPUC's Gas Safety Plan, 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.

2 California Air Resources Board. California's 2017 Climate Change Scoping Plan.

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. • 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. • Energy Action Plan identifies actions necessary to meet California's energy goals to be reliable, affordable, technologically advanced, and environmentally sound. • 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. • 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. • Governor Brown's Clean Energy Jobs Plan provides incentives for the increased use of cogeneration by 6,500 MW by 2030. • 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. Publication number: CEC-300-2012-XXX-XXX

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. • 2016 Mobile Source Strategy reduces emissions from the heavy-duty truck sector with cleaner combustion engines, renewable fuels, and zero-emission technology to meet GHG reduction targets and attain federal health-based air quality standards for ozone and particulate matter. • 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-3555 Guidance for Fiscal Year 2020-2021 Plan

CPUC Resolution G-3555 directed the CEC to do the following in developing the Fiscal Year 2020-21 budget plan.

a) **Disadvantaged communities outreach and engagement:** Enhance outreach and engagement with representatives and members of disadvantaged communities. Within the FY 2020-2021 Gas R&D Plan, CEC must provide documentation showing which disadvantaged community stakeholders were engaged, how the CEC engaged them, what feedback they provided, and how the CEC incorporated this feedback. This requirement shall remain in effect for each fiscal year's proposed budget, until otherwise directed by the Commission.

b) **Stakeholder outreach and engagement:** Enhance outreach and engagement with all stakeholders and document outreach within the Gas R&D Plan.

c) **Role of natural gas and hydrogen in a low-carbon economy:** Continue examining the role of natural gas in the state's transition to a low-carbon economy. This examination could include exploring opportunities to use natural gas infrastructure to support hydrogen that will be generated and used in a way that reduces system GHG emissions.

d) **Consistency with 2017 Climate Change Scoping Plan Update:** Ensure coordination and consistency with goals of the California Air Resources Board's (CARB) *2017 Climate Change Scoping Plan Update* by 1) ensuring safety of the natural gas system, 2) decreasing fugitive methane emissions, and 3) reducing dependence on fossil fuel natural gas.

e) **Emissions-Intensive and Trade-Exposed Facilities:** Continue targeting of emissions-intensive and trade-exposed facilities consistent with state goals under Assembly Bill 32.

f) **Health impacts inside homes:** Consider the health impacts associated with natural gas usage inside homes.

g) **Coordination for methane leakage research:** Ensure coordination with the Commission's Methane Leak Proceeding (R.15-01-008) for any leakage-related Gas R&D work, especially energy-related environmental research.

h) **Identify research areas when using encumbered and unspent funds:** Ensure that for any use of encumbered and unspent funds the CEC requests for new projects, CEC's request identifies the respective research areas for which the Commission originally authorized the funding.

CPUC Resolution G-3555 also directed the CEC to consider research in the following topic areas to inform the CPUC's proceedings and policies.

i) **Address microbiologically influenced corrosion:** Examine the causation, diagnostics, and mitigation of microbiologically influenced corrosion of pipelines

and storage facilities in the California natural gas industry, especially as they relate to safety.

j) **Assess effects of hydrogen on pipelines and end-uses:** Assess the effects of delivering hydrogen through the existing natural gas pipeline network, including the impact on pipeline facilities, natural gas generators, and end-use appliances.

k) **Research consequences of siloxane in biomethane:** Research the operational, health, and safety consequences of various concentrations of siloxane in biomethane supplies.

l) **Establish test method for detecting siloxane in biomethane:** Perform research to establish a standard test method approved by the National Environmental Laboratory Accreditation Program (NELAP) and Department of Defense Environmental Laboratory Accreditation Program (DoD ELAP) for detecting siloxane in biomethane.

This FY20-21 budget plan for the Natural Gas R&D Program closely aligns with the guidance provided in CPUC Resolution G-3555, as shown in Table 2. Additional discussions with CPUC staff helped develop the proposed initiatives for the FY20-21 budget plan by ensuring alignment with CPUC proceedings and policies. In connection with Guidance Items a and b, Chapter 2 details how the CEC continues to engage representatives from disadvantaged communities[6] and other stakeholders.

Table 2: Connections Among Proposed Initiatives for FY20-21 Budget Plan and CPUC Resolution G-3555 Guidance

Research Area	Proposed Initiatives for FY20-21 Budget Plan	CPUC Resolution G-3555 Guidance
Energy Efficiency Research	Examining the Effects of Hydrogen in End-Use Appliances	c. Role of natural gas and hydrogen in a low-carbon economy d. Consistency with *2017 Climate Change Scoping Plan Update* f. Health impacts inside homes j. Assess effects of hydrogen on pipelines and end-uses

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

Research Area	Proposed Initiatives for FY20-21 Budget Plan	CPUC Resolution G-3555 Guidance
Energy Efficiency Research	Accelerating Adoption of Modular Solar Water Heating in Low-Income or Disadvantaged Communities	a. Disadvantaged communities outreach and engagement c. Role of natural gas and hydrogen in a low-carbon economy d. Consistency with *2017 Climate Change Scoping Plan Update* f. Health impacts inside homes
Renewable Energy and Advanced Generation	Decarbonization via Efficient and Cost-Competitive Renewable Hydrogen and Biomethane (DECARB) 1: Emerging Renewable Hydrogen Production	c. Role of natural gas and hydrogen in a low-carbon economy d. Consistency with *2017 Climate Change Scoping Plan Update* e. Emissions-Intensive and Trade-Exposed Facilities
Renewable Energy and Advanced Generation	Decarbonization via Efficient and Cost-competitive Renewable Hydrogen and Biomethane (DECARB) 2: Emerging Gas Cleanup and Upgrading System for Biomethane	c. Role of natural gas and hydrogen in a low-carbon economy d. Consistency with *2017 Climate Change Scoping Plan Update* k. Research consequences of siloxane in biomethane l. Establish test method for detecting siloxane in biomethane
Natural Gas Infrastructure Safety and Integrity	Pilot Test and Demonstration of Hydrogen Blending into Existing California Natural Gas Pipelines	c. Role of natural gas and hydrogen in a low-carbon economy j. Assess effects of hydrogen on pipelines and end-uses

Research Area	Proposed Initiatives for FY20-21 Budget Plan	CPUC Resolution G-3555 Guidance
Natural Gas Infrastructure Safety and Integrity	Technologies to Inspect and Prevent Corrosion of Natural Gas Pipelines and Storage Facilities	g. Coordination with methane leakage research i. Address microbiologically influenced corrosion
Natural Gas Infrastructure Safety and Integrity	Analytics for Pilot Demonstration of Strategic Electrification and Decommissioning of Natural Gas Infrastructure	c. Role of natural gas and hydrogen in a low-carbon economy d. Consistency with *2017 Climate Change Scoping Plan Update* f. Health impacts inside homes
Energy-Related Environmental Research	Development of a Data-Driven, Actionable Tool and Case Studies to Support Strategic and Equitable Natural Gas Decommissioning	c. Role of natural gas and hydrogen in a low-carbon economy d. Consistency with *2017 Climate Change Scoping Plan Update* f. Health impacts inside homes
Transportation Research	Technology Integration and Demonstration of Hydrogen Fuel Cell Trucks and Buses	c. Role of natural gas and hydrogen in a low-carbon economy d. Consistency with *2017 Climate Change Scoping Plan Update*

Source: California Energy Commission

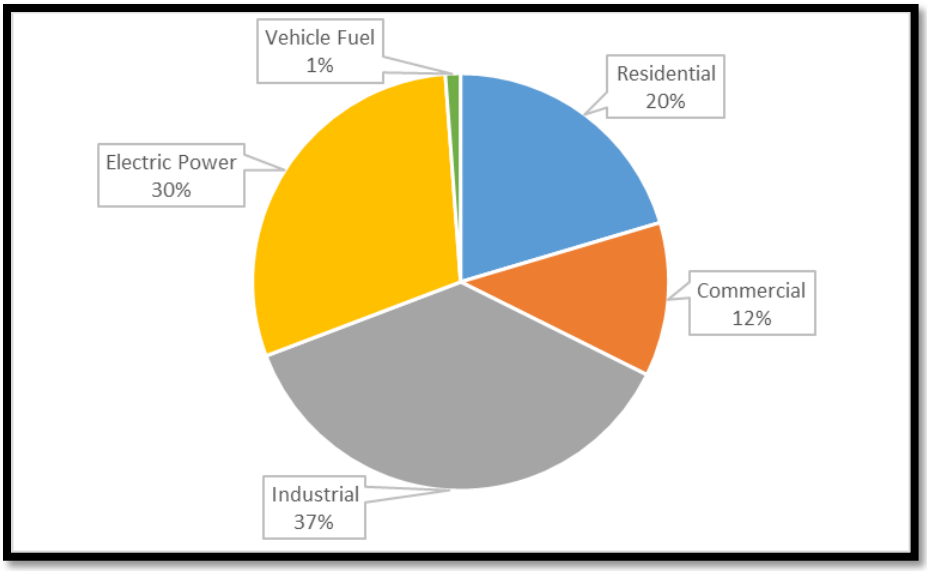
Importance of Natural Gas Research to Meet Decarbonization Goals

Natural gas is a major fuel in California's economy. In 2018, California's five end-use sectors—residential, commercial, industrial, transportation, and electricity generation—consumed about 2.1 trillion cubic feet (Tcf) per year, or about 5.8 billion cubic feet (Bcf) per day.[7] The electricity generation and the industrial sectors account for most of the natural gas use in California. Figure 1 provides a breakdown of natural gas use per sector in 2018. About 30 percent of the natural gas is used in electricity generation,

7 United States Energy Information Administration. Natural Gas Consumption by End Use (California, Annual, 2018).

which represented 46 percent of the total electricity produced in California in 2018.[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 vehicles sector, where natural gas can serve as an alternative to diesel.[9]

Figure 1: Percentage Use of Natural Gas by Sector in California (2018)



Source: U.S. Energy Information Administration

Despite a 34 percent increase in California's population since 1990, natural gas demand in the residential sector has experienced a slight yet continuous decline, while demand has been relatively flat in the commercial, industrial, and power generation sectors.[10] These results reflect California's 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]

8 California Energy Commission. 2018 Total System Electric Generation in Gigawatt Hours.
9 Bahrenian, Aniss, Jesse Gage, Sudhakar Konala, Bob McBride, Mark Palmere, Charles Smith, and Ysbrand van der Werf. 2017. *Transportation Energy Demand Forecast 2018—2030.* California Energy Commission. Publication Number: CEC-200-2017-010.
10 State of California, Department of Finance. California Population Estimates, with Components of Change and Crude Rates, July 1, 1900-2019. December 2019.
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.

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 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, especially in end-use sectors that are harder to electrify, such as certain industry subsectors and transportation, and potentially in electricity generation, as 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 2019 Annual Report* delivered to the CPUC provides a recent review of program achievements in FY 2018-19.[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 FY20-21 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 and electrification, alternatives to fossil-based natural gas such as biomethane and hydrogen, and renewable alternatives for water heating. The full set of initiatives is presented in Chapter 2.

12 Campagna, Jennifer, Leon Brathwaite, Anthony Dixon, Jason Orta, and Peter Puglia. 2019. *2019 Natural Gas Market Trends and Outlook Report*. California Energy Commission. Publication Number: CEC-200-2019-018.

13 Henderson, Braden. 2019. Energy Research and Development Division. 2019. *Natural Gas Research and Development Program 2019 Annual Report*. California Energy Commission. Publication Number: CEC-500-2019-057.

CHAPTER 2:
Natural Gas R&D Program Proposed Plan for Fiscal Year 2020-2021

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, and in some cases, they become partners on research projects. For example, the current National Ambient Air Quality Standards requirements for ozone attainment cannot be achieved in California's air basins suffering from the lowest air quality without significant reductions in oxides of nitrogen (NO_x) emissions from heavy-duty vehicle fleets. The CEC cofunded research with the South Coast Air Quality Management District and Southern California Gas Company to develop an engine technology that reduces NO_x emission rates to 90 percent below the 2010 standard.[14] The research project will include a production readiness plan to help accelerate natural gas engine technologies on the path to commercialization. The CEC also 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.

Commitment to Diversity

California is a diverse state in population and in geography. To serve all Californians better, 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

14 Observed rates below 0.02 grams per brake horsepower hour.

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, 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.[15]

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

- Continuing and advancing 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.
- Assisting applicants in understanding how to apply for funding from the CEC's programs.
- Continuing and advancing efforts to address energy-related challenges and opportunities in economically depressed 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.
- Notifying the Disadvantaged Communities Advisory Group of the January 21, 2020, Natural Gas Stakeholders Workshop and opportunities for public comment.

The CEC undertook activities in 2019 that bolstered its commitment to ensuring 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 Commission's Public Adviser to promote grant-funding opportunities.
- Meeting with community leaders, stakeholders, and business leaders.

15 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.

- Distributing R&D informational materials at conferences, meetings, workshops and public events such as:
    - Webinar for public comments on the preliminary draft research roadmap on renewable energy generation technologies for utility-scale applications (June 2019).
    - IEPR Commission workshop on the 2019 preliminary transportation energy demand forecast, including discussions on economic, regulatory, and technology attributes-based forecasts of natural gas vehicle and hydrogen fuel cell vehicle adoption through 2030 (July 2019).
    - IEPR Commissioner workshop on the 2019 preliminary California energy demand electricity and natural gas demand forecast, including discussions on scenario development based on future efficiency improvements and technology costs (August 2019).
    - IEPR joint agency workshop on energy efficiency and building decarbonization, including a presentation on the CEC's research on GHG impacts of the natural gas system (August 2019).
    - Request for comments on innovative waste heat recovery technologies to inform future research initiatives and solicitations (August 2019).
    - Staff presentation on CEC's programs, including the Natural Gas Research Program, at the Industrial Environmental Association 2019 Environmental Training Symposium and Conference (October 2019).
    - Staff workshop to identify research needs and opportunities for demonstrating fuel cells systems in rail and marine applications at California ports (October 2019).
    - Staff presentation on CEC's programs, including the Natural Gas Research Program at the UC Solar Thermal Symposium (November 2019).
    - Workshop on energy storage research needs in California during the Energy Storage North America 2019 Conference and Exhibition, including discussions on long-term storage and green electrolytic hydrogen (November 2019).
    - Pre-Application Workshop for GFO-19-502 — Storage monitoring, smart shutoff and three-dimensional mapping technologies for safer natural gas infrastructure (November 2019).
    - Pre-Application Workshop for GFO-19-501 — Characterizing air quality impact from renewable natural gas and improving natural gas system climate resilience (December 2019).
    - Emerging Technologies Coordinating Council webinars (ETCC Webinars)
        - Costs and Benefits of Community vs. Individual End-Use for Solar Water Heating, Lawrence Berkeley National Laboratory (LBNL) (February 2019)

- Energy-Efficient Concentration of Food and Beverage Products by Porifera (August 2019)
- Energy-Efficient Infrared Drying of Healthy Snacks and Walnuts by UC Davis (August 2019)

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

Advancing Clean Energy Equity

In CPUC Resolutions G-3546 and G-3555, the CEC was directed to enhance outreach and engagement with representatives and members of disadvantaged communities. Over the 2018-2019 fiscal year, the Natural Gas R&D Program included 78 active projects with 129 project sites, representing $82 million in allocated research funds. Of this total, 41 project sites were in either a disadvantaged community, low-income community, or both. Twenty-nine percent ($23.5 million) of the $82 million was allocated to project sites in a disadvantaged or low-income community or both (Table 3).[16] Figure 2 shows the locations of the project sites. 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 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.
- All Power Labs, Inc. is demonstrating a microscale combined cooling, heating, and power system integrated with a biomass gasification waste-to-energy system to reduce energy usage in industrial facilities in disadvantaged communities in Berkeley.
- 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.

16 Henderson, Braden. 2019. Energy Research and Development Division. 2019. *Natural Gas Research and Development 2019 Annual Report*. California Energy Commission. Publication Number: CEC-500-2019-057.

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) to realize targeted and equitable research benefits. Some current examples of such engagement include the following:

- The Effective Kitchen Ventilation for Healthy ZNE Homes With Natural Gas Appliances project, led by LBNL, will improve 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.
- 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. 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 project's technical advisory committee to provide guidance on maximizing project benefits to low-income and disadvantaged communities. Through their 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-come households (for example, wall and floor furnaces and room heaters) to lower energy bills and improve indoor air quality and thermal comfort. LBNL plans to collaborate with the Rising Sun Center of Opportunity and Every Neighborhood Partnership, inviting both organizations to participate on the project's technical advisory committee of and facilitate 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.

Table 3: FY 2018-19 Active Project Sites in Disadvantaged and Low-Income Communities

Diversity Category	# of Project Site(s)	Estimated Funding Amount	Percent of Funding
Disadvantaged Community	7	$6.4	8%
Low-Income Community	34	$17.1	21%
Overlapping Disadvantaged & Low-Income Community	27	$19.2	23%
Total	41	$23.5	29%

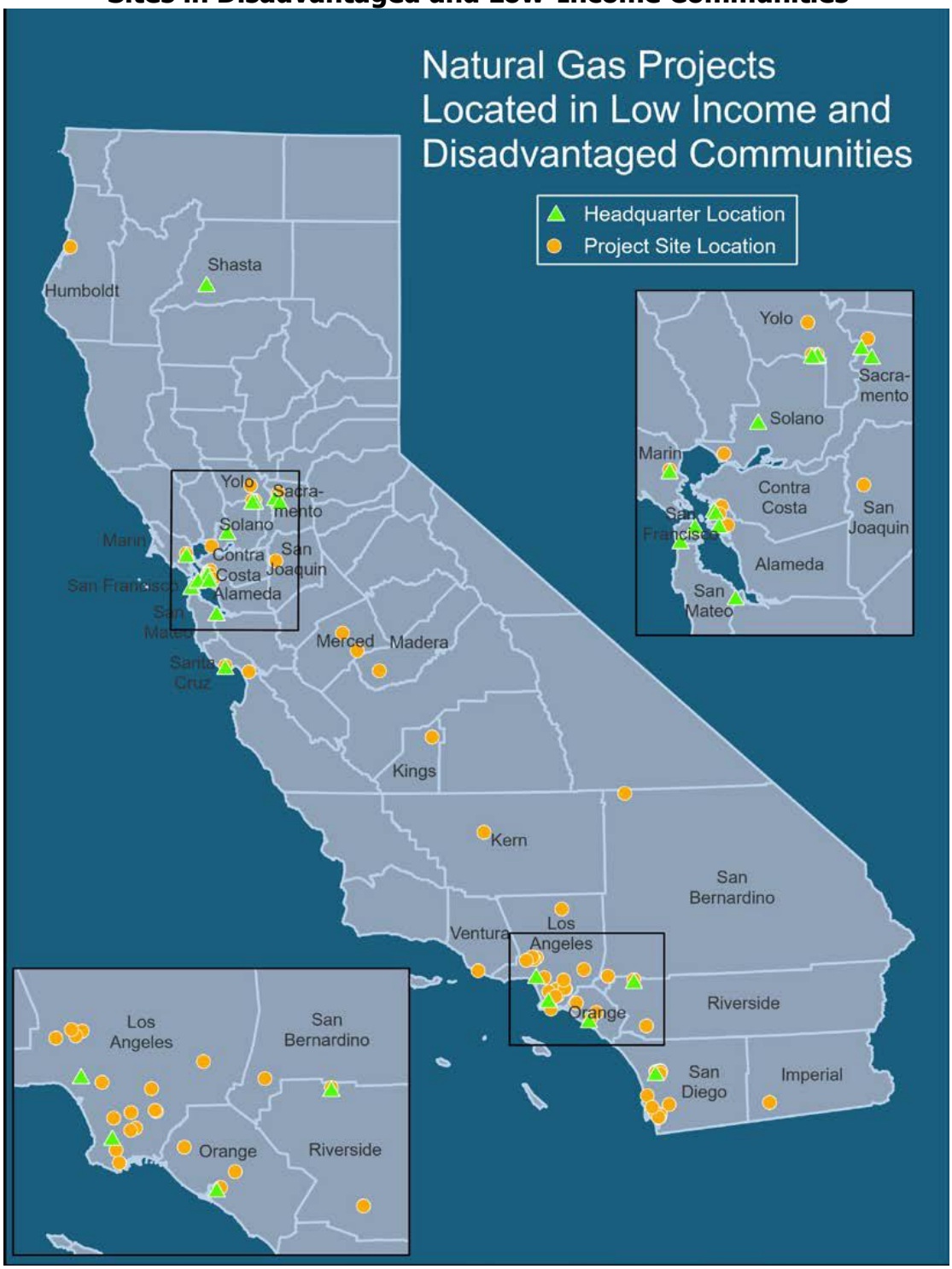
Source: California Energy Commission

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 pre-application 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

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.

creating partnerships, especially for communities that have historically been underrepresented.

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



Source: California Energy Commission

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.

As a recent example, ICF, a global consulting services company, developed a comprehensive assessment of the technical and market potential for small- and micro-scale combined heat and power (CHP) in California with funding from the Natural Gas R&D Program. The assessment summarized and compared the technical, economic, and environmental characteristics of various CHP technologies — including reciprocating engines, microturbines, and fuel cells — and examined integration issues and barriers that impede adoption of small- and micro-scale CHP systems and recommendations on how to address these barriers. Another example from the Natural Gas R&D Program is a new research roadmap that is underway (expected to be completed in 2020) 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.

An array of studies supplement roadmaps in the development of research priorities. For example, the *2015 Natural Gas Vehicle Research Roadmap*[19] provided research recommendations on natural gas vehicle range and storage, engine performance and availability, emissions and environmental performance, and analysis and information sharing. Two supplemental studies for this roadmap include (1) *The Feasibility, Issues, and Benefits Associated with Expanded Use of Natural Gas at Seaports and Other High Horsepower Applications;*[20] which evaluates scenarios where natural gas can beneficially displace diesel in locomotives or marine vessels at California ports, and (2) a technology assessment that is underway (due to be completed in 2020) to characterize real-world emissions and fuel usage across a variety of heavy-duty vehicle types, including natural

18 Various roadmaps can be found at the Energy Commission's publications database.
19 Schroeder, Alex. National Renewable Energy Laboratory. *2015 Natural Gas Vehicle Research Roadmap.* CEC-500-2015-091-CMF.
20 Leonard, Jonathan and Patrick Couch. Gladstein, Neandross & Associates. 2017. *The Feasibility, Issues, and Benefits Associated With Expanded Use of Natural Gas at Seaports and Other High Horsepower Applications.* CEC-500-2017-032.

gas trucks, and analyze technology benefits and shortfalls that can inform policies and future research priorities.

Proposed Budget

The proposed breakdown of the FY 2020-21 budget by research area is in Table 4. Detailed descriptions of proposed initiatives in each research area are provided below.

Table 4: FY 2020-21 Natural Gas Research and Development Program Proposed Budget Plan Summary

Research Areas	Proposed Budget
Energy Efficiency	$3,000,000
Renewable Energy and Advanced Generation	$4,000,000
Natural Gas Infrastructure Safety and Integrity	$9,100,000
Energy-Related Environmental Research	$1,500,000
Transportation	$4,000,000
Program Administration	$2,400,000
TOTAL	$24,000,000

Source: California Energy Commission

CPUC 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, Table 5 and Table 6 show the research funds from FY 2014-15 to FY 2017-18 encumbered within two years of budget approval. For FY 2014-2015 to FY 2018-19, the earliest date that encumbered project funds expire is June 30, 2020. After this date (the last date for expenditures, also known as the "liquidation expiration date"), the CEC cannot use the expired funds unless subsequent authorization is provided by the CPUC and the state Legislature. 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 2018-19 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, 2020 which is the last day that funds can be encumbered from the FY 2018-19 budget plan.

Table 5: Natural Gas Research Funds Encumbered Within Two Years of Budget Approval

Research Area	CPUC FY 2014-15 Approved Budget Plan	Total FY 2014-15 Funds Encumbered	Total FY 2014-15 Funds	CPUC FY 2015-16 Approved Budget Plan	Total FY 2015-16 Funds	Total FY 2015-16 Funds	CPUC FY 2016-17 Approved Budget Plan
Energy Efficiency	$8.60	$7.48	$0	$7.10	$7.10	$0	$7.10
Renewable Energy and Advanced Generation	$3.50	$2.48	$0	$5.80	$5.80	-$1.18	$4.40
NG Infra-structure Safety, Integrity*	$2.50	$4.68	$0	$1.00	$1.00	$0	$4.00
Energy-Related Environmental Research*	$3.00	$3.62	$0	$3.30	$3.30	$0	$2.60
Transportation	$4.00	$3.34	$0	$4.40	$4.40	-$1.50	$3.50
TOTAL	$21.60	$21.60	$0	$21.60	$21.60	-$2.68	$21.60

Amounts shown in table are in millions and rounded to the nearest $10,000.

Source: California Energy Commission

Table 6: Natural Gas Research Funds Encumbered Within Two Years of Budget Approval

Research Area	Total FY 2016-17 Funds Encumbered	Total FY 2016-17 Funds Disencumbered	CPUC FY 2017-18 Approved Budget Plan	Total FY 2017-18 Funds Encumbered	Total FY 2017-18 Funds Disencumbered	CPUC FY 2018-19 Approved Budget	Total FY 2018-19 Funds Encumbered**	Total FY 2018-19 Funds Disencumbered
Energy Efficiency	$5.20	$0	$6.60	$4.57	$0	$6.00	$0.00	$0
Renewable Energy and Advanced Generation	$5.02	$0	$4.00	$4.00	$0	$3.00	$0.00	$0
Natural Gas Infrastructure Safety, Integrity*	$3.87	$0	$5.00	$5.82	$0	$5.60	$0.00	$0
Energy-Related Environ-mental Research*	$2.69	$0	$3.00	$3.46	$0	$3.00	$0.00	$0
Transpor-tation	$4.81	-$1.99	$3.00	$3.75	$0	$4.00	$2.31	$0
TOTAL	$21.59	-$1.99	$21.60	$21.60	$0	$21.60	$2.31	$0

Amounts shown in table are in millions and rounded to the nearest $10,000.

*** In Resolution G-3507 (June 25, 2015), the CPUC directed the CEC to prioritize natural gas research and development projects on climate change, drought, and natural gas safety. The CEC shifted funding to these high-priority research areas when strong research proposals were received. For the FY 2014-15 to FY 2017-18 period, the CEC funded natural gas infrastructure safety and integrity research at about 120 percent of baseline funding.**

**** For the FY 2018-19 budget plan, approved on January 31, 2019, the CEC has committed the budget plan balance from FY 2018-19 and is executing agreements and encumbering funds.**

Source: California Energy Commission

Proposed Research Initiatives

This proposed FY 2020-21 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 (Table 4). 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.

Market trends and the state's clean energy goals signal a transition away from use of fossil-based natural gas for appliances, HVAC, and water-heating systems. One technological strategy for helping meet California's long-term decarbonization goals is blending hydrogen with natural gas.[21] However, the potential effects of adding hydrogen into existing natural gas infrastructure is not well understood. These effects include those of varying levels of hydrogen on end-use appliances, safety issues, impacts on air quality, operational performance, and appliance modifications needed. Achieving residential and commercial building adoption of hydrogen-natural gas blends could reduce greenhouse gas emissions because of the high proportion of existing natural gas-fueled appliances. For example, more than 80 percent of appliances in existing California homes run on natural gas.

One major use of natural gas in buildings is water heating. Water heating accounts for nearly 40 percent of the natural gas used by California households and 32 percent in the commercial building sector. Solar thermal water heating (SHW) offers a clean, renewable alternative that can significantly reduce natural gas consumption in the building sector. Unfortunately, the uptake of SHW systems has been slow, even with incentives, because of customized installations, cost, maintenance, and the requirement for backup systems. Customized installations can be inefficient, costly, and difficult for installers to manage with limited resources. A modular and standardized SHW system with various tank sizes and corresponding equipment could reduce the pressure on installers and significantly lower costs for customers. Multifamily and commercial buildings such as senior care centers provide a good test environment to develop modular, plug-and-play methods that can be replicated in other buildings because of the constant and high hot-water demands.

In alignment with the state's GHG reduction targets for 2030 and beyond, the FY 2020-2021 budget plan for energy efficiency research focuses on two areas: (1) analyzing the effects and potential limits for hydrogen and natural gas blends for end use appliances

21 California Air Resources Board. 2017. *California's 2017 Climate Change Scoping Plan.*

in residential and commercial buildings, and (2) developing modular plug-and-play solar thermal systems for use in buildings in disadvantaged or low-income communities.

The proposed research budget for energy efficiency is $3 million (Table 7). Research will be coordinated with other research areas, as appropriate.

Table 7: FY 2020-2021 Proposed Natural Gas R&D Budget Plan Summary — Energy Efficiency

Research Area—Energy Efficiency	Proposed Budget
Proposed Research Initiatives: ▪ Examining the Effects of Hydrogen in End-Use Appliances ▪ Accelerating Adoption of Modular Solar Water Heating in Low-Income or Disadvantaged Communities	$3,000,000

Source: California Energy Commission

Energy Efficiency Program Goals

- 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 emissions (for example, low NOx).
- Advance energy-efficient technologies that support decarbonization.
- Develop and demonstrate affordable energy-efficiency technologies, processes, and strategies.
- Maintain or increase productivity and increase industry competitiveness in the global market.
- Commercialize technologies with broad market potential.

Proposed Research Initiatives

Examining the Effects of Hydrogen in End-Use Appliances

The Issue

While California is in the vanguard of clean energy, it still relies heavily on natural gas to meet its energy needs. About 37 percent of natural gas in California is used for industrial processing, 30 percent for electricity generation, 20 percent by the residential sector, 12 percent for the commercial sector, and 1 percent for vehicles.[22] Though natural gas is lower-emitting than coal and petroleum, it still contributes significant greenhouse gas emissions, including from methane leakage in the natural gas supply

22 United States Energy Information Administration. Natural Gas Consumption by End Use (California, Annual, 2018).

chain. Hydrogen mixed with natural gas may prove to be a more sustainable option and could have a role in meeting California's long-term decarbonization goals.[23] However, the potential effects of adding hydrogen into existing natural gas infrastructure is not well understood, including the effects of varying levels of hydrogen on end-use appliances.

Research is needed to identify the maximum upper limit of hydrogen blended with natural gas that could be safely used in end-use appliances. There is uncertainty on the impact on air quality, operational performance, and residential appliance modifications needed. Achieving residential and commercial building adoption of hydrogen-natural gas blends could reduce greenhouse gas emissions because of the high proportion of existing natural gas-fueled appliances. For example, more than 80 percent of appliances in existing California homes run on natural gas. There is a need to understand the effect of hydrogen blends in building appliances — defined broadly here to include water heaters, boilers, furnaces, cooktop stoves, ovens, and dryers.

This research initiative aligns with Executive Order B-55-18, which sets a state goal to achieve carbon neutrality by 2045, among other state policies and plans (Table 1). This initiative also aligns with guidance from CPUC Resolution G-3555 to explore opportunities for hydrogen use that can reduce system GHG emissions, consider the health impacts associated with gas usage inside homes, and assess the effects of hydrogen delivered through the existing natural gas pipeline network on end-use appliances (Table 2).

The Research

The addition of hydrogen blends with natural gas could change combustion characteristics because of the differences in physical and chemical properties. The addition of hydrogen could also pose safety issues such as hydrogen embrittlement and other issues with end-use appliances caused by the presence of hydrogen.[24] There is a lack of experimental data, and further experimental work is needed to provide information that can be used to validate theoretical work.

This research will address the knowledge gaps and identify key benefits and challenges associated with using hydrogen blends in appliances, including:

- Establishing criteria for the "safe" use of hydrogen-blends in appliances.
- Conducting laboratory experiments to identify the maximum upper limit of hydrogen blended with natural gas that could be "safely" used in end-use appliances. These experiments would involve:
    - Developing a method for categorizing and selecting a representative sample of unmodified end-use appliances. Appliances would be

23 California Air Resources Board. 2017. *California's 2017 Climate Change Scoping Plan.*
24 Messaoudani, Z.L., Rigas, F., Hamid, M. D. B., & Hassan, C. R. C. 2016. "Hazards, Safety and Knowledge Gaps on Hydrogen Transmission via Natural Gas Grid: A Critical Review." *International Journal of Hydrogen Energy. 41*(39), 17511-17525.

categorized based on sector (residential, commercial) and application (for example, space heating, cooking, process heating).
    - Examining and testing the effects of hydrogen-blended fuel on unmodified natural gas service lines of varying materials.
    - Exploring appliance retrofits or modifications that could enable higher blends of hydrogen beyond the maximum upper limit (for example, controls and burner modifications).
    - Identifying specific new appliances and equipment specifications needed to enable higher blends of hydrogen at or beyond the maximum upper limit.
- Estimating the cost of retrofitting appliances and equipment to accommodate higher blends of hydrogen.
- Measuring the impact varying levels of hydrogen blends would have on the carbon intensity of natural gas-fueled appliances and overall contribution to state climate and energy goals.
- Optimizing fuel composition to produce the least amount of criteria air pollutants and maximize lean stability limits.

The study results would identify the impact of natural gas blends on existing and new appliances and the maximum concentration of hydrogen that can be handled by these appliances with and without modifications. The results will inform policy makers and the private sector of the technical and economic feasibility of this strategy and identify additional research and infrastructure needs to enable large-scale deployment.

The Benefits

- **Technology potential.** Increasing the amount of hydrogen that can be used in place of natural gas in appliances may be a cost-effective way of reducing GHG emissions.
- **Environmental benefits.** Use of hydrogen blends with natural gas in residential and commercial buildings could reduce criteria air pollutants,[25] particularly NOx and carbon monoxide (CO), which are known to be harmful to human health and the environment.

Accelerating Adoption of Modular Solar Water Heating in Low-Income or Disadvantaged Communities

The Issue

Water heating accounts for nearly 40 percent of the natural gas used by California households and 32 percent used in the commercial building sector. Solar thermal water

25 Zhao, Y., V. McDonell, and S. Samuelsen. 2019. "Influence of Hydrogen Addition to Pipeline Natural Gas on the Combustion Performance of a Cooktop Burner." *International Journal of Hydrogen Energy. 44*(23), 12239-12253.

heating (SHW) offers a clean, renewable alternative that can significantly reduce natural gas consumption in the building sector. For example, the commercial sectors of lodging, health, and restaurants have the highest potential savings from this technology because these building types typically use 20 to 60 percent of total energy for water heating. Furthermore, multifamily buildings, laundromats, and car washes are also ideal sites as they have large and constant hot water demands.

Unfortunately, the uptake of SHW systems has been slow, even with incentives, because of customized installations, cost, maintenance, and the requirement for backup systems. According to the California Solar Initiative (CSI) Thermal Incentive Program, the high amount of capital required upfront remains a major hurdle, as the installed costs of SHW systems have not declined in the 10 years since CSI began collecting SHW data.[26] Moreover, competition with solar photovoltaic systems, which require less capital to install, makes solar thermal systems less desirable. Current SHW systems could be good investments with available financial incentives, especially for customers with large domestic hot-water needs. For widespread adoption throughout California, however, a modular and standardized approach to SHW is needed.

This research initiative aligns with the goals set by the *2019 California Energy Efficiency Action Plan* – to double energy efficiency savings by 2030, reduce barriers to energy efficiency in low-income and disadvantaged communities, and reduce GHG emissions from buildings – as well as other state policies and plans (Table 1). This initiative also aligns with guidance from CPUC Resolution G-3555, including to increase engagement with disadvantaged communities and ensure consistency with the *2017 Climate Change Scoping Plan Update*, which calls for reducing dependence on fossil fuel natural gas (Table 2).

The Research

Solar thermal water heating systems require a large backup system to store hot water during nighttime and colder winters when solar insolation is absent. These backup systems, associated storage tanks, as well as other components of the system require extensive customization to meet the specific hot water needs and space constraints of each building. This customization approach is inefficient, costly, and difficult for installers to manage with limited resources. A modular and standardized SHW system with various tank sizes and corresponding equipment could ease the pressure on installers and significantly lower costs for customers. Research must be conducted to determine the optimal fraction of domestic hot water these systems can provide. Multifamily and commercial buildings such as senior care centers provide a good test

26 The average cost of a residential system ranges from $8,000 to $10,000 over the decade, without a clear long-term trend toward lower costs or higher performance. For details, see CSI Thermal Incentive Program database.

environment to develop modular, plug-and-play methods that can be replicated in other buildings due to constant and high hot water demands.

This initiative would fund the demonstration of modular solar water-heating systems in low-income and disadvantaged communities and include an analysis of the building applications and climate zones where it would be most cost-effective. The demonstrations should do the following:

- Select applications that represent those with high market potential such as multifamily residential, community centers, retirement communities, schools, lodging, health care centers, and restaurants.
- Achieve a minimum of 70 percent reduction in natural gas use for water heating.
- Achieve a minimum 20 percent cost reduction compared to conventional solar thermal.
- Document system performance that includes energy bill savings, system energy efficiency, and customer satisfaction.
- Develop modular, plug-and-play methods for designing each system so that they can be easily replicated to other buildings.
- Develop and distribute case studies based on documented performance.
- Coordinate with community-based organizations to determine community needs and barriers related to adoption of solar water heating.
- Develop guides for solar water heating system installers that provide the previously developed design methods, existing tools, and commercially available systems with a focus on disadvantaged and low-income community applications.
- Develop guides to help customers understand the benefits of solar water heating systems, available incentives, and resources to find installers.

The results are intended to provide specific data, establish a scientific basis for building standards, and inform decisions regarding California's low-carbon energy future.

The Benefits

- **Energy sector.** Solar water-heater systems could provide a cost-reducing building decarbonization solution that increases resilience during loss of power and can be applied in low-income and disadvantaged communities.
- **Environmental benefits.** Replacing natural gas hot water boilers with solar hot water systems will reduce GHG emissions.

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),

renewable combined-heat-and-power (CHP) systems under the Natural Gas R&D Program. 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.

For this year, the research initiatives focus on reducing fossil-derived fuel gas for heating and power generation applications to help achieve the state's clean energy and greenhouse gas reduction goals. Meeting those goals will require increasing the production and availability of clean and renewable fuels that can replace fossil natural gas. The proposed initiatives focus on the cost-effective production of renewable hydrogen and biomethane as a potential replacement for or blending with fossil natural gas.

The proposed research budget for renewable energy and advanced generation is $4 million (Table 8). Research will be coordinated with other research areas, as appropriate.

Table 8: FY 2020-2021 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: ▪ Decarbonization via Efficient and Cost-Competitive Renewable Hydrogen and Biomethane (DECARB) ○ Emerging Renewable Hydrogen Production ○ Emerging Gas Cleanup and Upgrading for Biomethane	$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:

- Advancing the development and market availability of clean and efficient DG and renewable combined heating, cooling, and power (CCHP) technologies.

- Developing cost-effective hybrid generation, fuel-flexible, energy-efficient, and low-emission DG technologies for renewable alternatives and natural gas.
- Accelerating decarbonization by developing technologies for the conversion, cleanup, and upgrading of biogas to renewable gas, as well as demonstrating diversified applications of advanced generation technologies that use renewable gas.

Proposed Research Initiatives

DECARB 1: Emerging Renewable Hydrogen Production

The Issue

Hydrogen produced from renewable sources could provide low-carbon energy and an alternative to fossil-based natural gas, helping meet California's GHG reduction goals of 40 percent below 1990 levels by 2030 and carbon neutrality by 2045.[27] California's industrial, commercial, and residential sectors account for two-thirds of natural gas consumption and generate roughly one-third of state GHG emissions.[28] Renewable hydrogen could replace or reduce this natural gas consumption and greenhouse gas emissions by providing an alternative for heating fuel and electricity generation and as an additive in natural gas pipelines (subject to pipeline safety and integrity limits).[29]

Today, 95 percent of commercially produced hydrogen comes from steam methane reforming processes using fossil fuels, mostly natural gas.[30] Although this pathway to hydrogen production is relatively low cost, steam methane reforming produces GHG emissions that do not align with the decarbonization goals of California. The costs of producing hydrogen from low-carbon sources — including solar or wind, biomass gasification, fermentation, photolysis, thermochemical water splitting, and anaerobic digestion[31] — remain high compared to the conventional pathways. Methods for generating low-costs renewable hydrogen are available but need further development for commercial readiness.

This research initiative aligns with Executive Order B-55-18, which sets a state goal to achieve carbon neutrality by 2045 – among other state policies and plans (Table 1). This initiative also aligns with guidance from CPUC Resolution G-3555 to explore opportunities to generate hydrogen to reduce system GHG emissions and target

27 Assembly Bill 398 (Garcia, Chapter 135, Statutes of 2017)
28 United States Energy Information Administration. Natural Gas Consumption by End Use (California, Annual, 2018).
29 Melaina, M. W., O. Antonia, and M. Penev. 2013. *Blending Hydrogen Into Natural Gas Pipeline Networks: A Review of Key Issues.*
30 United States Department of Energy. Fuel Cells Technologies Office. Hydrogen Production: Natural Gas Reforming.
31 International Renewable Energy Agency. 2018. *Hydrogen From Renewable Power: Technology Outlook for the Energy Transition.*

emissions-intensive and trade-exposed facilities that are challenging to decarbonize (Table 2).

The Research

This initiative proposes to advance precommercial or early market technologies and strategies for efficiently and cost-effectively producing hydrogen gas using emerging electrolysis and non-electrolysis solutions. Possible project strategies include:

- Developing and demonstrating electrolysis technologies that can use renewable electricity and waste heat to produce hydrogen (for example, combinations of waste heat and solid oxide electrolysis cells).
- Demonstrating methods for hydrogen production from renewable methane (for example, methane cracking into hydrogen with potential for carbon capture) and system integration that enables multiple product generation.
- Investigating the potential and readiness of earlier stage systems involving gas or liquid reforming, emerging fermentation, and photolysis for renewable hydrogen production.

Projects must demonstrate cost-effective hydrogen production for domestic industrial and transportation applications. Technologies should focus on improving hydrogen production efficiency, reducing costs, and delivering environmental benefits compared to conventional hydrogen production pathways.

The Benefits

- **Energy sector**. The technologies developed and demonstrated in this initiative will enable renewable hydrogen production and hydrogen enrichment of natural gas, which can reduce statewide consumption of natural gas.
- **Technology potential**. There is significant potential for hydrogen to decarbonize sectors that are hard to electrify, such as high-temperature industry.
- **Market connection**. Hydrogen can be used across sectors that currently use natural gas, including the commercial and industrial sectors, and in hydrogen fueling stations for fuel cell electric vehicles.
- **Energy and cost savings**. Cost reductions in renewable hydrogen production can result in cost reductions for heat, electricity, and vehicle fuel.
- **Environmental benefits**. Substitution of fossil-based natural gas with clean alternatives can help meet California's decarbonization goals. Developing renewable pathways for hydrogen production can play an important role. Some hydrogen production pathways may also be able to reduce waste heat and limit curtailment of valuable renewable energy sources.

DECARB 2: Emerging Gas Cleanup and Upgrading System for Biomethane

The Issue

A more fully developed market for biomethane can play an important role in meeting California's energy and environmental policies and objectives. Decomposition of organic wastes in digesters, landfills, and wastewater produces biogas — largely composed of methane and carbon dioxide — which is a significant source of greenhouse gas emissions (GHGs), accounting for nearly 82 percent of the state's total estimated methane emissions.[32] Using biogas in heating and power applications in place of fossil natural gas could provide environmental, financial, and energy productivity benefits. Furthermore, upgrading biogas into pipeline-grade biomethane will maximize related benefits by gaining access the broader gas market, as well as available incentives. However, upgrading biogas to pipeline-quality biomethane is expensive and must meet strict quality metrics to ensure safe delivery and consumption by end users.

Treating and upgrading biomethane to a level comparable to the characteristics of fossil-based natural gas are essential to ensuring the safety of end-user combustion devices. Removing contaminants from biomethane can increase the overall quality and heating value while meeting the appropriate energy content required for commonly used equipment. Southern California Gas Company completed a comprehensive study showing that biomethane with a heating value of "974 Btu/scf can be interchangeable with gas supplies," providing it meets other gas quality criteria.[33]

Contaminants in biomethane — such as siloxane, hydrogen sulfide, and volatile organic pollutants, among others — can create problems to commonly used downstream equipment, including combustion engines and appliances. For example, silica may lead to the formation of microcrystalline quartz which can build up on surfaces and cause clogging issues that will degrade end-user equipment such as fuel cells, heat exchangers, combustion engines, and so forth. The California Public Utilities Commission reaffirmed the maximum siloxane specification at 0.1 milligram (mg) Si/cubic meter (m^3), which was adopted in Decision D-14-01-034.[34]

Existing gas cleanup technologies need to improve to make biogas more competitive with fossil-based natural gas. This includes the need to clearly establish effective methods and standards for reducing contaminants to safe and acceptable levels. Advancing the emerging gas cleanup and upgrading technologies will stimulate increased production of biomethane, helping reduce fossil natural gas consumption and meet the state's decarbonization goals.

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32 Haines, Deanna. 2018. Getting the Facts on Renewable Natural Gas.
33 Lucas, Jim. 2017. Renewable Natural Gas and Interconnecting to the SoCalGas Pipeline.
34 California Council on Science and Technology. 2018. *Biomethane in California Common Carrier Pipelines: Assessing Heating Value and Maximum Siloxane Specifications: An Independent Review of Scientific and Technical Information.*

This research initiative aligns with state goals set by SB 1383 to increase the sustainable production of biomethane to reduce statewide short-lived climate pollutant emissions, among other state policies and plans (Table 1). This initiative also aligns with guidance from CPUC Resolution G-3555 to research the operational, health, and safety consequences of siloxane in biomethane and establish test methods for detecting siloxane in biomethane (Table 2).

The Research

This initiative will advance precommercial biomethane technologies and enable strategies for the efficient and economic production of clean and high-quality biomethane. Given the considerable funding and efforts from other state agencies like the California Department of Food and Agriculture for dairy digesters, this initiative will emphasize biogas and biomethane derived from municipal organic wastes and food processing wastes that are typically found in wastewater treatment plants, landfills, and other digesters. Possible projects include the following:

- Demonstrate biogas-to-biomethane technology that has been proven at a pilot scale.
- Lower the costs and improve process efficiency of biomethane production via sorbent-based technology.
- Demonstrate cost-effective and improved processes for removing siloxane and other impurities over a range of biogas quality levels and sources.
- Develop, test, and validate biomethane upgrading processes, targeting siloxane removal from wastewater and landfill gas sources.
- Investigate emerging methods and possible standards for removal of siloxane and other priority impurities from biogas derived from wastewater treatment and landfill sources.

The Benefits

- **Energy sector**. Upgraded biomethane can be injected into natural gas pipelines and delivered to power generation plants to serve the industrial, commercial, and residential sectors. Renewable gas can replace or supplement fossil-based natural gas, helping accelerate decarbonization.

- **Technology potential**. Upgrading biogas to biomethane and increasing the heating value remains expensive. However, support from state agencies and policies such as SB 1383 will advance these emerging cleanup and biomethane upgrade technologies.

- **Market connection**. There is a large market potential for biogas cleanup technologies to support biogas production systems. Already, California's Department of Food and Agriculture has funded more than $114 million for dairy

digester projects from 2014 through 2018.[35] Further research and development enable more biogas cleanup technology applications, for example, at wastewater treatment plants and landfills.

- **Energy and cost savings**. Increased production and utilization of biomethane could decrease demand of fossil natural gas and lower GHG emissions for various power generation, process heating, and fueling applications.
- **Environmental benefits**. Success of the research will drive reductions in GHG emissions and improve air quality, with positive impacts for public health.

Natural Gas Infrastructure Safety and Integrity

The infrastructure providing natural gas to customers is vast and covers most of the state. It includes producing wells, treatment plants, transmission lines, compressor stations, distribution lines, meters, and small pipes inside homes and buildings. 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 of the importance of 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 and other risks. 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, system-wide view and a focus on achieving the state's GHG reduction goals.

35 California Department of Food and Agriculture's Dairy Digester Research and Development Program. 2019. *Report of Funded Projects (2015-18).*

The proposed research budget for natural gas infrastructure safety and integrity is $9.1 million (Table 9). Research will be coordinated with other study areas, as appropriate.

Table 9: FY 2020-2021 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: ▪ Pilot Test and Demonstration of Hydrogen Blending Into Existing California Natural Gas Pipelines ▪ Technologies to Inspect and Prevent Corrosion of Natural Gas Pipelines and Storage Facilities ▪ Analytics for Pilot Demonstration of Strategic Electrification and Decommissioning of Natural Gas Infrastructure	$9,100,000

Source: California Energy Commission

Natural Gas Infrastructure Safety and Integrity Program Goals

The Natural Gas Infrastructure Safety and Integrity area seeks to increase safety and enhance the transmission and distribution capabilities of the natural gas system.

Proposed Research Initiatives

Pilot Test and Demonstration of Hydrogen Blending Into Existing California Natural Gas Pipelines

The Issue

Hydrogen can be a sustainable energy carrier and a promising means of storing renewable energy for California's clean energy future. However, this use of hydrogen requires developing infrastructure to connect hydrogen production, transmission, distribution, storage, and end-use equipment and appliances. Delivering hydrogen through the existing natural gas pipeline network has been proposed as a promising strategy to increase the percentage of renewable energy, such as solar and wind energy, in the current energy portfolio. Blending hydrogen at relatively low concentrations into existing natural gas systems helps avoid the cost of dedicated hydrogen pipelines.

Proposed initiatives under the Renewable Energy and Advanced Generation section (Emerging Renewable Hydrogen Production) and the Energy Efficiency section (Examining the Effects of Hydrogen in End-Use Appliances) will increase understanding of renewable hydrogen production and hydrogen blending for appliances. Research is also needed to understand the effects of hydrogen blending on the integrity and

performance of California's gas pipeline network, which could connect hydrogen production and end-uses. By researching production, pipeline distribution, and end-uses, improved system-wide planning for hydrogen blending will be possible.

There are a number of possible impacts of blending hydrogen into existing natural gas pipelines. Issues include material embrittlement, crack growth, gas permeation, interaction with reservoir caprock, sealant performance, and system leaks. Although some of these impacts have been researched individually, a research gap is identified, which necessitates the investigation of these impacts at the system level and how they affect the integrity and the overall performance of the natural gas pipeline network. In addition, the upper limit for hydrogen blending in the grid depends on the equipment connected to it, and this must be evaluated on a case-by-case basis. The case studies of hydrogen blending conducted in other states or countries may not be readily applicable to California's natural gas network since the systems were designed and constructed under different standards and conditions. Therefore, it is essential to develop hydrogen blending standards and deployment strategies tailored for California's gas system.

A pilot test or demonstration of hydrogen blending into existing California gas pipeline network will help quantify the impacts, suggest optimal integrity management practices, provide deployment strategies, and minimize system modifications to accommodate various blending levels.

This research initiative aligns with Executive Order B-55-18, which sets a state goal to achieve carbon neutrality by 2045, among other state policies and plans (Table 1). This initiative also aligns with guidance from CPUC Resolution G-3555 to explore opportunities to use natural gas infrastructure to support hydrogen to reduce system GHG emissions and assess the effects of hydrogen delivery through the existing natural gas pipeline network on pipeline facilities (Table 2).

The Research

This research initiative focuses on a pilot test and demonstration of hydrogen blending into existing California natural gas systems. Possible research includes:

- Pilot testing to measure various impacts of hydrogen blending on the system integrity of existing natural gas infrastructure in California.
- Demonstrating hydrogen blending to identify the best use cases, validate pilot test results, and develop replicable implementation strategies for safe blending.
- Assessing natural gas system modifications required to maximize hydrogen blending levels.
- Modifying integrity management and system maintenance practices for natural gas infrastructure to accommodate delivery of hydrogen.
- Developing hydrogen-blending methods and deployment strategies based on the lessons learned from the pilot test and demonstration.

The research will help shape and develop standards by identifying the requirements, steps, and procedures involved with interconnecting and authorizing the injection of hydrogen into the natural gas pipeline system. This research includes coordination with gas utilities to determine an optimal use case for hydrogen blending, identifying injection location(s) for interconnection, conducting research on system impacts due to hydrogen, obtaining permits for hydrogen blending into natural gas pipelines, and evaluating the overall performance of hydrogen injections and impacts to system integrity.

The Benefits

- **Energy sector.** The technologies developed and demonstrated in this initiative will increase renewable hydrogen production and use.
- **Technology potential.** Utilities could use the results and lessons learned from this initiative to develop guidelines and strategies for interconnecting and blending renewable hydrogen into existing natural gas infrastructure. The pilot test and demonstration will inform interconnection standards for hydrogen blending.
- **Market connection**. Research results will inform an array of market actors, including natural gas utilities, pipeline owners, gas operators, and hydrogen producers.
- **Energy and cost savings.** Blending hydrogen into existing natural gas pipeline networks would provide a boost to hydrogen supply technologies. Using the existing natural gas network to deliver hydrogen avoids the cost of building dedicated infrastructure for hydrogen.
- **Environmental benefits.** Blending renewable hydrogen into natural gas can significantly reduce GHG emissions.

Technologies to Inspect and Prevent Corrosion of Natural Gas Pipelines and Storage Facilities

The Issue

A significant portion of the existing natural gas infrastructure in California was constructed more than five decades ago. That has left California with the task of finding new technologies to address the issues of aging infrastructure, such as corrosion. According to the Pipeline and Hazardous Materials Safety Administration, a leading cause of pipeline failure is corrosion, and microbiologically influenced corrosion is one of the common failure modes for pipeline corrosion. An estimated 70 to 95 percent of pipeline internal leaks are due to localized corrosion caused mainly by microbiologically influenced corrosion.[36] In addition, the Gas Technology Institute (GTI) estimates microbiologically influenced corrosion costs the gas industry as much as $2 billion per

36 Little, Brenda and Jason Lee. 2007. Microbiologically Influenced Corrosion (Hoboken, NJ: John Wiley & Sons), p. 272.

year. With the potential risk of major leaks and the high cost of corrosion, it is imperative to address microbial corrosion within storage wells as well as pipelines.

California has 12 underground natural gas storage fields with 14 storage facilities and a total working gas capacity of 375 billion cubic feet of natural gas.[37] Many active wells in use for natural gas were designed for oil and gas production and constructed before 1970. Following the Aliso Canyon natural gas leak incident, an independent analysis of the leak identified that microbial corrosion on the well casing caused the rupture.[38] As a result of the well failure, California state legislators introduced Senate Bill 887 (Pavley, Chapter 673, Statutes of 2016), which included additional testing requirements for gas storage wells and required the operators of all gas storage wells to begin performing mechanical integrity testing before January 2018. The requirements included casing wall thickness inspection for possible degradation, including corrosion.

In addition, natural gas pipelines and storage facilities that may have been in the ground for as long as half a century are vulnerable to soil corrosivity. Soils of low pH level, low electric resistivity, or high concentration of aggressive ions such as chloride are more corrosive to metal materials. In October 2017, a gas transmission line in a Southern California desert ruptured, with contributing factors including corrosive desert soils and inaccurate assessment of pipe metal loss caused by corrosion. The development of new technologies and improvement of existing technologies will help inspect and prevent corrosion damages caused by the corrosive properties of soil.

This research initiative aligns with guidance from CPUC Resolution G-3555 – to examine the causation, diagnostics, and mitigation of microbiologically influenced corrosion of pipelines and storage facilities – as well as other state policies, plans, and guidance (Tables 1 and 2).

The Research

This initiative focuses on research, development, and demonstration of innovative technologies that can diagnose and address microbiologically and soil property-influenced corrosion of pipelines and storage facilities in the California natural gas industry. Possible research includes:

- Addressing corrosion damages to natural gas infrastructure from various causes, including microbiologically influenced corrosion and soil property-influenced corrosion.
- Developing and testing advanced coatings or chemical treatment on metal surfaces to prevent corrosion for pipelines as well as storage wells and demonstrating the performance of coatings or surface chemical treatment, including resistance to degradation.

37 California Department of Conservation, Division of Oil, Gas and Geothermal Resources.
38 Blade Energy Partners. 2019. *Root Cause Analysis of the Uncontrolled Hydrocarbon Release From Aliso Canyon SS-25.*

- Improving cathodic protection technologies – commonly used to electrochemically control metal corrosion in underground gas pipelines and storage facilities – that are specific to different corrosion mechanisms and conditions.
- Developing new technologies or improving existing technologies with better accuracy to detect, locate, and size corrosion defects or areas, including hydrostatic testing, direct assessment, and in-line inspection.
- Developing and demonstrating advanced repair technologies for internal and external corrosion.

Proposed projects will diagnose corrosion from various causes by conducting studies that include the measurement of corrosion damage to samples exposed to real-world environments. To help evaluate the performance of the corrosion mitigation treatment, corrosion monitoring data and test data should be collected from the same locations. Inspection techniques commonly used to detect and monitor corrosion-related damage generally include ultrasonic testing, radiographic testing, and magnetic flux methods.

The Benefits

- **Energy sector.** The technologies developed and demonstrated in this initiative are intended to improve safety and reliability and prevent failure of natural gas infrastructure by reducing the probability of incidents due to corrosion.
- **Technology potential.** The use of the technology helps assess, repair, and prevent corrosion damage in underground pipelines and storage wells.
- **Market connection**. Research results will inform an array of market actors, including natural gas utilities, pipeline owners and operators, as well as gas storage owners and operators.
- **Energy and cost savings.** The use of the technologies from this initiative will reduce failures from corrosion of pipelines and storage facilities and decrease down time and associated costs.
- **Environmental benefits.** Identifying and addressing corrosion can help curb methane leakage from the natural gas system.

Analytics for Pilot Demonstration of Strategic Electrification and Decommissioning of Natural Gas Infrastructure

The Issue

Aging natural gas infrastructure in California poses safety and integrity risks and challenges. Replacing aging pipelines is costly. It is estimated that cost per mile to replace pipelines varies from $1 million to $5 million.[39] Without some prior guarantee of

39 American Gas Association. 2014. AGA Guidelines for Reducing Natural Gas Emissions From Distribution Systems.

timely cost recovery, it is difficult for utilities to bear the relatively high cost of pipeline repair and replacement. The costs associated with the replacement are passed on to natural gas consumers, which raise concerns about ratepayer impact, particularly for disadvantaged and low-income communities. Furthermore, as California pursues a decarbonized energy system (Executive Order B-55-18), strategic electrification and decommissioning of natural gas infrastructure are key strategies for addressing aging infrastructure and avoiding future stranded assets. However, there is a need to develop analytics for demonstrating strategic decommissioning and electrification. Analytics can deliver information on project costs, benefits, feasibility, options, and equity considerations.

This research initiative aligns with guidance from CPUC Resolution G-3555 – to examine the role of natural gas in the state's transition to a low-carbon economy and ensure alignment with the goals of the *2017 Climate Change Scoping Plan Update* by 1) ensuring safety of the natural gas system, 2) decreasing fugitive methane emissions, and 3) reducing dependence on fossil fuel natural gas – as well as other state policies and plans (Tables 1 and 2).

The Research

This research initiative focuses on in-depth analytics to inform a pilot demonstration of pipeline decommissioning and electrification in California. It requires a multidisciplinary approach to address interrelated issues holistically, such as identification of the most applicable use cases for demonstrations, technical requirements, short- and long-term cost/benefit analysis for customers and utilities, customer acceptance information, and equity considerations. To this end, the research would:

- Summarize the impacts of decommissioning and electrification on gas and electric infrastructure, including electric system upgrades, gas system depreciation, operational conditions, system maintenance costs, and integrity management.
- Perform short-term and long-term cost/benefit analysis for customers and utilities.
- Analyze and quantify GHG emission reduction and air quality improvement.
- Identify at least one applicable location in California for a pilot demonstration, with low-income or disadvantaged community representation.
- Engage and coordinate among community groups, customers, and utilities of the identified location and develop strategies to simplify gas-to-electricity transition.
- Conduct surveys and collect user acceptance data.

The result of this research would enable an analytically grounded pilot demonstration at an identified location in California.

The Benefits

- **Energy sector.** The transition from natural gas to electricity would move the energy sector toward a low-carbon future.
- **Technology potential.** The research will address the technological barriers of electrification and pipeline decommissioning.
- **Market connection.** The research will engage and connect community groups, gas and electric utilities, ratepayers, and technology vendors.
- **Energy and cost savings.** The research will collect data and perform benefit analysis on the energy and cost savings for customers and utilities.
- **Environmental benefits.** Decommissioning part of the natural gas system lowers end-use emissions and can reduce methane leakage.

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 $1.5 million (Table 10). Research will be coordinated with other research areas, as appropriate.

Table 10: FY 2020-2021 Proposed Natural Gas R&D Budget Plan Summary Energy-Related Environmental Research

Research Area—Energy-Related Environmental Research	Proposed Budget
Proposed Research Initiative: ▪ Development of a Data-Driven, Actionable Tool and Case Studies to Support Strategic and Equitable Natural Gas Decommissioning	$1,500,000

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.

Proposed Research Initiative

Development of a Data-Driven, Actionable Tool and Case Studies to Support Strategic and Equitable Natural Gas Decommissioning

The Issue

The Natural Gas R&D Program previously funded Energy and Environmental Economics, Inc. and the University of California, Irvine to develop a strategic assessment of the long-term role of natural gas in a carbon constrained and water efficient future. This research evaluated different technology scenarios — including electrification and different approaches to generating renewable natural gas — that achieve California's goals for midcentury reductions of greenhouse gas (GHG) emissions. The researchers performed cost analyses to illuminate implications of the different scenarios on natural gas customers, as well as air quality modeling to quantify impacts to ambient air quality and public health.

Among the key findings of the analysis is that electrification appears to be a lower-cost, lower-risk strategy for reaching midcentury emissions reduction goals in buildings than use of renewable natural gas (RNG), even with optimistic assumptions about technological learning to produce RNG more cheaply and pessimistic assumptions for electricity rates. Moreover, natural gas demand in the building sector is likely to fall, whether an RNG-based or electrification strategy is pursued to achieve decarbonization. With fewer customers and less natural gas demand, the cost of natural gas for remaining retail customers could rise. Thus, the prospect of significant reductions in retail customer demand for natural gas creates a planning imperative for the state. A strategic transition is needed to manage equity issues, safety, and cost-effectiveness. The need for a managed transition is also supported by leading external analyses, such as those conducted by GridWorks and the Environmental Defense Fund.[40,41]

Although there is a clear need for a managed transition to contain costs, ensure safety, and address equity concerns, decision-makers lack (1) a conceptual framework for charting a strategic transition and (2) a data-based tool to support strategic planning. The FY 2019-20 Natural Gas funding plan includes an initiative on (1): "natural gas infrastructure analysis and strategic pathway to a low-carbon energy future," which will support development of a methodology for strategic decommissioning, including concerns related to cost-effectiveness of investments, equity, and infrastructure safety. The proposed FY 2020-21 research addresses (2).

This research initiative aligns with Executive Order B-55-18, which sets a state goal to achieve carbon neutrality by 2045, among other state policies and plans (Table 1). This initiative also aligns with guidance from CPUC Resolution G-3555 to examine the role of

40 Gridworks. 2019. California's Gas System in Transition: Equitable, Affordable, Decarbonized and Smaller.

41 Bilich, Andy, Michael Colvin, and Timothy O'Connor. 2019. Environmental Defense Fund. Managing the Transition: Proactive Solutions for Stranded Gas Asset Risk in California.

natural gas in the state's transition to a low-carbon economy and ensure alignment with the goals of the *2017 Climate Change Scoping Plan Update* by 1) ensuring safety of the natural gas system, 2) decreasing fugitive methane emissions, and 3) reducing dependence on fossil fuel natural gas (Table 2).

The Research

The proposed research would build on the above-mentioned FY 2019-20 methodological work to develop a data-driven, actionable tool to support strategic and equitable natural gas decommissioning. Furthermore, this decision-support tool would complement analytics for a demonstration pilot proposed under the Natural Gas Infrastructure Safety and Integrity section (that is, *Analytics for pilot demonstration of strategic electrification and decommissioning of natural gas infrastructure*) by promoting broader replication of decommissioning projects.

The tool developed by this research would provide new capabilities to support a managed transition for California's retail gas system and ensure that as California decarbonizes its energy system, it does so cost-effectively and in a manner that is equitable and safe. The tool will illuminate geospatially specific cost and equity issues with broad regional coverage. Similar to previous research efforts to develop actionable planning tools like Cal-Adapt, the tool will be developed to support a variety of users – including utilities, community choice aggregators (CCAs), CPUC, and newly constructed communities (for example, to examine gas system cost savings) – and inform infrastructure investment decisions.

This research would also support using the tool to analyze specific groups of buildings and proposed developments within a geographic zone. This application will deliver case studies that inform decommissioning options and impacts. Local communities, as well as the users of the tool, will be engaged to inform the analysis and ensure research results are actionable. As an example, a case study may include a jurisdiction with an electrification ordinance, including a low-income community or disadvantaged community portion of that jurisdiction.

The success of this project depends on voluntary or required sharing of (potentially sensitive) data from natural gas IOUs (for example, on geospatial positioning, age, and condition of natural gas and electricity system infrastructure). For that reason, the proposed research may focus on regions within a single IOU territory.

The Benefits

- **Energy sector**. This research promotes strategic decommissioning informed by analyses of infrastructure status and safety concerns. The research supports development and execution of a long-term strategy for the role of the natural gas in the context of statewide decarbonization goals articulated by Executive Order B-55-18 and Senate Bill 100 (De León, 2018).
- **Energy and cost savings.** The tool developed under this research will enable data-driven development of a strategic transition for the retail natural gas system

that meets the state's energy-related environmental goals while managing cost and equity considerations.

- **Environmental benefits.** This tool would help achieve the state's decarbonization goals with associated health, environmental, and economic benefits.

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 greatest contributor to the state's greenhouse gas emissions, directly accounting for 39 percent of GHG emissions and 80 percent of NO_x emissions. Heavy-duty trucks are the largest contributors to NO_x emissions and continue to impact air quality heavily in the state's severely polluted air basins. To address these concerns, extensive near-term use of zero- and near-zero emission technologies is necessary to meet current and future clean air standards. The development, demonstration, and deployment of transportation technologies that meet the state's sustainability goals while increasing freight transportation efficiency and competitiveness are vital.

When used as an alternative fuel to diesel, 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 vehicle technology to reduce emissions to zero- or near-zero levels. Previous work includes developing near-zero NO_x 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 of natural gas vehicles, including high-energy ignition, hybridization, and advanced and innovative engine concepts. Research on improving fast-fill compressed natural gas fueling infrastructure continues with the goal of maximizing vehicle range and on-board storage use. 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. The FY 2019-20 Budget Plan expanded the transportation research area to include fuel cell technologies in rail and marine applications.

The proposed budget for Transportation Research is $4 million (Table 11). Research will be coordinated with other research areas, as appropriate.

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

Table 11: FY 2020-2021 Proposed Natural Gas R&D Budget Plan Summary Transportation Research

Program Area — Transportation Research	Proposed Budget
Proposed Research Initiative: ▪ Technology Integration and Demonstration of Hydrogen Fuel Cell Trucks and Buses	$4,000,000

Source: California Energy Commission

Transportation Research Program Goals

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

- Accelerate the beneficial commercial adoption of near-zero-emission gas vehicles.
- Improve the energy efficiency and performance of gas vehicles to reduce carbon emissions and compete with conventional fuel vehicles.
- Increase the use of renewable gas to reduce the GHG emissions of the transportation sector.
- Improve fueling infrastructure technology capabilities to promote the further adoption of low-carbon gas vehicles.

Proposed Research Initiative

Technology Integration and Demonstration of Hydrogen Fuel Cell Trucks and Buses

The Issue

Hydrogen production at scale can integrate more renewables into the electric grid by providing long-term grid-scale energy storage, decarbonizing difficult-to-electrify end uses, and enhancing energy security and resiliency. However, hydrogen faces several challenges to providing these benefits at scale such as high costs, need for lower carbon hydrogen, and lack of infrastructure. Existing policies such as Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006), which requires state-funded hydrogen stations to dispense 33 percent renewable hydrogen, and the Low Carbon Fuel Standard, which generates credits to encourage the adoption of fuels with low-carbon pathways, provide drivers for increasing renewable hydrogen to support growing demand from the transportation sector.

Heavy-duty vehicles are responsible for 20 percent of greenhouse gas emissions from the transportation sector. On-road trucks and buses emit 28 percent of statewide NO_x emissions, and recent studies have shown that real-world NO_x emissions may be

considerably higher than estimated in current emissions inventory models.[43] The South Coast Air Basin requires an additional 70 percent reduction in truck and bus emissions beyond current programs to attain national ambient air quality standards for ozone by 2031. California truck and bus fleets will be required to transition to zero-emission vehicles under forthcoming mandates such as the CARB's Innovative Clean Transit[44] and Advanced Clean Trucks (ACT)[45] regulations. In heavy-duty vehicle applications, hydrogen fuel cell electric vehicles (FCEV) are eligible zero-emission technology options that can provide more operational flexibility than battery-electric vehicles (BEV), such as longer driving range, faster refueling times, lower vehicle weight, and resiliency to extreme temperatures. Attributable to these benefits, FCEVs may be a preferable zero-emission technology option for certain fleets or vehicle applications.

FCEVs have high total cost of ownership (TCO), affecting competitiveness with conventional heavy-duty diesel vehicles. Other barriers for fleet adoption include uncertain fueling infrastructure needs and lack of durability and operational data for a variety of duty cycles. Although expanding, there is a limited number of hydrogen fuel cell truck and bus models available for purchase. There is a need to conduct real-world technology demonstrations to address these barriers and accelerate fleet adoption of hydrogen fuel cell trucks and buses.

This research initiative aligns with state goals set by the *Sustainable Freight Action Plan*, *2016 Mobile Source Strategy*, and Low Carbon Fuel Standard to deploy freight vehicles and equipment capable of zero-emission operation, reduce emissions from heavy-duty trucks, and reduce the life cycle carbon intensity of transportation fuels (Table 1). This initiative also aligns with guidance from CPUC Resolution G-3555 to explore opportunities for using hydrogen in a way to reduce system GHG emissions (Table 2).

The Research

This initiative advances research, development, and demonstration of precommercial heavy-duty FCEV and hydrogen fueling infrastructure technologies that may reduce TCO and improve efficiency and performance. Projects should target truck and bus types that lack commercially available options. Demonstrations should gather real-world fleet operational data such as driving performance, refueling practices, durability, and qualitative feedback to inform continued technology development, infrastructure planning, cost models, and continued fleet deployment.

Near-term opportunities for accelerating deployment of heavy-duty FCEV technologies include vehicles that operate near hydrogen production facilities or industrial centers already using hydrogen. Examples include warehouses with hydrogen fuel cell material handling equipment, refineries, and biogas production plants. Prioritizing

43 Tan, Yi, Paul; Henderick, Seungju Yoon, Jorn Herner, Thomas Montes, Kanok Boriboonsomsin, Kent Johnson, George Scora, Daniel Sandez, and Thomas Durbin. "On-Board Sensor-Based NOx Emissions From Heavy-Duty Diesel Vehicles." *Environmental Science & Technology* 2019, 53, 9, 5504-5511
44 California Air Resources Board. Innovative Clean Transit.
45 California Air Resources Board. Advanced Clean Trucks.

demonstrations at these locations will also benefit disadvantaged and low-income communities near the facilities.

Projects must integrate and demonstrate precommercial technologies, which may include:

- Improved fuel cell system components and integration strategies to improve ease of assembly and maintenance access, alleviate supply chain challenges, lower costs, and increase efficiency. Examples include catalysts and electrodes with reduced platinum group metal loading, lower cost membranes, improved cell and stack assemblies, and lower cost balance of plant components.
- Improved fuel cell system diagnostics to reduce the total cost of ownership of heavy-duty fuel cell vehicles.
- Advanced onboard storage tanks that can reduce costs and increase storage capacity.
- Improved hydrogen fueling infrastructure technologies such as high-capacity nozzles, cryopumps, and compressors that can improve reliability, uptime, and cost-effectiveness when supporting medium- and heavy-duty vehicles.

The Benefits

- **Energy sector**. Increasing demand for hydrogen in the transportation sector can lead to investments in renewable hydrogen production, which can benefit the grid by providing long-term energy storage for intermittent renewable electricity. Increased renewable hydrogen production can also help decarbonize the gas grid through pipeline blending and industrial processes that rely on hydrogen reformed from fossil gas.
- **Technology potential**. California has an estimated 1.6 million Class 2b-8 medium- and heavy-duty vehicles.[46] CARB's ACT regulation is estimated to result in the deployment of only around 75,000 zero-emission trucks by 2030. Accelerated progress to achieve cost parity of FCEVs with diesel can help exceed deployment estimates.
- **Market connection**. Sectors of interest include fleets with truck and bus operations suitable for FCEV deployment but lack access to commercially available options. This initiative also targets vehicles that operate near hydrogen production facilities and industrial centers that use hydrogen.
- **Energy and cost savings**. If projects succeed in integrating advanced technologies that can reduce the TCO of hydrogen fuel cell trucks and buses, cost savings can be realized by fleets. Increased investment in scaled

46 Bahrenian, Aniss, Jesse Gage, Sudhakar Konala, Bob McBride, Mark Palmere, Charles Smith, and Ysbrand van der Werf. 2018. *Revised Transportation Energy Demand Forecast, 2018-2030*. California Energy Commission. Publication Number: CEC-200-2018-003.

deployment of hydrogen for the transportation sector can also reduce costs related to renewable hydrogen production.

- **Environmental benefits**. Heavy-duty trucks and buses are responsible for 20 percent of greenhouse gas emissions from the transportation sector, 28 percent of statewide NO_x emissions, and 23 percent of statewide diesel particulate matter emissions. Accelerated deployment of hydrogen fuel cell trucks and buses can reduce greenhouse gas emissions and improve air quality in the communities where they operate.

LIST OF ACRONYMS

Term	Definition
AB	Assembly Bill
Bcf	Billion cubic feet
CARB	California Air Resources Board
CBO	Community-based organization
CHP	Combined heat and power
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CPUC	California Public Utilities Commission
EPIC	Electric Program Investment Charge
GHG	Greenhouse gas
GFO	Grant funding opportunity
GWh	Gigawatt-hour
HVAC	Heating, ventilation, and air-conditioning
IoT	Internet of Things
kW/kWh	Kilowatt/kilowatt-hours
LCFS	Low Carbon Fuel Standard
MCF	Metric cubic feet
MGD	Million gallons per day
mm/Btu	Million British thermal units
NO_x	Oxides of nitrogen
PIER	Public Interest Energy Research

Term	Definition
PON	Program opportunity notice
R&D	Research and development
RNG	Renewable natural gas
SB	Senate Bill
Tcf	Trillion cubic feet
UC	University of California
U.S. EIA	United States Energy Information Administration

APPENDICES

Appendix A: Natural Gas Stakeholders Workshop Presentation and Appendix B: Summary of Public Comments and CEC Responses are available as a separate volume, Publication Number CEC-500-2020-081-APA-B.